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Data were collected on energy requirements to recycle prompt industrial and obsolete scrap for nine metal commodities: iron and steel, aluminum, copper, zinc, lead, stainless steel, titanium, tin, and nickel and nickel alloys. Major process routes for recycling were considered, starting from the first collection point through scrap preparation, transportation, smelting and/or refining to the molten metal, ingot, or other semi-finished form approximately equivalent to a primary metal of a similar composition. Available data for 1976 were collected on the amounts of each metal commodity recycled by major scrap categories. In addition, energy requirements were estimated for separating municipal solid wastes into four major categories: refuse-derived fuel, and magnetic, aluminum, and glass cullet fractions. Finally areas of research were identified to enhance recycling and/or increase the efficiency of energy use.

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Information Circular 8781

Energy Use Patterns for Metal Recycling

By Charles L. Kusik and Charles B. Kenahan

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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CONTENTS

Page

Abstract.. 1
Introduction.. 1
Acknowledgments... 2
Methodology... 3
Scrap recycled.. 3
Energy analysis... 3
Process selection... 4
Flowsheet development... 4
Energy requirements... 5
Heat losses... 8
Energy research and development areas............................. 8
Nomenclature and conventions...................................... 8
Scrap categories.. 8
New scrap and virgin materials.................................... 8
Aluminum.. 9
Background.. 9
Types and classifications of scrap................................ 9
Scrap consumption... 9
Products.. 10
Scrap preparation methods... 11
Major preparation methods... 11
Other preparation methods... 15
Smelting and refining... 15
Major processing methods.. 15
Alternative demagging schemes..................................... 18
Other processing schemes.. 19
Energy analyses... 19
Scrap preparation... 19
Reverb melting aluminum scrap to alloy 380 ingots................. 23
Reverb melting aluminum scrap to hot metal........................ 24
Recycling aluminum cans... 26
Scrap preparation... 27
Reverb melting.. 27
Energy analysis... 27
Major heat losses... 29
Research and development.. 30
References.. 30
Copper.. 31
Background.. 31
Types and classifications of scrap................................ 31
Consumption... 32
Products.. 34
Scrap preparation methods... 34
Smelting and refining... 35
Major processing methods.. 35
Reverb melting No. 1 copper scrap................................. 35
Recycling No. 2 copper scrap...................................... 37
Recycling low-grade, copper-bearing scrap......................... 38

CONTENTS--Continued

Page

Recycling brass and bronze scrap to ingots.............. 40
Other processing methods.................................. 41
Energy analysis.. 41
Scrap preparation... 41
Reverb melting No. 1 copper scrap........................ 45
Recycling No. 2 copper scrap.............................. 46
Recycling low-grade, copper-bearing scrap................ 49
Recycling brass and bronze scrap to brass and bronze ingot.... 49
Major heat losses.. 54
Research and development..................................... 54
References... 55
Iron and steel.. 57
Background... 57
Industry.. 57
Types and classifications of scrap....................... 57
Consumption... 59
Scrap preparation.. 60
Home scrap.. 60
Purchased scrap... 60
Other processing methods.................................. 66
Transportation.. 67
Melting and refining... 67
Major processing methods.................................. 67
Other processing methods for obsolete scrap.............. 69
Energy analysis... 70
Transportation.. 77
Materials handling.. 77
Scrap preparation operations.............................. 77
Electric furnace... 77
Cupola.. 78
Major heat losses.. 78
Electric furnace.. 78
Cupola.. 78
Ladle drying and preheating............................... 78
Casting... 78
Research and development..................................... 79
Reference.. 80
Lead.. 81
Background... 81
Types of classifications of scrap........................ 81
Products.. 82
Scrap preparation.. 82
Smelting and refining.. 83
Major processing methods.................................. 83
Blast furnace... 83
Reverb/blast furnace.................................. 84
Pot melting... 85
Other processing methods.................................. 85

CONTENTS--Continued

Page

Energy analysis.... 85
Producing hard lead by blast furnace process.... 85
Producing hard and soft lead by reverb/blast furnace scheme... 91
Pot melting lead scrap.... 94
Major heat losses.... 95
Blast furnace.... 95
Reverb furnace.... 95
Pot furnace.... 96
Refining kettles.... 96
Research and development.... 96
References.... 97
Nickel and nickel alloys.... 98
Background.... 98
Types and classifications of scrap.... 98
Contamination problems.... 99
Scrap preparation.... 100
Superalloy scrap.... 100
Turnings.... 100
Solids.... 100
High-nickel alloys and heating element alloys.... 100
Pure nickel, nickel-copper alloys.... 103
Pure nickel scrap.... 103
Monels.... 103
Melting and refining.... 103
Major processing methods.... 103
Superalloys meant for critical applications.... 103
Other alloys meant for less critical applications.... 103
Other processing methods.... 104
Energy analysis.... 106
Major heat losses.... 110
Research and development.... 110
References.... 111
Stainless steel.... 112
Background.... 112
Types and classifications of scrap.... 112
Contamination problems.... 113
Scrap preparation.... 114
Melting and refining.... 115
Energy analysis.... 116
Major heat losses.... 123
Electric furnace, casting, ladle drying, and preheating.... 123
Argon-oxygen decarburization (AOD) vessel.... 123
Research and development.... 123
Reference.... 124
Tin.... 125
Background.... 125
Types and classifications of scrap.... 125
Products.... 126

CONTENTS--Continued

Page

Scrap preparation........ 126
Tin recovery processes........ 126
Major processing method........ 126
Other processing method........ 126
Energy analysis........ 127
Detinning new tin-plated scrap........ 127
Recovering tin from detinning leach solution........ 129
Major heat losses........ 130
Research and development........ 131
Titanium........ 132
Background........ 132
Types and classifications of scrap........ 132
Scrap consumption........ 133
Contamination problem........ 134
Scrap preparation........ 134
Light scrap preparation........ 134
Heavy scrap preparation........ 136
Melting and refining........ 136
Major processing method........ 136
Other processing methods........ 138
Pollution control........ 138
Energy analysis........ 140
Major heat losses........ 144
Research and development........ 144
References........ 145
Zinc........ 146
Background........ 146
Types and classifications of scrap........ 146
Products........ 147
Scrap preparation........ 147
Distillation and remelting........ 148
Major processing methods........ 148
Retort distillation........ 148
Muffle furnace distillation........ 149
Pot melting........ 149
Other processing methods........ 150
Energy analysis........ 150
Scrap preparation........ 150
Producing zinc dust by retort distillation process........ 156
Producing zinc oxide by muffle furnace distillation process... 159
Pot melting clean die-cast scrap........ 161
Pot melting off-specification die-cast scrap........ 161
Major heat losses........ 162
Distillation retorts........ 162
Muffle furnace........ 162
Pot furnace........ 163
Research and development........ 163
Reference........ 163

CONTENTS--Continued

Page

Municipal solid waste 164
Background 164
Process technology 164
Products 165
Fractions 167
Magnetic fraction 167
Nonmagnetic fraction 168
Refuse-derived fuel (RDF) fraction 168
Glass fraction 168
Process description and energy analysis 169
Subsystems 169
Preparing concentrates 169
Aluminum subsystem 174
Magnetic subsystem 174
Glass subsystem 174
Further processing 175
Research needs 175
References 176
Summary 177
Appendix 180

ILLUSTRATIONS

1. Format used in preparing flowsheets 5
2. Aluminum: Preparing aluminum clippings 11
3. Aluminum: Preparing clean, dry aluminum borings and turnings 12
4. Aluminum: Preparing aluminum drosses 13
5. Aluminum: Preparing high-iron aluminum scrap 14
6. Aluminum: Preparing aluminum sheet and cast scrap 14
7. Reverberatory (reverb) furnace 16
8. Delivery of hot metal in ladles 17
9. Aluminum: Reverb furnace melting aluminum scrap to alloy 380 ingots 24
10. Aluminum: Reverb furnace melting aluminum scrap to hot metal (alloy 380) 26
11. Aluminum: Recycling aluminum cans to hot metal for can sheet stock 28
12. Reverb furnace for melting and refining copper and brass scrap 36
13. Casting copper 37
14. Blast furnace for smelting copper-base scrap, slag, and residues... 39
15. Copper: Copper wire chopping 43
16. Copper: Copper wire incineration 44
17. Copper: Reverb melting No. 1 copper wire scrap 46
18. Copper: Recycling No. 2 copper scrap 48
19. Copper: Recycling low-grade, copper-bearing scrap 51
20. Copper: Recycling brass and bronze scrap to brass and bronze ingot (85:5:5:5) 53
21. Iron and steel: Automotive scrap preparation by shredding 61
22. Iron and steel: Automotive scrap preparation by guillotine 63 shearing 63

ILLUSTRATIONS--Continued

		Page
23.	Iron and steel: Scrap preparation by guillotine shearing..........	64
24.	Iron and steel: Ferrous scrap preparation by baling...............	64
25.	Iron and steel: Ferrous scrap preparation by alligator shearing...	65
26.	Iron and steel: Purchased scrap preparation by torch cutting......	65
27.	Iron and steel: Home scrap preparation by torch cutting...........	66
28.	Iron and steel: Prompt industrial scrap preparation from borings and turnings (crushing)......................................	66
29.	Iron and steel: Electric arc furnace steelmaking with 100% scrap..	67
30.	Iron and steel: Gray iron casting by cupola process...............	69
31.	Secondary lead blast furnace.......................................	84
32.	Lead: Preparing broken battery scrap..............................	88
33.	Lead: Preparing prompt industrial and general lead scrap..........	89
34.	Lead: Producing hard lead by blast furnace process................	90
35.	Lead: Producing secondary lead by reverb/blast furnace process....	91
36.	Lead: Producing cast lead by pot melting process..................	94
37.	Nickel alloys: Preparing nickel alloy scrap from superalloy turnings..	101
38.	Nickel alloys: Preparing nickel alloy scrap from superalloy solids	102
39.	Nickel alloys: Preparing nickel and nickel-copper (Monel) scrap from solids...	102
40.	Vacuum induction furnace...	104
41.	Nickel alloys: Superalloy ingotmaking by double vacuum induction melting..	105
42.	Nickel alloys: Nickel alloy ingotmaking by air induction melting..	106
43.	Argon-oxygen decarburization (AOD) vessel.........................	115
44.	Stainless steel: Preparing scrap from turnings....................	120
45.	Stainless steel: Preparing light scrap............................	120
46.	Stainless steel: Preparing heavy scrap............................	121
47.	Stainless steel: Producing strand cast stainless steel billets by argon-oxygen decarburization (AOD).............................	122
48.	Tin: Detinning new tin-plated scrap...............................	128
49.	Tin: Tin recovery from detinning leach solution...................	130
50.	Titanium: Preparing light scrap...................................	135
51.	Titanium: Preparing heavy scrap...................................	136
52.	Titanium melting furnace for double or triple vacuum melting.......	137
53.	Titanium: Ingotmaking by double melting in vacuum arc furnace.....	139
54.	Effect of the percentage of scrap on total energy consumed.........	144
55.	Zinc: Retort distillation furnace.................................	148
56.	Muffle furnace and condenser.......................................	149
57.	Zinc: Preparing galvanizing dross or zinc skimmings...............	151
58.	Zinc: Preparing auto die-cast scrap...............................	152
59.	Zinc: Producing mixed die-cast scrap..............................	153
60.	Zinc: Producing zinc dust from scrap in distillation retorts......	154
61.	Zinc: Recycling clean zinc die-cast scrap by pot melting..........	155
62.	Zinc: Recycling off-specification zinc die-cast scrap by pot melting..	155
63.	Zinc: Producing zinc dust from scrap in muffle furnace............	160
64.	Municipal solid waste (MSW): Preparing refuse-derived fuel (RDF) product and concentrates..	170

TABLES

Page

1. Energy values used for fuels and energy sources and modes of transportation.... 6
2. Data on secondary aluminum industry.... 9
3. Purchased and toll-treated aluminum-base scrap and sweated pig consumed in 1976.... 10
4. Aluminum: Preparing aluminum clippings.... 20
5. Aluminum: Preparing clean, dry aluminum borings and turnings.... 21
6. Aluminum: Preparing aluminum drosses.... 21
7. Aluminum: Preparing high-iron aluminum scrap.... 22
8. Aluminum: Preparing aluminum sheet and cast scrap.... 22
9. Aluminum: Reverb furnace melting aluminum scrap to alloy 380 ingots.... 23
10. Aluminum: Reverb furnace melting aluminum scrap to hot metal (alloy 380).... 25
11. Aluminum: Recycling aluminum cans to hot metal for can sheet stock 29
12. Data on secondary copper industry.... 31
13. Purchased copper-base scrap consumed in 1976.... 33
14. Copper: Copper wire chopping.... 42
15. Copper: Copper wire incineration.... 44
16. Copper: Reverb melting No. 1 copper wire scrap.... 45
17. Copper: Recycling No. 2 copper scrap.... 47
18. Copper: Recycling low-grade, copper-bearing scrap.... 50
19. Copper: Recycling brass and bronze scrap to brass and bronze ingot (85:5:5:5).... 52
20. Data on iron and steel industry.... 57
21. Obsolete and prompt industrial iron and steel scrap receipts in 1976.... 60
22. Iron and steel: Automotive scrap preparation by shredding.... 71
23. Iron and steel: Automotive scrap preparation by guillotine shearing.... 71
24. Iron and steel: Scrap preparation by guillotine shearing.... 72
25. Iron and steel: Ferrous scrap preparation by baling.... 72
26. Iron and steel: Ferrous scrap preparation by alligator shearing... 73
27. Iron and steel: Purchased scrap preparation by torch cutting.... 73
28. Iron and steel: Home scrap preparation by torch cutting.... 74
29. Iron and steel: Prompt industrial scrap from borings and turnings (crushing).... 74
30. Iron and steel: Electric arc furnace steelmaking with 100% scrap.. 75
31. Iron and steel: Gray iron casting by cupola process.... 76
32. Data on secondary lead industry.... 81
33. Lead scrap consumption by smelters and refiners in 1976.... 82
34. Lead: Preparing broken battery scrap.... 86
35. Lead: Preparing prompt industrial and general scrap.... 86
36. Lead: Producing hard lead by blast furnace process.... 87
37. Lead: Producing secondary lead by reverb/blast furnace process.... 92
38. Lead: Producing cast lead by pot melting process.... 95
39. Data on secondary nickel industry.... 98
40. Nickel alloys: Preparing nickel alloy scrap from superalloy turnings.... 107

TABLES--Continued

Page

41. Nickel alloys: Preparing nickel alloy scrap from superalloy solids.. 108
42. Nickel alloys: Preparing nickel and nickel-copper (Monel) scrap from solids.. 108
43. Nickel alloys: Superalloy ingotmaking by double vacuum induction melting.. 109
44. Nickel alloys: Nickel alloy ingotmaking by air induction melting. 110
45. Data on secondary stainless steel industry...................... 112
46. Stainless steel: Preparing scrap from turnings.................. 117
47. Stainless steel: Preparing light scrap.......................... 117
48. Stainless steel: Preparing heavy scrap.......................... 118
49. Stainless steel: Producing strand cast stainless steel billets by argon-oxygen decarburization (AOD)............................ 119
50. Data on secondary tin industry.................................. 125
51. Tin metal equivalents recovered from various secondary scrap sources in 1976.. 125
52. Tin: Detinning new tin-plated scrap............................ 127
53. Tin: Tin recovery from detinning leach solution................. 129
54. Data on secondary titanium industry............................. 132
55. Titanium: Preparing light scrap................................ 141
56. Titanium: Preparing heavy scrap................................ 142
57. Titanium: Ingotmaking by double melting in vacuum arc furnace.... 143
58. Data on secondary zinc industry................................. 146
59. Zinc scrap consumption by smelters and distillers in 1976......... 146
60. Zinc: Preparing galvanizing dross or zinc skimmings............. 157
61. Zinc: Preparing auto die-cast scrap............................ 157
62. Zinc: Preparing mixed die-cast scrap........................... 158
63. Zinc: Producing zinc dust from scrap in distillation retorts..... 158
64. Zinc: Producing zinc dust from scrap in muffle furnace........... 159
65. Zinc: Recycling clean zinc die-cast scrap by pot melting......... 161
66. Zinc: Recycling off-specification zinc die-cast scrap by pot melting.. 162
67. Potential uses for components of municipal solid waste (MSW)...... 166
68. Municipal solid waste (MSW): Preparing refuse-derived fuel (RDF) product and concentrates...................................... 172
69. Summary of energy requirements by commodity and process in secondary metal recycling.. 178
70. Amount of scrap recycled in 1976................................ 179
A-1. Energy values for fuels, other energy sources, and commodities.... 181

ENERGY USE PATTERNS FOR METAL RECYCLING[1]

by

Charles L. Kusik[2] and Charles B. Kenahan[3]

ABSTRACT

A study was conducted for the Bureau of Mines, U.S. Department of the Interior, to provide information which will lead to an increase in the recycling of mineral materials, in order to help conserve the Nation's mineral resources. Data were collected on energy requirements to recycle prompt industrial and obsolete scrap for nine metal commodities: Iron and steel, aluminum, copper, zinc, lead, stainless steel, titanium, tin, and nickel and nickel alloys. Major process routes for recycling were considered, starting from the first collection point through scrap preparation, transportation, smelting and/or refining to the molten metal, ingot, or other semifinished form approximately equivalent to a primary metal of a similar composition. Available data for 1976 were collected on the amounts of each metal commodity recycled by major scrap categories. In addition, energy requirements were estimated for separating municipal solid wastes into four major categories: Refuse-derived fuel, and magnetic, aluminum, and glass cullet fractions. Finally, areas of research were identified to enhance recycling and/or increase the efficiency of energy use.

INTRODUCTION

Large quantities of scrap metals are discarded each year by industry and householders. Substantially less energy might be used to recover and reuse these metals than would be needed to produce new or "primary" metals from ores. Since only general estimates of potential energy savings have been made in the past, this study was undertaken to gather data on U.S. energy requirements in 1976 for recycling nine metal commodities: Iron and steel, aluminum, copper, zinc, lead, titanium, stainless steel, nickel and nickel alloys, and tin. Energy requirements for recycling prompt industrial (new) and obsolete (old) scrap metal have been estimated by major process routes, starting from the first collection center and ending with molten metal, ingots, or other semifinished forms roughly equivalent to a primary metal of similar composition.

[1]This report was compiled and prepared by Arthur D. Little, Inc., Cambridge, Mass., under Bureau of Mines contract number J0166143.

[2]Project director, Arthur D. Little, Inc., Cambridge, Mass.

[3]Research director, Avondale Metallurgy Research Center, Avondale, Md., and technical project officer, Bureau of Mines.

This study was an extension of an earlier project done for the Bureau of Mines by Battelle Columbus Laboratories to develop detailed estimates of energy needed to extract 83 metals and nonmetallic minerals, and convert them to primary products that are essential to the U.S. economy. The results are given in a series of reports entitled "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing."

Fourteen of the mineral commodities, covered in the first of the reports, were assigned "highest priority" for study because of their large energy requirements, or because they are produced in extremely large volume each year. The commodities are aluminum, calcium, cement, ceramics, chlorine, copper, glass, iron and steel, lead, nitrogen, phosphorus, refractories, sulfur, and zinc.

"Intermediate priority" minerals covered in the second report are argon, asbestos, barium, boron, bromine, chromium, clays, diatomite, feldspar, fluorine, gypsum, magnesium, manganese, mica, molybdenum, nickel, oxygen, perlite, potassium, pumice, sand and gravel, silicon, sodium, talc (including soapstone and pyrophyllite), titanium, uranium, and vermiculite.

The third report contained detailed estimates of energy requirements for producing 42 "low-priority" mineral commodities. Pertinent data from each of the three detailed reports are summarized in a fourth report, and opportunities for research to improve energy consumption efficiency are described in a fifth report. Each of these reports is available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.[4] "Phase 4--Energy Data and Flowsheets, High-Priority Commodities" (PB 246 357/AS); "Phase 5--Energy Data and Flowsheets, Intermediate-Priority Commodities" (PB 246 357/AS); "Phase 6--Energy Data and Flowsheets, Low-Priority Commodities" (PB 261 150/AS); "Phase 7--Summary of the Results of Phases 4, 5, and 6" (PB 261 151/AS); "Phase 8--Opportunities To Improve Energy Efficiency in Production of High-Priority Commodities Without Major Process Changes" (PB 261 152/AS); "Phase 9--Areas Where Alternative Technologies Should Be Developed To Lower Energy Use in Production of High-Priority Commodities" (PB 261 153/AS).

The volumes also are on open file for public reference during regular working hours at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C., and at the following Bureau of Mines facilities: Albany Metallurgy Research Center, Albany, Oreg.; Boulder City Metallurgy Engineering Laboratory, Boulder City, Nev.; Avondale Metallurgy Research Center, Avondale, Md.; Reno Metallurgy Research Center, Reno, Nev.; Rolla Metallurgy Research Center, Rolla, Mo.; Salt Lake City Metallurgy Research Center, Salt Lake City, Utah; Tuscaloosa Metallurgy Research Center, Tuscaloosa, Ala.; Twin Cities Metallurgy Research Center, Twin Cities, Minn.

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[4]Contact National Technical Information Service for current price information.

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For their many insights, critique, and guidance of this program, we would like to express our appreciation to the following Bureau of Mines personnel, Paul M. Sullivan, Robert S. Kaplan, Frank A. Peters, and Kenneth B. Higbie.

METHODOLOGY

Scrap Recycled

After discussions with personnel from the Bureau of Mines (U.S. Department of the Interior), Department of Commerce, National Association of Recycling Industries (NARI), Institute of Scrap Iron and Steel (ISIS), and other organizations, best estimates were made of scrap recycled in 1976 (as summarized in table 70). In general, most of the data detailing the amounts of scrap recycled that were finally used originated from the Bureau of Mines.

Energy Analysis

Two major methodological approaches have been used in generating energy flow data: Process analysis and input-output analysis. In this study a process analysis approach was used in which energy requirements for recycling were determined by process step and summarized in flowsheet format for major processes considered, which are shown in table 69. Other less prevalent processes are described in the text.

In addition, energy requirements were estimated for separating municipal solid waste into the following four major categories: Refuse-derived fuel (RDF), and magnetic, nonmagnetic, and glass cullet fractions.

The process analysis approach used in this study included the following major elements: Process selection, flowsheet development, energy requirements, and identifying major heat losses. Each is further described below.

Process Selection

For each commodity being considered, typical processing schemes were selected for consideration based upon discussions with Bureau of Mines personnel, consultants, Arthur D. Little specialists, NARI, ISIS, the American Iron and Steel Institute (AISI), and the Aluminum Recycling Association, as well as other trade organizations, and were confirmed with plant personnel during field visits.

For some commodities, only one sequence of process steps was selected since it was the only or predominant recycling method, while for others several processes were included for detailed analysis. The authors believe that every major recycling process practiced in the United States in 1976 has been considered for these nine metal commodities.

In addition, one municipal solid waste flowsheet was selected for analysis. This flowsheet was included to indicate the potential for recovering the components of raw refuse in a form suitable for recycling into the economy.

Flowsheet Development

For each of the major recycling methods, a flowsheet was developed using the format of figure 1. The starting point for each flowsheet is the first scrap collection center, which could be a recycling center, such as in the collection of aluminum cans; an auto service center accumulating old lead batteries; a scrapyard gathering junk automobiles; or a galvanizing operation saving drosses and skimmings for recycle. The boxes in figure 1 are numbered and show major process steps in the recycling sequence such as a melting furnace, a shredding operation, or a transportation step. To the extent possible, a common format has been used for these flowsheets, as discussed below.

Vertical lines.--Scrap entering the processing sequence and the subsequent upgraded product are shown to flow vertically down the flowsheet to a raw, crude, or semifinished product, such as a billet, ingot, or wirebar.

Horizontal lines.--Major nonscrap raw materials consumed are shown by horizontal arrows entering the left-hand side of the box representing a process step, while major byproducts, wastes, and energy credits are shown leaving by horizontal arrows from the right-hand side of the flowsheet.

Circles.--Pollution control units found to be associated with a given process step are indicated by a circle adjoining the process unit box with symbols A representing air, W representing water, and S representing solid waste.

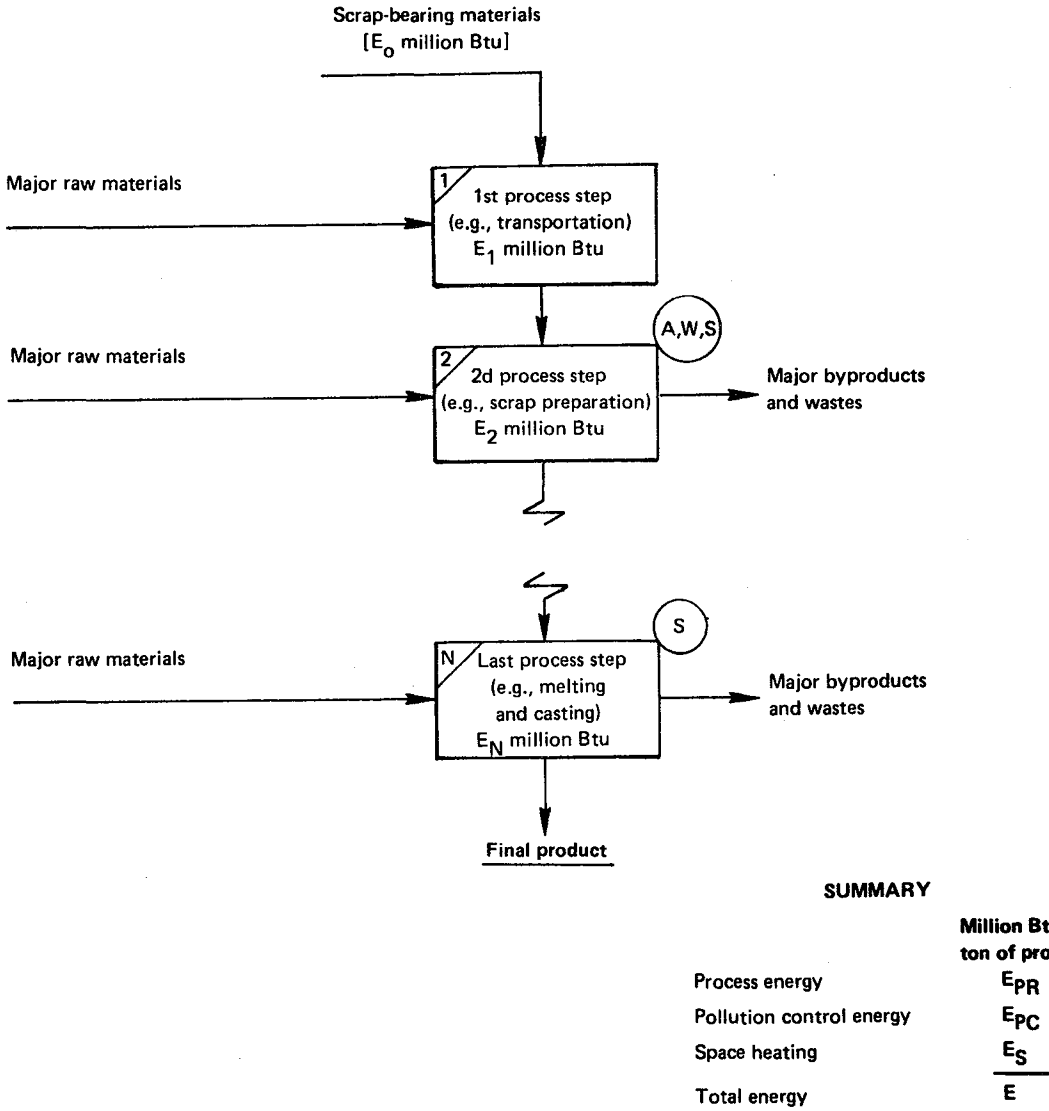


FIGURE 1. - Format used in preparing flowsheets.

Energy Requirements

All of the energy numbers reported and materials consumed for a given process are based upon averages of data as gathered largely from the field during the year 1976. Where this information has been supplemented by information from the literature or other sources, it has been so indicated.

After obtaining the data on materials used and energy requirements by process step, a computer program was used to facilitate calculating energy requirements per ton of product as described below.

Energy values excluding scrap.--Table 1 shows energy values for fuels, other energy sources, and transportation that were derived from previous work done for the Bureau of Mines by Battelle Columbus Laboratories (1975). Using the same source documents, a similar list of energy values for materials used in recycling was developed and entered into an energy file, which is summarized in the appendix.

TABLE 1. - Energy values used for fuels and energy sources and modes of transportation

	Energy value
Modes of transport:	
Truck.............million Btu per net ton[1] mile transported...	0.0024
Rail..do.[1]........	0.00067
Water...do.[1]........	0.00025
Fuels and energy sources:	
Anthracite coal.....................million Btu per net ton..	25.4
Bituminous coal................................do..........	25.0
Metallurgical coke.............................do..........	31.5
Distillate fuel oil.........................Btu per gallon..	139,000
Residual fuel oil..............................do..........	150,000
Natural gas.............................Btu per cubic foot..	1,000
Electricity.........................Btu per kilowatt-hour[2]..	10,500
Steam, low-pressure (per 1,000 pounds steam).....million Btu..	1.0
Steam, at 100 psig (per 1,000 pounds steam).......do..........	1.4

[1]1 net ton = 1 short ton = 2,000 pounds.
[2]Based on approximate fossil fuel equivalent used to generate 1 kilowatt-hour.

Energy value of scrap.--Scrap is assigned a zero energy content in this analysis. Thus in figure 1 the energy content E_0 of the scrap entering is normally zero. However, when several types of scrap and modes of preparation had to be considered in the recycling process, prepared scrap from one flowsheet is often shown entering the top of another flowsheet. Such prepared scrap has an entailed energy requirement, E_0 million Btu per ton of final product, which is indicated by a figure in brackets below the type scrap being used (as shown in fig. 1). An estimated breakdown of scrap use by type is shown in the energy tables accompanying the flowsheets.

Process step energy requirements.--After all materials and energy used within a typical[5] processing sequence were identified, energy consumption requirements were estimated for producing 1 net ton of final product, using the above-mentioned energy file for ease in manipulating and assuring consistency in the use of the basic data. Exceptions to this procedure are noted in the energy tables and include some major alloy additions, such as silicon, in the manufacture of certain grades of aluminum diecasting alloys (for example, type 380 alloy from aluminum scrap). To the extent possible, primary metals used to "sweeten" the product (that is, control the impurity specification) were not included in the energy analysis. However, it has been noted in the flowsheet discussion where primary metal additions are not unusual industry practice. Examples include the addition of primary aluminum to secondary aluminum furnaces, and the addition of primary ingot in recycling titanium.

[5]Within the context of this report, the word "typical" is used to identify those operations handling the largest tonnages of materials.

In each of the flowsheets for recycling metals, a transportation distance estimate was made. Such estimates were based upon field visits and discussions with individuals knowledgeable in the secondary metals industry. Generally, the amount of energy required for transporting secondary metals is small, with the exceptions identified easily in the tables showing the energy analysis.

The total energy content of the materials used and energy consumed (for example, electric power, fossil fuels, steam, etc.) minus any energy in credits accrued to a process step are shown by a number in the box (such as, E_1, E_2 in fig. 1) with details presented in energy tables accompanying the flowsheet.

Process energy requirements.--Energy requirements for all process steps and for any entailed energy for scrap (E_O) are summarized separately at the bottom of the figure. Thus this process energy (E_{PR}) is the sum of E_O, E_1, E_2+ . . . as shown on the flowsheet.

Pollution control, space heating, and other energy use.--Since pollution control units and space heating are often associated with many process units, the related energy requirements (E_{PC} and E_S) were indicated for the entire flowsheet (as summarized at the bottom of the figure). For the purpose of this analysis, space heating represented an average value for plants not experiencing extreme climatological conditions (for example, Philadelphia, Pa., St. Louis, Mo., Denver, Colo., and Salt Lake City, Utah). Pollution control energy requirements are average estimates for typical operations found in the field visits.

It was generally found that fuel use for in-plant transportation was small. Thus, it has been included in the energy for the processing units. An exception to this convention is found in the municipal solid waste (MSW) sector where in-plant transportation has been separately identified.

Total energy requirements.--Total energy required per ton of product (E) is simply obtained by adding process energy, pollution control energy, and space heating.

Byproducts.--When two or more salable products result from a given processing sequence shown on a flowsheet, consideration was given to the relative weight and value of the products to determine whether an item was a byproduct or a coproduct. Generally, a product was labeled as a byproduct when the economics of the recycling processing scheme did not depend to a major degree on credits from a product generated. When only byproducts were produced, all of the energy consumed in the processing sequence was attributed to the major product shown emanating from the bottom of the flowsheet.

At times the economics of the processing scheme dictated that both products be considered for the process to be economically viable, in which case the energy requirements were handled in a manner shown on the energy tables and discussed in the accompanying text. Alternative allocation methodologies can be easily accommodated since all of the energy information is presented in the energy tables.

Heat Losses

Upon completing the energy analysis, major heat losses were identified for each of the recycling processes.

Energy Research and Development Areas

In the course of field trips and in undertaking the relevant energy analyses, technical research and development sectors were identified in each commodity sector that would either help in making the processes more energy-efficient or would aid in recycling metal commodities.

Nomenclature and Conventions

Certain terms and conventions have been adopted in the presentation of this analysis, as discussed in the following text.

Scrap Categories

Scrap metals are normally classified into three categories: Home scrap, prompt industrial scrap, and obsolete scrap. Home scrap is generated within the smelting or refining facility and is recycled directly back into the melting furnaces. Prompt industrial scrap is normally generated within manufacturing operations and is recycled back to the smelting and refining facilities, which may be located some distance from the manufacturing facilities (for example, scrap generated during the manufacture of automobiles or scrap generated in lead battery manufacturing operations). Obsolete scrap (or post-consumer scrap) is old scrap generated at the end of the products' life cycles.

This study considered only the prompt industrial and obsolete scrap generated and recycled in 1976. Home scrap use, however, has been identified if it is a typical part of the processing sequence.

New Scrap and Virgin Materials

Use of the term "new materials" can refer to either new scrap (prompt industrial scrap) or new materials derived largely from ore. To avoid such ambiguity, the authors have attempted to restrict their terminology, referring to new scrap as prompt industrial scrap and referring to commodities largely derived from ore as virgin materials.

ALUMINUM

Background

Table 2 presents data on the secondary aluminum industry.

TABLE 2. - Data on secondary aluminum industry

	Net tons[1]
Secondary raw materials (1976):	
New scrap	1,030,000
Old scrap	416,000
Secondary U.S. production (1976)	709,000

[1]All figures are rounded to the nearest thousand.

NOTE.--Commodity: Aluminum.
Primary products: Casting alloys (die cast, sand, and permanent mold), wrought alloys, steel-deoxidizer-grade alloys, and hardeners.
Byproducts: None.
Coproducts: None.

Source: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys, 1976.

Types and Classifications of Scrap

Aluminum scrap can be subdivided into four main categories: New aluminum clippings, forgings, and solids; aluminum borings and turnings; aluminum drosses and skimmings; and old casting and sheet. New aluminum clippings, forgings, and solids include segregated low-copper, mixed low-copper, segregated high-copper, segregated high-zinc, and mixed high-zinc alloy aluminum clips, painted aluminum clips, and special aluminum cast and alloy solids. Aluminum borings and turnings consist of segregated high-grade (low-copper alloy and high-copper alloy); mixed high-grade borings (low-zinc alloy); segregated borings (high-zinc alloy); miscellaneous turnings; and contaminated turnings. Aluminum drosses consist of aluminum oxide and metallic aluminum produced by oxidation during processing of molten aluminum; aluminum skimmings consist of the mixture of aluminum oxide and salts produced by fluxing during processing of molten aluminum. Old casting and sheet consist of old cast aluminum, old sheet aluminum, aluminum foil, aluminum cans, ACSR (aluminum conductor steel reinforced), insulated aluminum cable, and contaminated aluminum (breakage).

Scrap Consumption

As shown in table 3, 1,446,000 tons of aluminum base scrap were consumed in 1976 (5).[6] Of this about 55% was consumed by secondary aluminum smelters, about 24% was consumed by primary smelters, and the remaining 21%, by other consumers, including fabricators with melting facilities and foundries. Of the total aluminum-base scrap consumed, new clippings and solids accounted for 39%; borings and turnings represented 10%; drosses and skimmings, 16%; old castings and sheet, 15%; and aluminum cans, about 7%.

[6]Underlined numbers in parentheses refer to items in the list of references at the end of each chapter.

TABLE 3. - Purchased and toll-treated aluminum-base scrap and sweated pig consumed in 1976

Scrap item	Melted or consumed, thousand short tons	Old scrap, %	New scrap, %
Solids and clippings	564	0	100
Borings and turnings	149	0	100
Drosses and skimmings	229	0	100
Other (includes foil and high-iron scrap)	88	0	100
Castings, sheet, and clippings	209	100	0
Aluminum cans	103	100	0
Other (includes aluminum-copper radiators and high-iron scrap)[1]	104	100	0
Total	1,446	-	-

[1]This type of scrap is used to make sweated pig.

Sources: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys, 1976; and Arthur D. Little, Inc., estimates. Figures are from the Bureau of Mines. Scrap item categories have been rearranged by Arthur D. Little, Inc.

Of the old aluminum cans recycled, less than 10% are processed at secondary smelters. Most old aluminum cans (more than 90%) are purchased by primary producers and are used in the production of hot metal for canstock sheet production. In 1975, total aluminum can scrap consumption was 83,835 tons, 6,943 tons (8.3%) of which was consumed by secondary smelters. The remainder was consumed largely by the primary producers (5). The major primary aluminum producers, beverage manufacturers, and private contractors operate collection centers where consumers can redeem used all-aluminum cans at 17 cents per pound. The recycling of aluminum cans has been dealt with separately later in this chapter.

Products

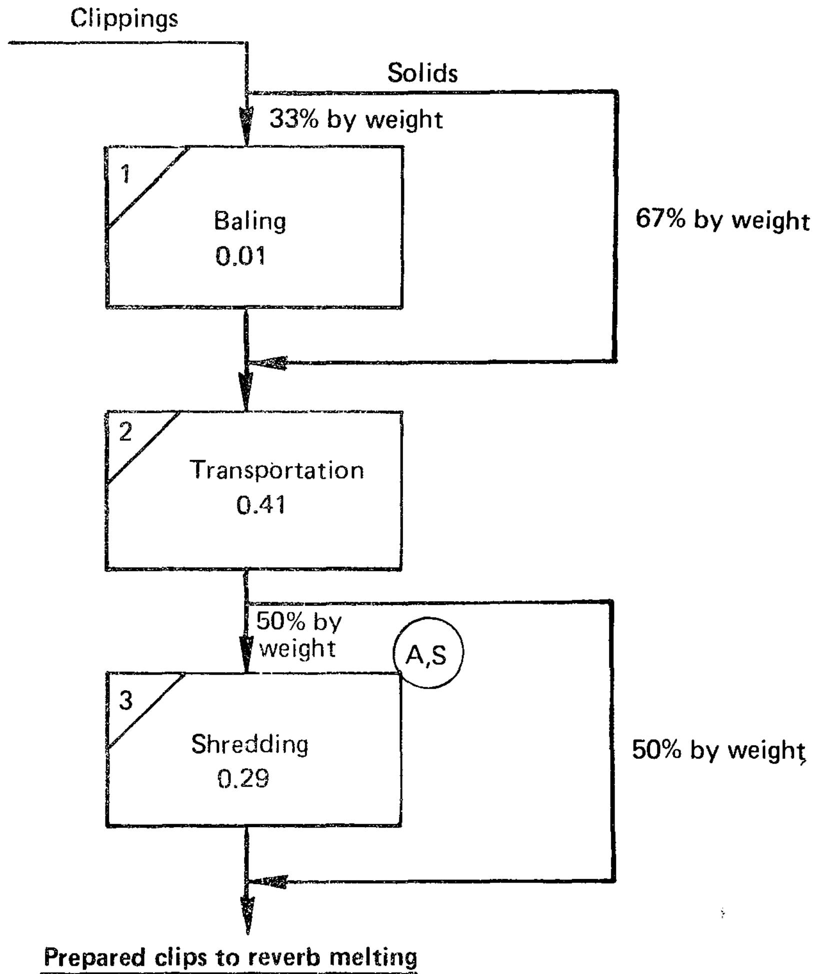
The principal products of the secondary aluminum industry are casting alloys, wrought alloys, steel-deoxidizer-grade alloys, and hardeners. The main casting alloys in turn are the diecasting alloys, such as alloy 380 (3% to 4% Cu, 8.5% to 9.5% Si, 1.0% Fe, 1.0% to 3.0% Zn, 0.1% Mg), alloy 13, and alloy 360. Other casting alloys include those for sand and permanent mold casting, such as No. 356, No. 12, No. 319, and F-132. Casting alloys are normally produced as 15- or 30-pound ingots, 1,000-pound sows, or molten metal in 12,000- to 35,000-pound hot metal ladles. Casting alloys represented 83.8% of secondary smelter production in 1976.

Wrought alloys are produced by secondary smelters in the form of extrusion billets. Most of the production is comprised of 6063 and 6061 alloys. Extrusion billets accounted for 8.8% of secondary smelter production in 1976. Steel deoxidizers accounted for 3.9%, and hardeners and other miscellaneous alloys, for 3.6%

Scrap Preparation Methods

Major Preparation Methods

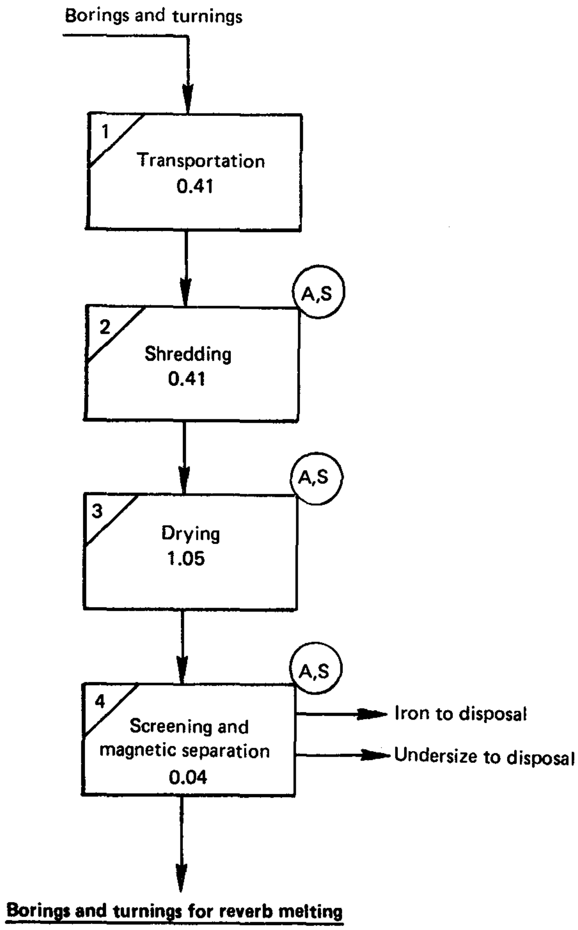
New aluminum clippings, forgings, and solids, if clean, require no preparation. However, if solids have iron inclusions, or other contaminants, they are usually run through a shredder to reduce the size of the scrap and then through a magnetic separator to remove the iron. This preparation method is shown in figure 2.



SUMMARY

	Million Btu per ton of product
Process energy	0.71
Pollution control energy	.20
Space heating	.00
Total energy	.91

FIGURE 2. - Aluminum: Preparing aluminum clippings.



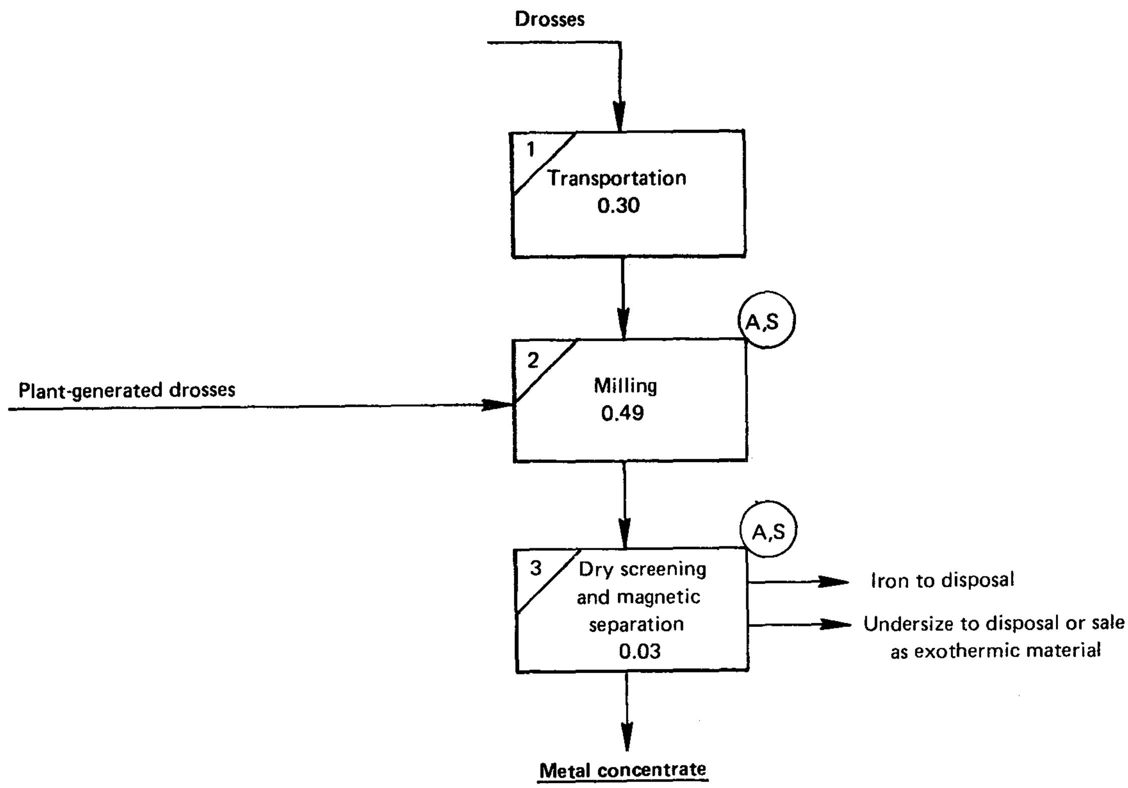
SUMMARY

	Million Btu per ton of product
Process energy	1.91
Pollution control energy	1.14
Space heating	.00
Total energy	3.05

FIGURE 3. - Aluminum: Preparing clean, dry aluminum borings and turnings.

Aluminum borings and turnings (especially bulky spinnings) almost always require processing since they normally contain oil, moisture, and free iron which must be removed before the scrap can be melted. Borings are charged to a ring crusher which reduces them to a uniform size. They are then dried in a rotary kiln-type dryer where the oil and moisture are volatilized. Finally, the borings are passed over a magnetic separator where the iron is removed and the clean, dry borings drop into "tote boxes" for storage and later use. This preparation method is shown in figure 3.

Most aluminum drosses, skimmings, and slags are processed by milling, screening, and magnetic separation to obtain an end-product with a minimum of 60% to 70% metal suitable for charging to the melting furnace (fig. 4). Oxides and dirt are loosened from the metallics by crushing in a ball mill, rodmill, or hammer mill, and then removed by screening or air separation to produce a high metallic "concentrate." The undersize fraction containing oxides and fine metallics is either sold as an exothermic material for hot-topping ingots or disposed of as a waste product. Rich metallic skims normally do not require milling prior to use.

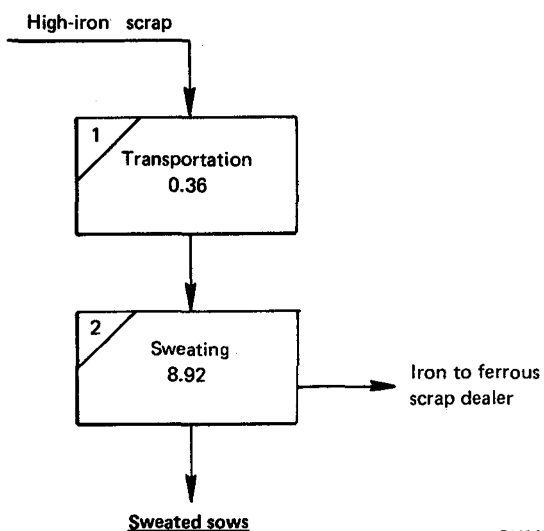


SUMMARY

	Million Btu per ton of product
Process energy	0.82
Pollution control energy	.24
Space heating	.00
Total energy	1.06

FIGURE 4. - Aluminum: Preparing aluminum drosses.

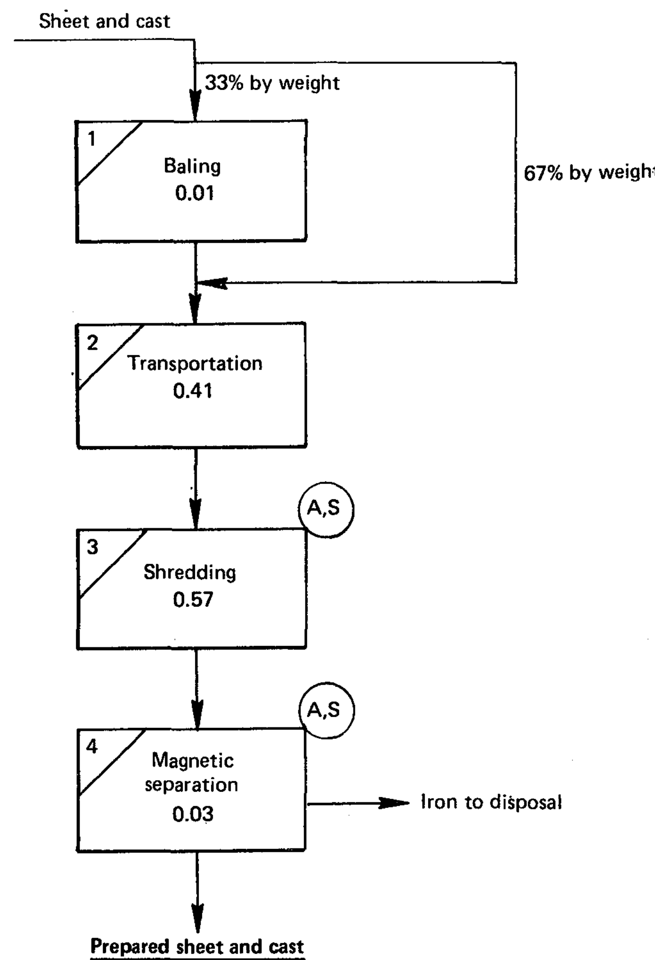
Aluminum cast (or sheet) containing massive iron pieces or a large quantity of iron is processed in a "sweat" furnace, as shown in figure 5. "Sweating" consists of selectively melting the aluminum alloy (melting point 1,100° F) at a temperature below the melting point of iron or steel and letting the molten aluminum fraction flow into a ladle or mold while the iron-containing portion is raked out of the furnace.



SUMMARY

	Million Btu per ton of product
Process energy	9.28
Pollution control energy	.00
Space heating	.00
Total energy	9.28

FIGURE 5. - Aluminum: Preparing high-iron aluminum scrap.



SUMMARY

	Million Btu per ton of product
Process energy	1.02
Pollution control energy	.16
Space heating	.00
Total energy	1.18

FIGURE 6. - Aluminum: Preparing aluminum sheet and cast scrap.

Old scrap (cast and sheet) usually has enough free iron rivets, bushings, and other tramp attachments or contaminants to require shredding to small size followed by magnetic separation as shown in figure 6.

Aluminum wire scrap is handled by wire-chopping methods similar to those described for copper. Chopped aluminum wire is used for alloying and as a deoxidant in steelmaking. The energy consumed in aluminum wire chopping is of the same order as that for copper wire chopping.

The main air pollution controls in scrap preparation are afterburners used to consume combustible black smoke generated in drying aluminum turnings, and baghouses used to collect dust from shredding and milling operations. There are normally no process water effluents in the aforementioned scrap preparation processes. High iron or steel scrap separated from the aluminum scrap is either sent to landfill or, at times, to scrap iron/steel processors.

Other Preparation Methods

A processing scheme used by a small part of the secondary aluminum industry is wet preparation of secondary smelter slag containing soluble salts. In this scheme, the slag is fed into a long tumbling drum with a stream of water passing through the drum that washes and carries away the fluxing salts. The residue, consisting largely of metallics and insoluble oxides, is then screened, dried, and passed over a magnetic separator to remove any magnetic materials. The nonmagnetic fraction is stored for charging to the melting furnace. If fluxes dissolving in the water are not recovered from this stream before discharge, they constitute a potential water pollution problem.

Another scheme for dross preparation is one in which the dross is treated in a rotary furnace with a NaCl-KCl salt flux to entrain the Al_2O_3 in the dross and recover the aluminum metal. A solid waste disposal problem is generated by this scheme since it generates a slag containing chloride salts of sodium and potassium, as well as aluminum metal and oxide.

Smelting and Refining

Major Processing Methods

The main processing method used in the secondary aluminum industry is reverberatory (reverb) melting of aluminum scrap, as shown in figure 7. The reverb furnaces are either gas-fired or have dual-firing (gas and oil) capability. In the past few years, with at least occasional natural gas curtailments in most parts of the country, this dual capability has become very useful. The furnaces, ranging in capacity from 30,000 to 200,000 pounds of molten metal, have one or two external charging wells or forewells (for charging scrap), which are separated from the main hearth of the furnace by a refractory wall called a "hot wall." The hot wall has two openings, connecting the hearth and the charging wells, which are 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

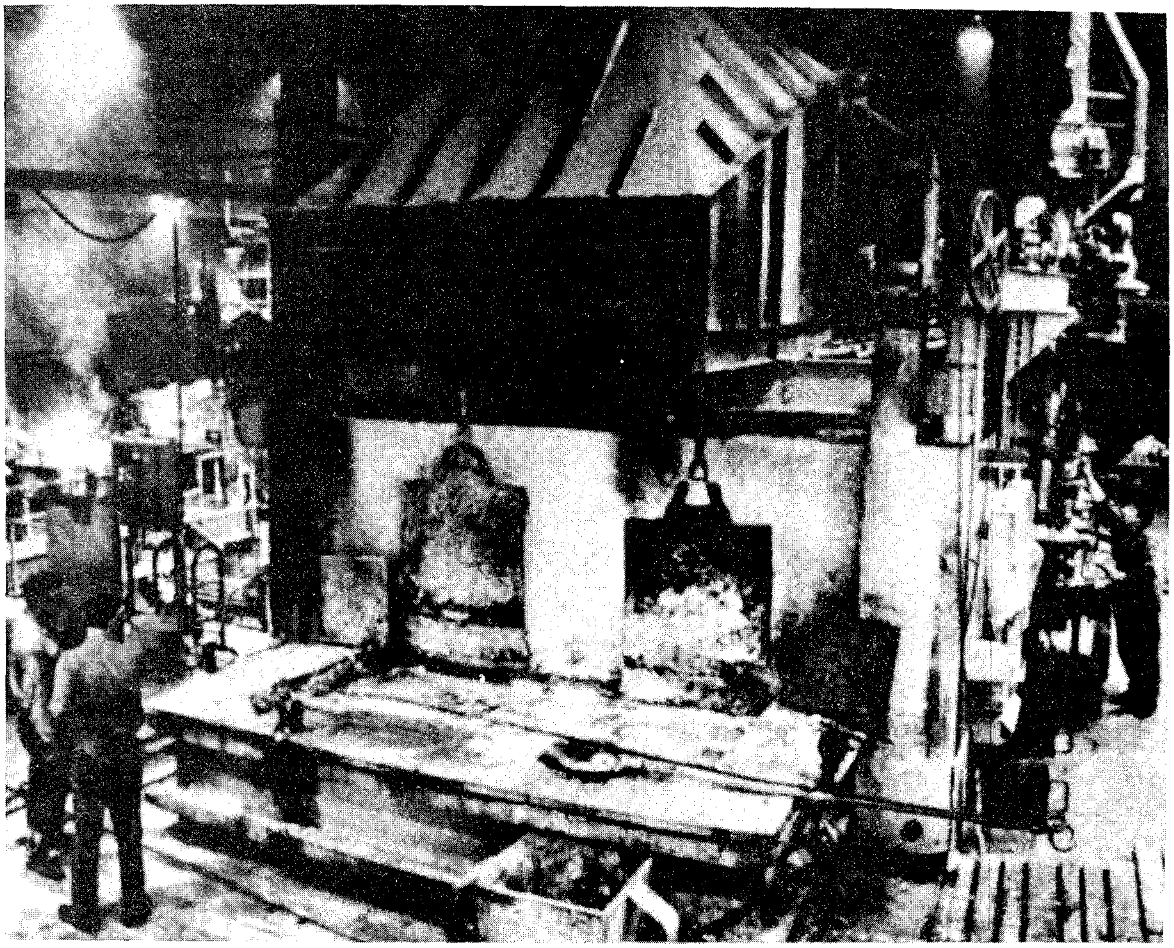


FIGURE 7. - Reverberatory (reverb) furnace.

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. A "molten heel"--molten metal of known composition that occupies the bottom of the furnace and is left over from a previous heat--can be used to shorten the heat time. If a liquid heel is not maintained in the furnace from heat to heat, heavy solids are charged into the furnace, generally through the side doors. Once charged, the material must be completely melted, skimmed, sampled, and assayed before other materials can be charged. Scrap charged subsequently is charged through the forewell. After each charge, the slag is skimmed off and the metal 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 as possible in composition to the alloy being produced.

Fluxing salts (commonly 47.5% NaCl, 47.5% KCl, 5% cryolite) are used to entrain oxides on the metal charging suface. 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, to bring the melt to specification. Mixing the bath is carried out manually, or by injecting nitrogen gas, or using mechanical puddlers.

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% Mg. Excess magnesium is removed from the bath through the addition of AlF_3 or chlorine gas. Finally, the metal is degasified by bubbling nitrogen, chlorine, or a mixture of the two in the molten bath. The overall metal recovery of the reverb melting scheme is around 90%. Metal losses are mostly in the slag.

Twenty-four to 42 hours after initial scrap charging the metal is ready for casting. The casting temperature for ingots is around 1,350° F. Ingot molds are filled by automatic casting methods. After skimming, the ingots are cooled with water sprays, removed from the mold, and stacked manually or by a hydraulic ingot stacker into 2,000-pound shipping stacks.

Metal is also delivered to a customer as "hot metal," as shown in figure 8. Hot metal is tapped from a reverb furnace directly into preheated ladles at approximately 1,550° 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 1,350° F. The average load of hot metal now being delivered is 30,000 to

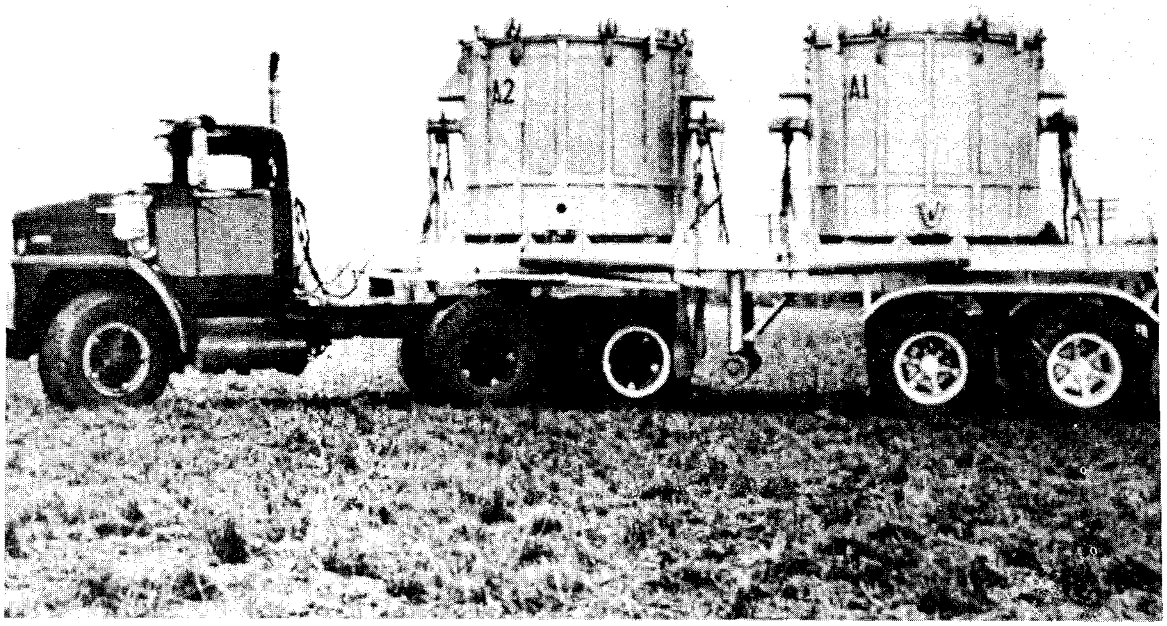


FIGURE 8. - Delivery of hot metal in ladles. *(Courtesy, National Association of Secondary Material Industries)*

35,000 pounds. This can be accomplished by using one 35,000-pound ladle or two 15,000-pound ladles. 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.

Furnace air pollution controls consist mainly of hoods over the charging wells to collect fumes and dust before exhausting them through a baghouse. Generally, the combustion gases on the hearth side are clean and thus ducted directly to a stack. However, when AlF_3 is used for removing magnesium, air contaminants in the form of gaseous fluorides may result from the hearth side. The dry emission control process, using coated baghouses (such as the modified Teller system), differs from the normal baghouse system in that the bags are precoated with a solid, such as lime, to absorb effluent acid gases as well as particulates. When the bag is saturated, the coating and the dust are removed by vibration and the bags are recoated.

Alternative Demagging Schemes

The alternative demagging schemes that can be used involve the use of chlorine. Chlorine is introduced through tubes to the bottom of the melt and the reaction product--$MgCl_2$--is skimmed off. In the later stages of demagging, $AlCl_3$ is formed and causes fuming. Therefore, ventilation and air pollution control are needed. If wet scrubbers are used, chlorides are absorbed in the water, and treatment may be required before discharge of waste streams.

Improvements in chlorine demagging include increasing the efficiency of the demagging process, thereby reducing air pollutant emissions. For example, Alcoa (2) has developed a reaction chamber through which molten aluminum flows. Chlorine is introduced through a rotating "contactor" that disperses the gas in tiny bubbles. Demagging efficiencies of 100% have been reported. A potentially salable byproduct of the process is $MgCl_2$, which is collected on the surface of the melt in the reaction container. Another process is the Metaullics process (2) developed by the Carborundum Co. In this process a pump forces the molten alloy into a reaction chamber where chlorine gas is injected to remove a portion of the magnesium, before returning it to the reverb furnace. Flow rates are adjusted so that only $MgCl_2$ is formed.

The Derham process (2) is another demagging scheme in which molten metal is circulated from the main furnace hearth to the Derham chlorination unit by pumping with an air-driven siphon through a thick layer of molten salt covering the bath. The flux traps the aluminum chloride fumes and makes them available for further reaction at the aluminum flux interface. Efficiencies of better than 97% have been reported at 0.1% magnesium levels in the bath. Emissions of aluminum chloride to the atmosphere are greatly reduced; however, a wet scrubber is generally maintained as standby.

Yet another demagging process, the INTEC chlorinator system (1), is based on the introduction of a diffused stream of chlorine deep into the molten bath. This infusion causes reaction products to be trapped within a cast iron bell partially submerged in the bath, with any aluminum chloride emissions being scrubbed.

Other Processing Schemes

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

In the 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 Ti, B, and Cr for alloying purposes. These are produced in small induction furnaces (4) 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 2,000° to 2,200° F after the metal is skimmed to remove oxides.

Energy Analyses

In this section, energy analyses for the following aluminum processing methods are presented: Scrap preparation, reverb melting of aluminum scrap to alloy 380 ingot, and reverb melting of aluminum scrap to hot metal. These schemes are representative of casting alloy, which accounted for about 84% of secondary smelter production in 1976.

Scrap Preparation

Figures 2-6 and tables 4-8 present an analysis of scrap transportation and preparation. Preparing clippings requires 0.91 million Btu per ton of prepared scrap, of which 78% is required for processing and the remaining 22%, for air pollution control. As shown in figure 2, solids need not be baled. Shredding is needed only if the scrap is contaminated. Based on discussion with industry personnel, it is assumed in this analysis that one-half of the scrap requires shredding.

Preparing borings and turnings requires 3.05 million Btu per ton of clean dry borings, of which 1.91 million Btu is process energy and 1.14 million Btu is air pollution control energy for the afterburner and baghouse. It should be noted that energy consumption in the shredding step depends on the type of scrap, which also affects the throughput rate. For bushy (bulky) turnings, for example, the throughput can be quite significantly decreased. The materials handling system in many cases limits the throughput. The energy consumption numbers used here are based on average throughputs.

TABLE 4. - Aluminum: Preparing aluminum clippings

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) BALING (0.67 TON)				
ELECTRICAL ENERGY	KW HR	0.5000	0.010500	0.01
			SUBTOTAL	0.01
(2) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
RAIL	TON MI	70.0000	0.000670	0.05
			SUBTOTAL	0.41
(3) SHREDDING (0.50 TON)				
ELECTRICAL ENERGY	KW HR	28.0000	0.010500	0.29
			SUBTOTAL	0.29
* TOTAL PROCESS ENERGY				0.71
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	18.7000	0.010500	0.20
			SUBTOTAL	0.20
* TOTAL POLLUTION CONTROL ENERGY				0.20
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				0.91

Preparing aluminum drosses consumes 1.06 million Btu per ton of concentrate, of which 0.82 million Btu is process energy and the remainder, air pollution control energy for the baghouse which collects the dust generated during milling, screening, and magnetic separation.

Figure 5 and table 7 show the energy requirements for sweating high-iron scrap and breakages. It is assumed that the metallic recovery is 40%. The preparation of sows from such scrap requires 9.28 million Btu per ton sow. Occasionally, afterburners are found on aluminum sweating furnaces, in which case about 1 to 1.5 million Btu of additional energy would be required per ton of product.

Preparing old aluminum sheet and cast requires 1.18 million Btu per ton of prepared scrap, of which 86.4% is process energy and the remainder, air pollution control energy.

TABLE 5. - Aluminum: Preparing clean, dry aluminum borings and turnings

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
RAIL	TON MI	70.0000	0.000670	0.05
			SUBTOTAL	0.41
(2) SHREDDING				
ELECTRICAL ENERGY	KW HR	39.2000	0.010500	0.41
			SUBTOTAL	0.41
(3) DRYING				
NATURAL GAS	CU. FT.	920.0000	0.001000	0.92
ELECTRICAL ENERGY	KW HR	12.3000	0.010500	0.13
			SUBTOTAL	1.05
(4) SCREENING AND MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	3.8300	0.010500	0.04
			SUBTOTAL	0.04
* TOTAL PROCESS ENERGY				1.91
AIR POLLUTION CONTROL				
NATURAL GAS	CU. FT.	940.0000	0.001000	0.94
ELECTRICAL ENERGY	KW HR	19.2000	0.010500	0.20
			SUBTOTAL	1.14
* TOTAL POLLUTION CONTROL ENERGY				1.14
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				3.05

TABLE 6. - Aluminum: Preparing aluminum drosses

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
RAIL	TON MI	450.0000	0.000670	0.30
			SUBTOTAL	0.30
(2) MILLING				
ELECTRICAL ENERGY	KW HR	47.0000	0.010500	0.49
			SUBTOTAL	0.49
(3) SCREENING AND MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	3.0000	0.010500	0.03
			SUBTOTAL	0.03
* TOTAL PROCESS ENERGY				0.82
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	22.9000	0.010500	0.24
			SUBTOTAL	0.24
* TOTAL POLLUTION CONTROL ENERGY				0.24
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				1.06

TABLE 7. - Aluminum: Preparing high-iron aluminum scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
			SUBTOTAL	0.36
(2) SWEATING				
NATURAL GAS	CU. FT.	8640.0000	0.001000	8.64
ELECTRICAL ENERGY	KW HR	26.9000	0.010500	0.28
			SUBTOTAL	8.92
* TOTAL PROCESS ENERGY				9.28
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				9.28

TABLE 8. - Aluminum: Preparing aluminum sheet and cast scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) BALING (0.67 TON)				
ELECTRICAL ENERGY	KW HR	0.5000	0.010500	0.01
			SUBTOTAL	0.01
(2) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
RAIL	TON MI	70.0000	0.000670	0.05
			SUBTOTAL	0.41
(3) SHREDDING				
ELECTRICAL ENERGY	KW HR	54.4000	0.010500	0.57
			SUBTOTAL	0.57
(4) MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	3.0000	0.010500	0.03
			SUBTOTAL	0.03
* TOTAL PROCESS ENERGY				1.02
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	14.9000	0.010500	0.16
			SUBTOTAL	0.16
* TOTAL POLLUTION CONTROL ENERGY				0.16
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				1.18

Reverb Melting Aluminum Scrap to Alloy 380 Ingots

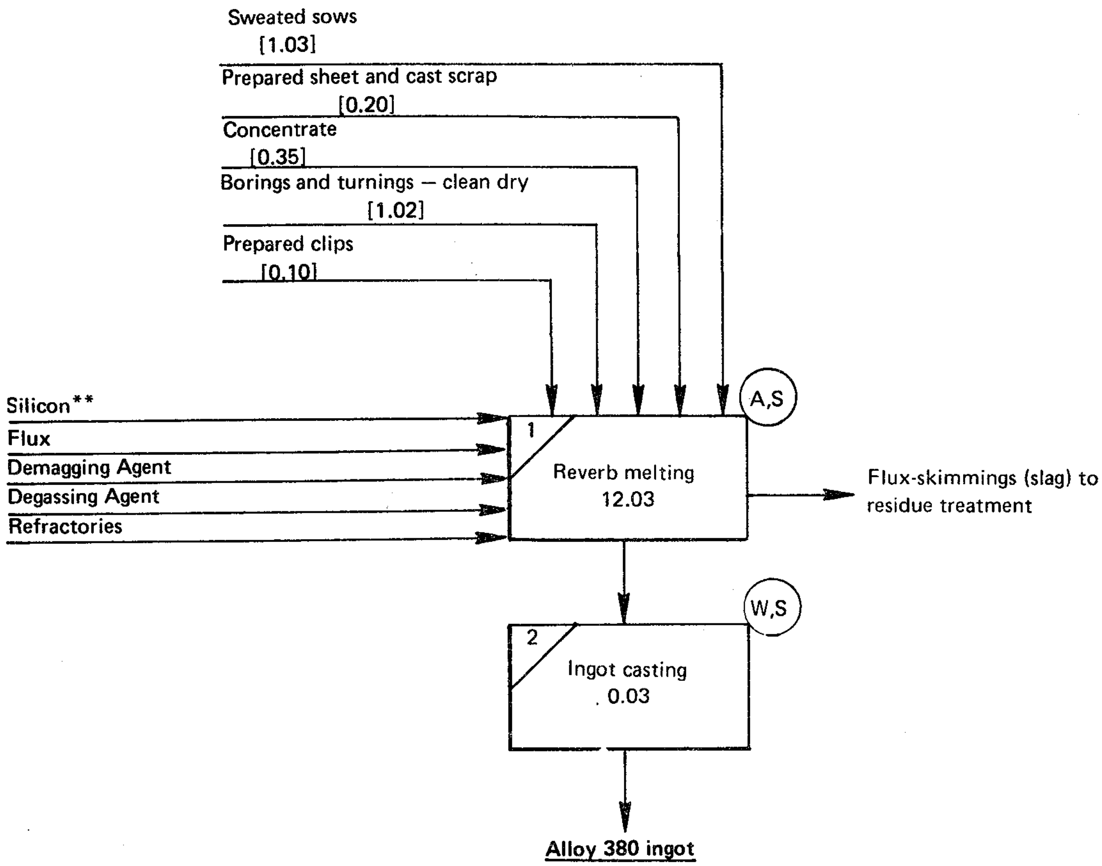
Figure 9 and table 9 present the energy requirements for producing alloy 380-type ingot by reverb melting. The process energy requirements[7] are 14.76 million Btu per ton of alloy 380 ingot. Pollution control and space heating requirements per ton ingot are 0.30 million Btu. Solid waste disposal consumes less than 0.01 million Btu. The total energy requirements are 15.06 million Btu per ton alloy 380 ingot (or 7,530 Btu per pound).

TABLE 9. - Aluminum: Reverb furnace melting aluminum scrap to alloy 380 ingots

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) REVERB MELTING				
NATURAL GAS	CU. FT.	10000.0000	0.001000	10.00
ELECTRICAL ENERGY	KW HR	14.8000	0.010500	0.16
SODIUM CHLORIDE	NET TON	0.0420	0.490000	0.02
KCL BY FLOTATION	NET TON	0.0420	2.590000	0.11
CRYOLITE	NET TON	0.0040	155.000000	0.62
ALUMINUM FLOURIDE	NET TON	0.0200	51.400002	1.03
GASEOUS NITROGEN	NET TON	0.0053	2.900000	0.02
GASEOUS CHLORINE	NET TON	0.0013	18.000000	0.02
REFRACTORY	NET TON	0.0018	26.600000	0.05
SILICON	NET TON	0.0500	**	**
SCRAP-CLIPPINGS	NET TON	0.1110	0.910000	0.10
SCRAP-BORINGS & TURNINGS	NET TON	0.3330	3.050000	1.02
SCRAP-CONCENTRATES	NET TON	0.3330	1.060000	0.35
SCRAP-SWEATED SOWS	NET TON	0.1110	9.280000	1.03
SCRAP-SHEET AND CAST	NET TON	0.1670	1.180000	0.20
			SUBTOTAL	14.73
(2) INGOT CASTING				
ELECTRICAL ENERGY	KW HR	2.8500	0.010500	0.03
			SUBTOTAL	0.03
* TOTAL PROCESS ENERGY				14.76
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	23.4000	0.010500	0.25
			SUBTOTAL	0.25
* TOTAL POLLUTION CONTROL ENERGY				0.25
SPACE HEATING				
NATURAL GAS	CU. FT.	50.0000	0.001000	0.05
			SUBTOTAL	0.05
* TOTAL SPACE HEATING ENERGY				0.05
* TOTAL ENERGY PER NET TON OF PRODUCT				15.06

** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE

[7] The energy content of alloying elements is not included in the analysis. On the average, silicon usage as an alloying addition is about 5% of the metallics feed. The remainder consists of clippings, 10%; borings and turnings, 30%; concentrates, 30%; sows, 10%; and sheet and cast, 15%.



SUMMARY

	Million Btu per ton of product
Process energy	14.76
Pollution control energy	.25
Space heating	.05
Total energy	15.06

**Energy content of these alloying elements is not included in the total process energy.

FIGURE 9. - Aluminum: Reverb furnace melting aluminum scrap to alloy 380 ingots.

The principal energy-consuming items are natural gas, 66.7%; prepared scrap, 17.9%; demagging agent, 6.8%; flux, 5.0%; and electrical energy, 2.9%.

Reverb Melting Aluminum Scrap to Hot Metal

Figure 10 and table 10 present the energy requirements for producing hot metal by reverb melting aluminum scrap. The total energy requirements are 19.60 million Btu per ton of hot metal, 19.30 million Btu of which represent process energy.

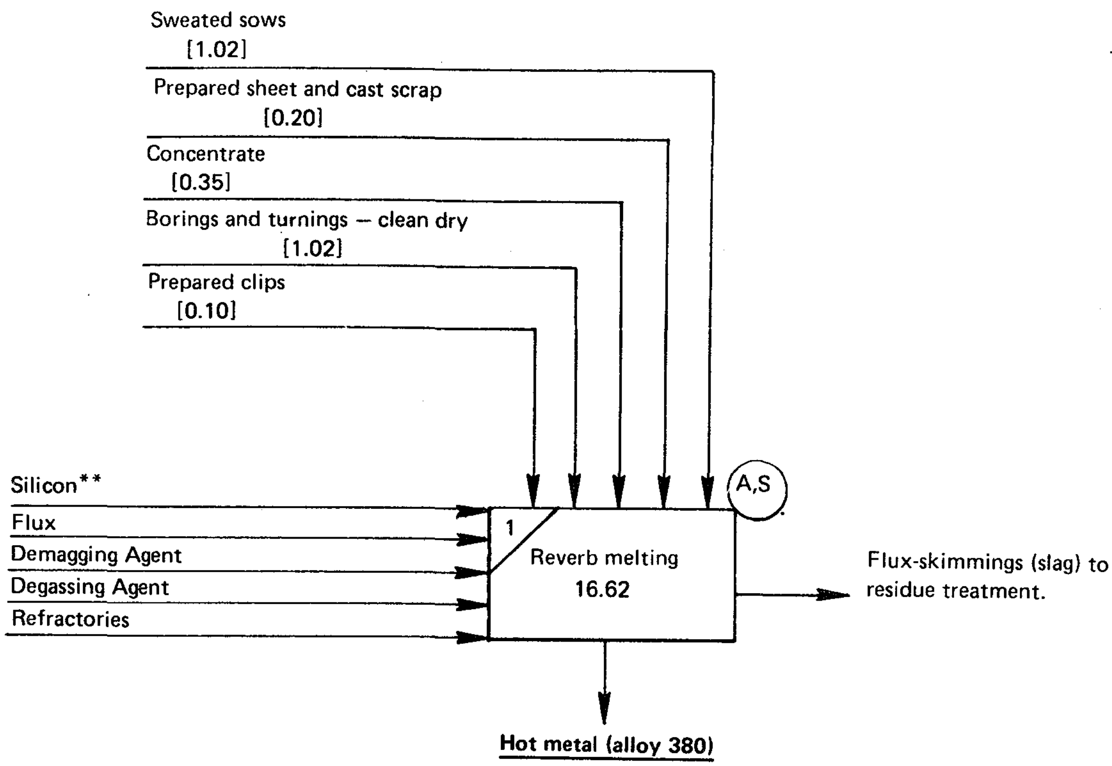
A TABLE 10. - Aluminum: Reverb furnace melting aluminum scrap to hot metal (alloy 380)

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) REVERB MELTING				
NATURAL GAS	CU. FT.	14570.0000	0.001000	14.57
ELECTRICAL ENERGY	KW HR	14.8000	0.010500	0.16
SODIUM CHLORIDE	NET TON	0.0420	0.490000	0.02
KCL BY FLOTATION	NET TON	0.0420	2.590000	0.11
CRYOLITE	NET TON	0.0040	155.000000	0.62
ALUMINUM FLOURIDE	NET TON	0.0200	51.400002	1.03
GASEOUS NITROGEN	NET TON	0.0053	2.900000	0.02
GASEOUS CHLORINE	NET TON	0.0013	18.000000	0.02
REFRACTORY	NET TON	0.0018	26.600000	0.05
SILICON	NET TON	0.0500	**	**
SCRAP-CLIPPINGS	NET TON	0.1110	0.910000	0.10
SCRAP-BORINGS & TURNINGS	NET TON	0.3330	3.050000	1.02
SCRAP-CONCENTRATES	NET TON	0.3330	1.060000	0.35
SCRAP-SWEATED SOWS	NET TON	0.1110	9.280000	1.03
SCRAP-SHEET AND CAST	NET TON	0.1670	1.180000	0.20
			SUBTOTAL	19.30
* TOTAL PROCESS ENERGY				19.30
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	23.4000	0.010500	0.25
			SUBTOTAL	0.25
* TOTAL POLLUTION CONTROL ENERGY				0.25
SPACE HEATING				
NATURAL GAS	CU. FT.	50.0000	0.001000	0.05
			SUBTOTAL	0.05
* TOTAL SPACE HEATING ENERGY				0.05
* TOTAL ENERGY PER NET TON OF PRODUCT				19.60

** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE

The main difference in energy requirements between producing hot metal and ingot is that additional fuel is consumed in hot metal production to provide superheat required for molten metal transportation and for ladle preheating. Because the hot metal has to be delivered when the customer needs it, additional holding of the molten metal in the reverb furnace may also be required. The natural gas requirements in hot metal production amount to 14.57 million Btu per ton (compared with 10 million Btu per ton ingot). In hot metal production, however, ingot casting is not required, so there is a small saving in electrical energy (0.03 million Btu per ton).

In comparing the hot metal and ingot routes, it should be borne in mind that a diecaster using alloy ingot has to invest in capital equipment and expend energy to melt the ingot, whereas with hot metal the only equipment and fuel requirements are those for holding the metal at temperature before casting.



SUMMARY

	Million Btu per ton of product
Process energy	19.30
Pollution control energy	.25
Space heating	.05
Total energy	19.60

**Energy content of these alloying elements is not included in the total process energy.

FIGURE 10. - Aluminum: Reverb furnace melting aluminum scrap to hot metal (alloy 380).

Recycling Aluminum Cans

The analysis in this section is based on data supplied by members of the Aluminum Association. The energy data are aggregate numbers for the member companies and include variations in operating practice, such as reshredding of cans by some primary producers, waste heat recovery with some melting furnaces, and different mixes of rail to truck transportation.

According to the Aluminum Association, 175 million pounds of aluminum were recovered from 3.9 billion discarded cans in 1975. These 3.9 billion cans are equivalent to 25.4% of the all-aluminum cans used by consumers that year. There are now more than 2,100 collection points in all 50 States and the District of Columbia that receive discarded all-aluminum beverage cans from consumers. Based on statistics from the Bureau of Mines, the Aluminum Association, and the present analysis, it is estimated that about 90% of the discarded cans are shipped to primary aluminum producers, with the primary mode of scrap transportation being rail.

Scrap Preparation

The principal preparation step is shredding, usually done in hammer mills. Shredding is carried out either by a large collection center (before shipment to the primary producer), or else by a primary producer receiving baled cans. It should be noted that some of the primary producers are set up to shred all the can scrap prior to processing so that some material may be shredded twice, as shown in figure 11.

The next preparation step is delacquering of cans, which is carried out as a separate operation or in the melting furnace. Delacquering involves heating the cans at an intermediate temperature (below the melting temperature) to remove the organics, as shown in figure 11.

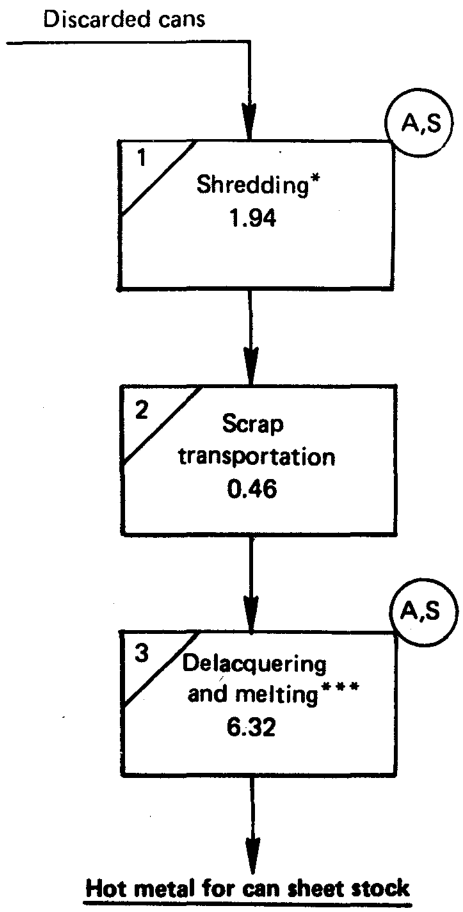
Reverb Melting

Reverb furnaces fired with natural gas or oil are used in melting. A typical charge to the furnace consists of 35% virgin aluminum and 65% scrap derived from such sources as internal scrap, customer scrap, and discarded cans. The discarded can fraction is the smallest of these scrap fractions. Most aluminum can scrap is used to make 3004 alloy for body stock. Usually, in making body stock alloy, manganese and magnesium additions are required. Some of these furnaces are equipped to recover waste heat, which is utilized for combustion air preheating or space heating.

Energy Analysis

Based on information submitted to them from their members, the Aluminum Association has estimated that (1) average losses in shredding and reshredding cans are 6.9%, and (2) average melt loss in casting (calculated on the basis of furnace charge) is 5.8%. Consequently, to make 1 ton of molten aluminum from discarded cans, 1.14 tons of unshredded cans, or 1.07 tons of shredded cans, are required.

In addition, the association reports the average shredding energy to be 850 Btu per pound. Energy required in transportation from collection centers to ultimate processor is reported to be 200 Btu per pound. The energy required for melting, delacquering, and auxiliary use, such as in-house transportation, loading, and space heating, is reported to be 2,976 Btu per pound.



SUMMARY

	Million Btu per ton of product
Process energy Pollution control energy Space heating	8.72
Total energy	8.72

*Includes some reshredding at the primary smelter.

***Includes credit for waste heat recovery where practiced.

FIGURE 11. - Aluminum: Recycling aluminum cans to hot metal for can sheet stock.

The flowsheet and energy analysis for aluminum can recycling, presented in figure 11 and table 11, show total energy requirements[8] to be 8.72 million Btu per ton of hot metal for canstock. Of this, shredding requires 1.94 million Btu, and scrap transportation, 0.46 million Btu. The remaining 6.32 million Btu are required for delacquering, melting, materials handling, and space heating. Although typical mix to the furnace consists of virgin metal and scrap, the energy for delacquering and melting is representative for melting 100% aluminum scrap charge.

TABLE 11. - Aluminum: Recycling aluminum cans to hot metal for can sheet stock

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) SHREDDING				
ELECTRICAL ENERGY	KW HR	185.0000	0.010500	1.94
			SUBTOTAL	1.94
(2) SCRAP TRANSPORTATION				
TRUCK	TON MI	21.0000	0.002400	0.05
RAIL	TON MI	612.0000	0.000670	0.41
			SUBTOTAL	0.46
(3) DELACQUERING AND MELTING				
NATURAL GAS	CU. FT.	6320.0000	0.001000	6.32
			SUBTOTAL	6.32
* TOTAL ENERGY PER NET TON OF PRODUCT				8.72

Recycling aluminum cans also conserves alloying elements such as manganese and magnesium. The savings amount to about 20 pounds of manganese and 15 pounds of magnesium per ton of sheet stock alloy.

Major Heat Losses

The thermal efficiency of melting in the reverb furnace ranges from 18% to 25% (3). A 24-hour average cycle for producing an alloy 380 heat consists of 12.5 hours charging and melting, 1 hour sampling, 5 hours pouring, 1 hour hot cleaning (that is, patching refractories), and about 4.5 hours magnesium removal. For 11.5 hours the furnace operates as a holding furnace, and the heat input is used to compensate heat losses. Consequently, the overall efficiency in melting and refining is reduced to 10% to 15%. Flue gas exits the furnace at temperatures exceeding 1,800° F, carrying approximately 55% of the heat input. Another 20% of the heat is lost to the atmosphere by radiation conduction and convection losses (3), leaving only about 25% available for melting.

[8] The energy content of alloying elements such as magnesium and manganese is not included in this analysis.

Research and Development

Potential areas for research and development in the secondary aluminum industry include the following:

1. Incorporation of waste heat recovery from reverb furnace offgases through recuperation for the purpose of preheating combustion air and/or preheating suitable scrap, for example, sows. Such waste heat recovery requires the development of efficient and economic heat exchangers having materials resistant to corrosion from halides and erosion due to dust in the exhaust gases;

2. Improvement of the thermal efficiencies of sweating furnaces and reduction of melt losses in sweating;

3. Development of economic methods for the removal of oil and grease from scrap, for example, borings and turnings, such as by use of solvents; and

4. Investigation of alternatives to the dry processing of salt-containing dross which involves a screening operation that produces an undersize fraction containing oxides, salts, and aluminum, and which may present a solid waste disposal problem; for example, further research into wet processing methods that recover flux or salt by evaporation of the leach water using waste heat from the reverb furnace offgases would lead to energy as well as materials conservation.

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COPPER

Background

Table 12 presents data on the secondary copper industry.

TABLE 12. - Data on secondary copper industry

	Net tons[1]
Secondary raw materials (1976):	
Refineries and brass and bronze ingot makers:[2]	
Old scrap	455,000
New scrap	312,000
Brass mills:	
Old scrap	30,000
New scrap	628,000
Secondary U.S. production (1976):	
Unalloyed copper: Refined copper	375,000
Alloyed copper:	
Brass and bronze ingots	[3]213,000
Brass mill products	[3]647,000

[1]All volume figures have been rounded to the nearest thousand.
[2]Includes secondary copper smelters and primary, as shown in table 13.
[3]Tonnage refers to tons product from copper-base scrap containing approximately 79% Cu.

NOTE.--Commodity: Copper.
Primary products: Refined copper (unalloyed), brass and bronze casting alloys, and brass and bronze alloys.
Byproducts: Nickel sulfate and precious metals.
Coproducts: None.

Source: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys, 1976.

Types and Classifications of Scrap

Details on copper scrap categories can be obtained from the American Metal Market statistics for 1976. These categories are described briefly below.

No. 1 Copper.--This category consists of 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 gage. Included in this category are wire and cable (excluding burnt wire), copper clippings, punchings, busbars, commutator segments, and copper tubing.

No. 2 Copper.--This category consists of miscellaneous unalloyed copper scrap having a nominal 96% Cu content (minimum 94%). Examples of scrap not included in this category are copper scrap containing excessive amounts of lead, tin, or solder; brasses or bronzes; burnt copper wire; and scrap with a high oil, iron, or nonmetallic content.

Light Copper.--This category consists of miscellaneous unalloyed copper scrap having a nominal 92% Cu content (minimum 88%), such as sheet copper, gutters, downspouts, kettles, boilers, and similar scrap.

Refinery Brass.--Scrap in this category contains a minimum of 61.3% Cu and a maximum of 5% Fe and includes brass and bronze solids, turnings, and alloyed and contaminated copper scrap.

Copper-Bearing Scrap.--This category consists of 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.

Consumption

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. Low-grade scrap is treated by a series of pyrometallurgical operations and electrorefined. The cathodes are then melted and cast into refinery shapes. 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. Brass and bronze ingotmakers 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 alloying additives such as slab zinc, lead, tin, and nickel, as shown in table 13.

In 1976 primary and secondary copper producers consumed 767,000 tons of scrap (13). The breakdown among the various scrap types is as follows: No. 1 copper made up about 19% of the scrap; 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%. Of 767,000 tons consumed, 59% was old scrap.

Brass mills consumed 658,000 tons of purchased scrap in 1976 of which more than 95% was new scrap. The breakdown of consumption by scrap type is as follows: No. 1 copper accounted for 24%; No. 2 mixed heavy and light represented 11%; and brass and bronze scrap (mostly yellow brass, cartridge cases, cartridge brass, low brass, and nickel silver and cupronickel) accounted for the remaining 65%. In 1976, brass mills also consumed 839,000 tons of home scrap, 575,000 tons of refined copper, and 155,000 tons of slab zinc.

TABLE 13. - Purchased copper-base scrap consumed in 1976[1]

Class of consumer and scrap item	Consumption, thousand short tons	Old scrap, %	New scrap, %
Secondary copper smelters:			
No. 1 wire and heavy	25	87.5	12.5
No. 2 wire, mixed heavy and light	58	72.3	27.7
Composition or soft red brass	58	77.1	22.9
Railroad-car boxes	2	100	0
Yellow brass	46	88.9	11.1
Cartridge cases	-	100	0
Auto radiators (unsweated)	49	100	0
Bronze	20	82.9	17.1
Nickel, silver, and cupronickel	3	89.7	10.3
Low brass	2	33.2	66.8
Aluminum bronze	-	23.8	76.2
Low-grade scrap and residues	77	16.9	83.1
Total	340	68.5	31.5
Primary producers:			
No. 1 wire and heavy	118	48.0	52.0
No. 2 wire, mixed heavy and light	129	27.5	72.5
Refinery brass	4	50.4	49.6
Low-grade scrap and residues	176	72.9	27.1
Total	427	52.0	48.0
Brass mills:			
No. 1 wire and heavy	156	17.7	82.3
No. 2 wire, mixed heavy and light	73	2.6	97.4
Yellow brass	272	0	100
Cartridge cases and brass	78	0	100
Bronze	4	0	100
Nickel, silver, and cupronickel	29	0	100
Low brass	46	0	100
Aluminum bronze	-	0	100
Total	658	4.5	96.5
Grand total	1,425	-	-

[1]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 Arthur D. Little estimates based on 1974 data in U.S. Bureau of Mines Minerals Yearbook chapter dealing with copper.

Sources: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys; and Arthur D. Little, Inc., estimates.

Products

Principal copper products are as follows:

Unalloyed Copper.--The main product of refineries is electrolytic, tough-pitch[9] copper in the form of wirebars, billets, cakes, and ingots. To make shapes with satisfactory cast surfaces, a controlled amount of oxygen, nominally 0.03% to 0.04%, must be present in the copper as copper oxide. Other products from unalloyed copper include fire-refined, tough-pitch copper; deoxidized[10] copper; and oxygen-free[11] copper.

Cast Copper Alloys Produced by Brass and Bronze Ingotmakers.--Ingotmakers produce a wide range of cast copper alloys for nonferrous foundries. The most important of these are red brass, tin bronze, and yellow brass. Red brass includes the alloy 85:5:5:5 (85% Cu, 5% Sn, 5% Pb, and 5% Zn) and accounted for 53.1% of brass and bronze ingot production in 1976. Because of its importance, red brass is used as an example of the energy requirements for recycling brasses and bronzes. The tin bronze category accounted for 26.5% of the brass and bronze ingot production in 1976. The remaining 20.4% included yellow brass, manganese bronze, and silicon bronze.

Wrought Copper Alloys Produced by Brass Mills.--Brass mills produce wrought alloys from purchased scrap, home scrap, and refined copper. These alloys are fabricated into products such as sheets, tubes, rods, and pipes.

In 1976, refined copper production from scrap was 375,000 tons (5). Brass and bronze ingot production was 213,000 tons, and brass mill production (from scrap) was 647,000 tons.

Scrap Preparation Methods

Secondary copper scrap is classified, segregated, and prepared for melting and refining by a variety of methods (3, 9, 12). Segregating scrap by classification standards is one of the most important steps in the recovery of secondary copper. Segregation practices depend on the amount and variety of scrap handled. Small scrapyards usually segregate scrap into a few basic types, while larger yards find it practicable to segregate their scrap more thoroughly. Segregation methods range from visual recognition of products to chemical or spectrographic analysis.

Methods of scrap preparation may be classified as either mechanical or thermal. Mechanical schemes include wire choppers such as shears and guillotines that cut the wire into small pieces (8). Most wire is chopped into pieces smaller than 0.5 inch to assure liberation of wire from insulation so

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[9] Tough-pitch is copper which contains a controlled amount of oxygen (0.03% to 0.04%) as Cu_2O, indicating it is suitable for casting into products with satisfactory cast surfaces.

[10] Oxygen is removed from tough-pitch copper by phosphorus additions to the molten bath.

[11] Usually achieved by melting in a controlled reducing atmosphere.

that a separation can then be made by air-tabling. Another mechanical device strips insulation from long lengths of cable. Fine loose wire, then plate, and wire screen scraps are usually compressed into briquettes, bales, or bundles for convenient handling in subsequent processing operations. Large solid items are reduced in size by shearing machines, pneumatic cutters, or manually by a sledgehammer. Brittle, springy turnings are crushed in hammer mills or ball mills to reduce bulk for easier handling in subsequent operations. Slags, drosses, skimmings, foundry ashes, spills, and sweepings may be ground to liberate prills or other metallics from the nonmetallics so that the metallic fraction can be recovered by gravity separation or other physical means. Materials such as drillings, clippings, and crushed turnings are often run through a magnetic separator for removal of tramp iron.

Incineration is the major thermal method of copper scrap preparation. In this method, insulation is burned off copper wire (3). Black smoke from the burning of insulation is incinerated in afterburners. Should the insulation contain polyvinyl chloride (PVC), scrubbing of the offgases may be required to prevent chloride emissions.

Sweating is a minor thermal method of copper scrap preparation. The lower melting impurities, such as lead and solder, attached to the copper scrap are selectively melted for recovery of these constituents.

Smelting and Refining

Following preparation, secondary copper is smelted and refined by any one of a number of processing methods (5-6, 9, 12).

Major Processing Methods

Equipment and refining procedures used for processing high-grade copper scrap, such as No. 1 and No. 2 copper, are very similar to those used to refine primary copper. Frequently, both high-grade scrap and virgin materials are processed together. On the other hand, low-grade scrap and residues are processed by smelting in a blast furnace-converter operation and then refined by conventional fire refining and electrorefining. Copper-alloy scrap is processed to ingots by melting, some refining, and alloying to brass and bronze alloys.

Reverb Melting No. 1 Copper Scrap

As shown in figure 12, No. 1 copper is usually melted in a reverb furnace, with scrap being charged by forklifts or electrical charging machines. Gas-fired or dual-fired (gas and oil) reverb furnaces with capacities of up to 400 tons are used. Refractory materials used in these furnaces include magnesite brick walls, fused magnesite bottoms, and suspended magnesite roofs. Superduty firebrick is used in furnace areas that are not in contact with molten metal. Fire refining involves the oxidation with air of impurities which are then skimmed from the melt as a slag. Usually it is necessary to saturate the melt with Cu_2O for satisfactory removal of impurities. The oxygen content of the melt at this stage is around 0.9%. This reverb is similar

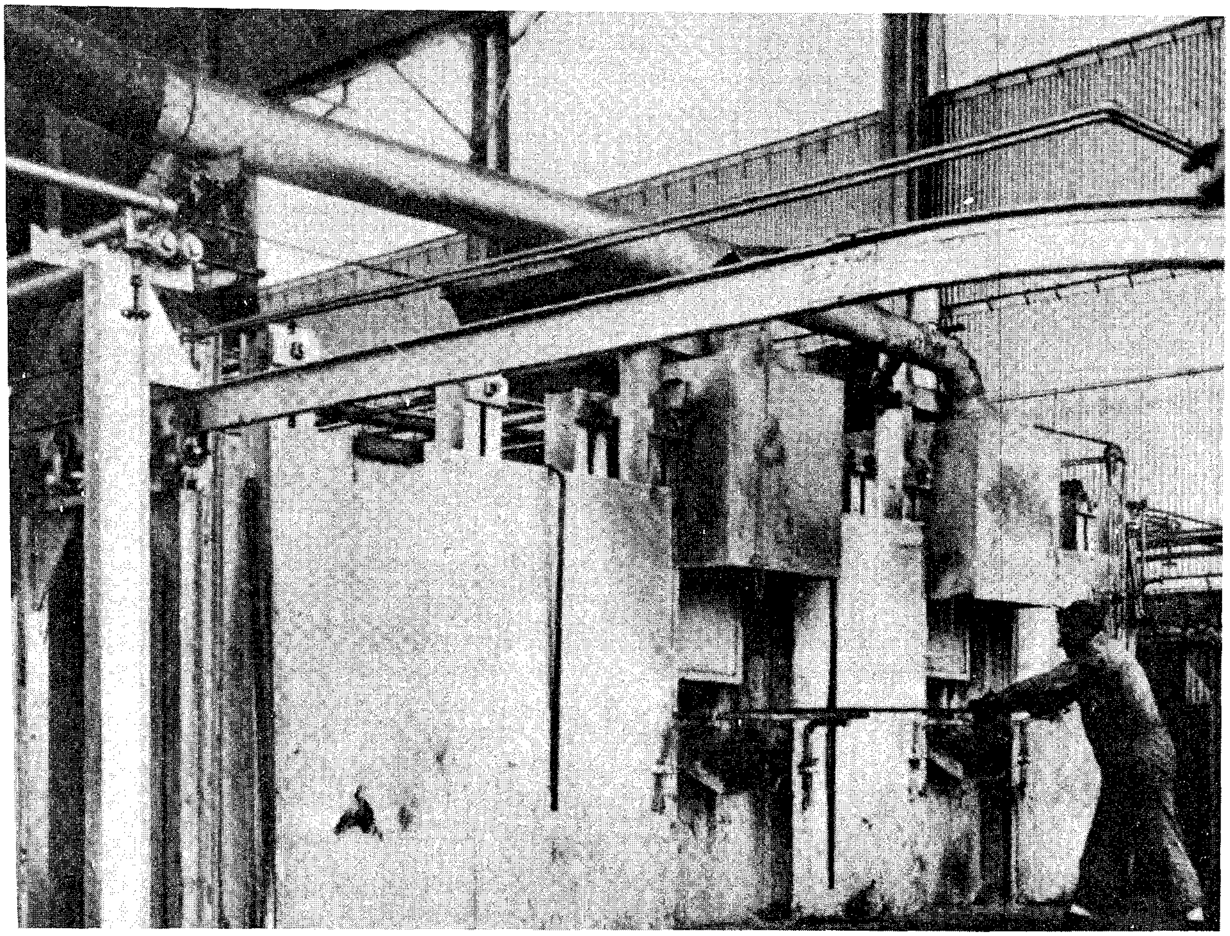


FIGURE 12. - Reverb furnace for melting and refining copper and brass scrap.

to the cathode melting furnace used in primary copper production (8), and often No. 1 copper is melted along with copper cathodes before being fire-refined.

The next stage in refining is reducing the oxygen content to levels suitable for casting. This is achieved by "poling" the melt with wood poles which decompose and release reducing gases or by using natural gas as the reducing agent. "Poling" is carried out until the correct "pitch" of a sample [indicating the desired oxygen content (0.03% to 0.04%)] of the bath is achieved. "Pitch" refers to the appearance of the fracture surface of a sample taken from the melt. When "poling" is complete, the fracture surface of a solidified sample of the melt has a satiny orange-red sheen. The copper is then "tough-pitch" and is ready for casting into refined shapes such as cakes, billets, and wirebar.

Recycling No. 2 Copper Scrap

No. 2 copper scrap is melted and refined in a reverb furnace, similar to the anode furnace used in primary copper production (6). In the reverb, scrap is melted and partially fire-refined. After the melt is oxidized to saturation with Cu_2O (oxygen content 0.8% to 0.9%), the "poling" step is carried out until the oxygen content is around 0.2%. Offgases are ducted to a waste heat boiler for the production of high-pressure steam which can provide the major portion of the steam required in the electrolytic refinery. Gases from the waste heat boiler are sent to a baghouse for dust collection.

The molten copper is then cast on a wheel (fig. 13) into large anodes for electrorefining. The casting wheel consists of iron molds, which are rotated sequentially into position for pouring. In some designs one wheel can service two furnaces. Finished anodes contain 99% Cu with small amounts of Ag, Au, Pb, Se, Te, and other metals, some of which arise from additions of copper derived from copper ore. Such impurities are removed during further refining in electrolytic cells.

The electrolytic cell consists of anodes and cathode (initially consisting of starting sheets)[12] immersed in a copper sulfate, sulfuric acid electrolyte which is circulated through the cell. Passage of a direct electric current from the anode through the electrolyte to the cathode causes copper from the anode to dissolve and deposit on the cathode. During this process two types of impurities are removed from the copper: Those that do not

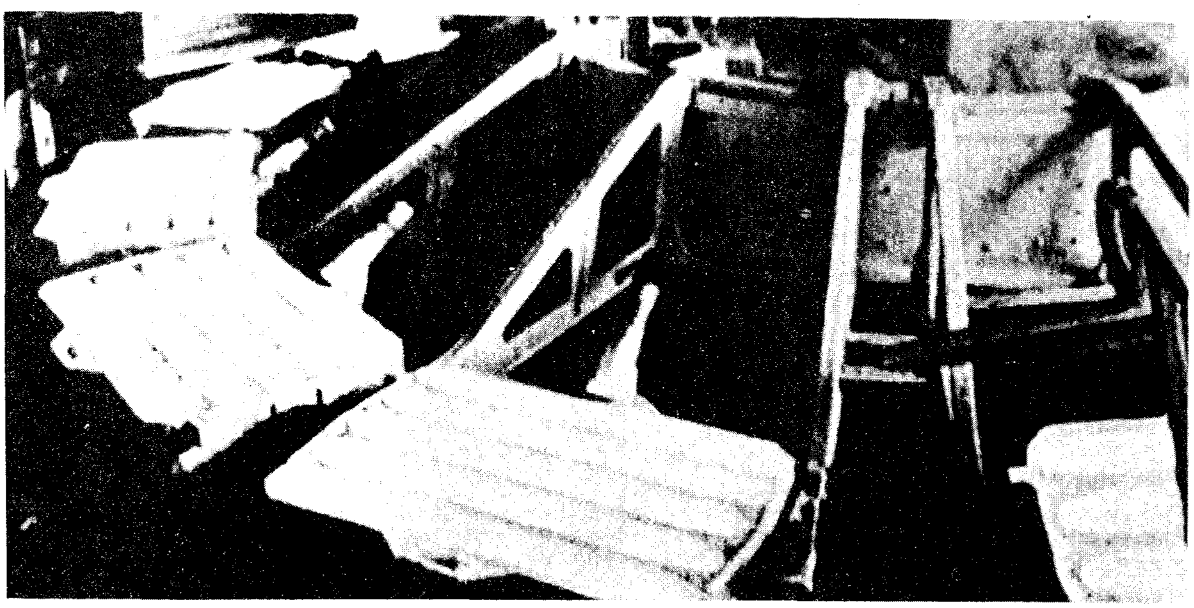


FIGURE 13. - Casting copper. *(Courtesy, National Association of Secondary Material Industries)*

[12]The cathode starting sheets are produced electrolytically in "stripper" cells, either on highly polished, oiled copper blanks or on titanium blanks.

dissolve at the anode, but collect in the anode slime (such as Ag, Au, and other precious metals, and Pb, Se, and Te); and those that dissolve, build up in the electrolyte, and are controlled by removal in a bleed stream (such as Ni, Zn, and Fe). Anode slimes are collected and sent to a precious metals refinery, while the bleed stream is electrolyzed in "liberator" cells with insoluble lead anodes, where dissolved copper is plated out. The decopperized stream is then treated for nickel sulfate recovery in which process the decopperized stream is concentrated in evaporator vessels to precipitate nickel sulfate crystals. The resulting liquor is called black "acid;" the liquor and nickel sulfate are usually salable byproducts, although the black sulfuric acid may be more difficult to market than clean (white) sulfuric acid.

Cathodes are removed from the electrorefining cells after 14 days, when they are about 0.375 inch thick, while anodes remain in the cells for about 28 days. Anode scrap, representing 15% to 20% of the anode by weight, is returned to the anode furnace for melting. After removal from the cells, cathodes are melted either in a reverb furnace (described earlier) or in an ASARCO shaft furnace (5). The ASARCO furnace is a vertical shaft furnace with shaft heights ranging from 20 to 30 feet and a diameter to accommodate 3-foot-wide cathodes. Besides cathodes, it can accommodate a limited amount of selected scrap. Natural gas is the most common fuel used in this furnace with burners (as many as 35 per furnace) specially designed to get a high-intensity flame. Each of the burners is continuously monitored and controlled by individual control units for fuel-to-air ratio. The operation is continuous and has higher thermal efficiency (50%) and higher melting rates than a reverb furnace.

After melting, the cathodes are cast into wirebar, cakes, billets, or other special shapes. Another approach is using the ASARCO shaft furnace followed by continuous casting and rolling. At present about one-half of the consumption of copper in wire mills is by the latter route. Since reheating of copper wirebar, cakes, or billets is not required, continuous casting and rolling saves energy in comparison to the conventional route.

Recycling Low-Grade, Copper-Bearing Scrap

Low-grade, copper-bearing scrap, such as copper-containing skimmings, grindings, ashes, iron-containing brasses, and copper residues, is usually smelted in a blast furnace (cupola), as shown in figure 14, to produce black copper. This is converted to blister copper in a converter and then is fire-refined or electrorefined, much as in the primary copper refining industry.[13]

The conventional, secondary, copper blast furnace (2, 12) is a top-charged, bottom-tapped shaft furnace using coke as a fuel and reductant. Typical dimensions are 3.3 to 9.8 feet wide, 6.6 to 13.1 feet long, and 9.8 to 16.4 feet high (2). The coke burns in a blast of air which is introduced through tuyeres around the bottom of the shaft. A hearth to collect the molten metal and slag is located directly below the bosh, which is the lower section of the shaft. The ladle is lined with magnesite or chrome brick. Refractories

[13] Some light copper is processed with No. 2 copper.

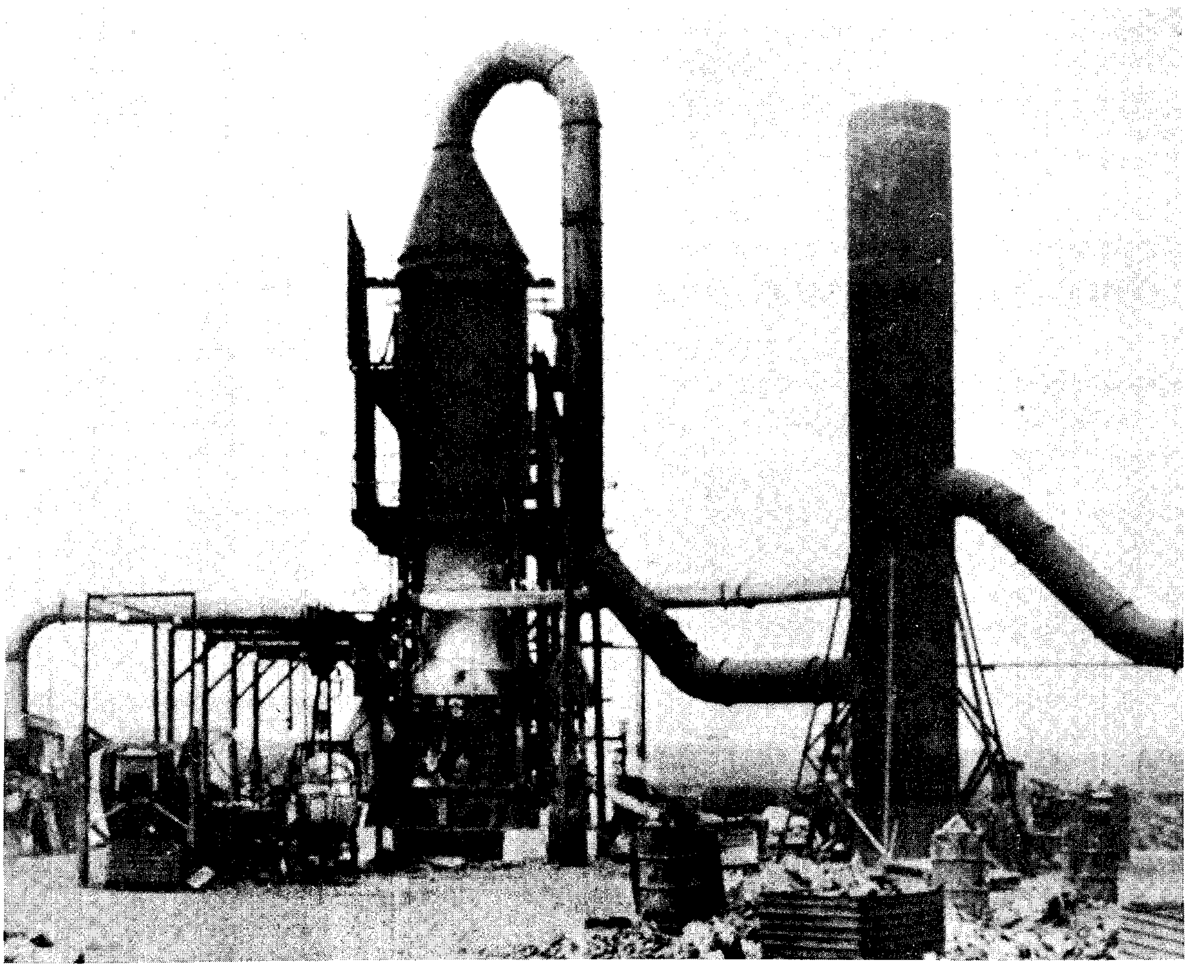


FIGURE 14. - Blast furnace for smelting copper-base scrap, slag, and residues.

from the in-wall, or well, are usually fire-clay brick from top to bottom. A layer of chilled slag takes the place of refractories in the water-jacketed steel bosh.

The charge to the blast furnace consists of the following: Copper-bearing materials, such as iron-containing brass and copper, fine insulated wire, motor armatures, foundry sweepings, and slags and drosses; coke as a reductant as well as a fuel; and limestone and millscale or other iron-containing material as flux for the formation of an iron-silicate slag. To provide the required permeability for the products of coke combustion, fine materials are agglomerated by methods, such as pelletizing, before being charged to the blast furnace. Air entering the tuyeres reacts with the coke, resulting in a gas mixture consisting largely of CO, CO_2, and N_2 rising up the shaft. These hot gases transfer heat to the charge, while providing a potential reducing agent, CO, for reducing any copper oxides.

In addition to the product, solids discharged from this operation include slag and dust. The black copper product analyzes 75% to 88% Cu, 1.5% Sn, 1.5% Pb, 0.1% to 1.7% Sb, 3.0% to 7.0% Fe, and 4% to 10% Zn. The slag, containing approximately 1.5% Cu, is granulated, and can be sold as aggregate or sent to landfill. At times a settling furnace is used for recovering some of the copper from the molten slag before granulation. The hot gases from the blast furnace containing oxide dusts are passed via a water spray cooler to a baghouse for dust collection. The collected dusts usually contain 58% to 61% Zn, 2% to 8% Pb, 5% to 15% Sn, 0.5% Cu, 0.1% Sb, 0.1% to 0.5% Cl, and some unburnt carbon. These dusts are usually sold for their zinc and tin content.

The molten black copper is transferred by ladle to a converter, generally Pierce-Smith, sometimes Hoboken or siphon-type (2), where it is blown, along with tin-bearing copper scrap, to blister copper by the preferential oxidation of impurities. The converter is heated by a dual burner (gas or oil) located at the side. The offgases containing oxides of tin, lead, and zinc are collected with hoods, cooled, and sent to a baghouse for recovery of oxide dust. Like blast furnace dusts, the converter dust is sold principally for its zinc and tin content.

The molten blister copper is then conveyed to an anode furnace where it is fire-refined and cast into anodes that are further electrorefined. The resulting cathodes are melted and cast into wirebars, cakes, billets, or other special shapes.

Recycling Brass and Bronze Scrap to Ingots

Brass and bronze scrap is processed by simple melting techniques with a minimum of refining (9, 12). Usually well-sorted brass and bronze scrap is melted and excess alloy constituents are diluted with high-grade scrap or virgin metal to the desired composition specification. Product specifications call for a very low content of certain elements, such as aluminum and silicon. In the red brass series, for example, the maximum acceptable levels of aluminum and silicon are 0.005% and 0.003%, respectively. Meeting these specifications is achieved by controlling the composition of the scrap charged to the furnace. Impurities such as Fe, S, Cd, Bi, P, and Mn can be removed by various refining techniques involving oxidation and slagging.

As with No. 2 copper scrap, the melting of brass and bronze scrap is commonly carried out in reverb furnaces having capacities ranging from a few thousand pounds to 100 tons and more. The furnaces are either gas-fired or have dual-firing (oil and gas) capacity. The charge to the reverb furnace consists of batches of scrap selected to produce a melt of the desired composition with a minimum of dilution of metal constituents. Scrap is charged at regular intervals until the furnace is filled to capacity. Fluxes, such as sodium nitrate and borax, are added to make a fluid slag. Oxidation and volatilization losses from copper-base alloys are kept to a minimum by rapid melting in a slightly oxidizing atmosphere with a fluid slag cover. The reverb slags contain copper values that are recoverable in a cupola or blast furnace. Overall process yield is around 90%. Most of the copper that is not recovered is to be found in the slag.

The offgases from the reverb furnace are cooled with dilution air and sent to a baghouse. The collected oxide dust is salable, principally for its zinc content.

The molten metal in the reverb furnace is tapped into feeder ladles that transport the metal to a mold line for making ingots, each weighing approximately 25 pounds. The mold line is a series of ingot molds placed on a rack that is either stationary or movable. If the mold line is stationary, portable ladles are used. Auxiliary mold conditioning involves spraying the molds with a mold wash before the metal is cast. Charcoal is sometimes sprinkled on the metal to produce smooth-topped ingots. The cast ingots are usually cooled with a water spray, dumped from the molds, and placed in racks for shipping.

Other Processing Methods

Top-blown, rotary converters are sometimes used to smelt and refine copper-bearing materials (7) such as brass and bronze scrap. These furnaces are more flexible than reverbs, but the capacity of such furnaces is limited to moderate tonnages, that is, from several tons to about 50 tons. A rotary furnace consists of a cylindrical steel shell with a refractory lining of either magnesite or chrome magnesite. Linings usually last 100 or more heats. The cylindrical furnace is mounted with its axis in a horizontal position, supported by piers and trunnions at each end. The furnace is fired by oil or gas burners that are inserted through either or both trunnions. The flame is directed lightly onto the surface of the flux cover. One or more charging spouts is located at either side of the cylinder, and a pouring spout is attached to the furnace at a level slightly higher than the slag level when the furnace is fully charged. Charging, alloying, and fluxing techniques are essentially the same as for reverb practice. Baghouses or electrostatic precipitators are used for controlling emissions.

In addition, brass mills use low-frequency induction furnaces to melt copper, copper-alloy scrap, run-around (home) scrap, and significant amounts of primary copper alloying elements, such as slab zinc, to produce intermediate products, such as billets, rods, and flat cake.

Energy Analysis

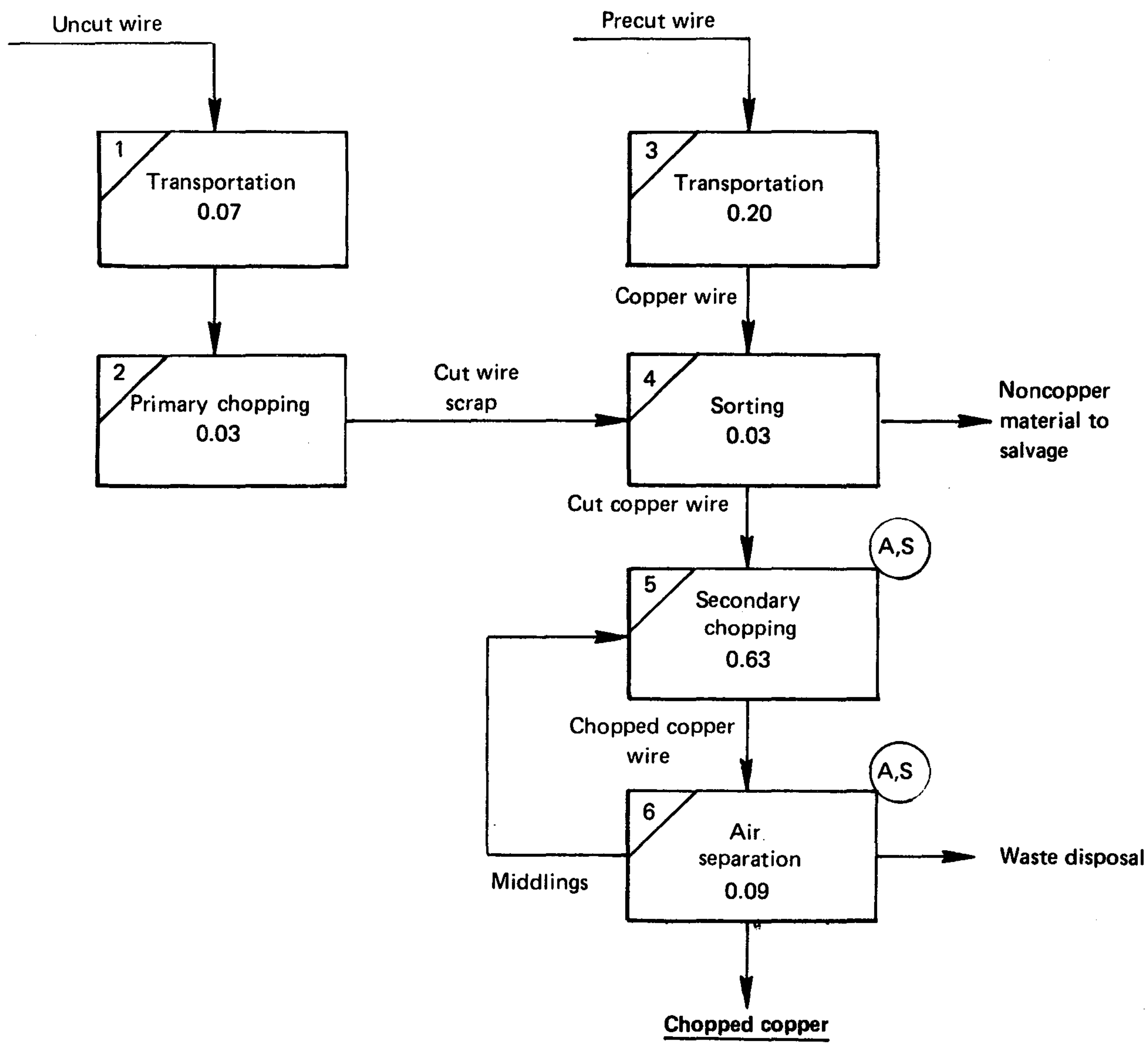
The energy analysis for copper recycling includes the following representative schemes found in recycling copper: Scrap preparation (chopping and incinerating copper wire, and baling or briquetting loose scrap); recycling No. 2 copper scrap; recycling low-grade, copper-bearing scrap; and recycling brass and bronze (BB) scrap to BB ingot.

Scrap Preparation

Figure 15 and table 14 present a flowsheet and an energy analysis of copper wire chopping to remove insulation from copper wire. The chopping of copper wire requires about 1.75 million Btu per ton of prepared scrap, of which 1.05 million Btu represents process energy, 0.40 million Btu is pollution control energy, and 0.3 million Btu is for space heating.

TABLE 14. - Copper: Copper wire chopping

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION OF UNCUT WIRE				
TRUCK	TON MI	25.0000	0.002400	0.06
RAIL	TON MI	12.0000	0.000670	0.01
			SUBTOTAL	0.07
(2) PRIMARY CHOPPING				
ELECTRICAL ENERGY	KW HR	3.0000	0.010500	0.03
			SUBTOTAL	0.03
(3) TRANSPORTATION OF PRECUT WIRE				
TRUCK	TON MI	75.0000	0.002400	0.18
RAIL	TON MI	37.0000	0.000670	0.02
			SUBTOTAL	0.20
(4) SORTING				
ELECTRICAL ENERGY	KW HR	3.0000	0.010500	0.03
			SUBTOTAL	0.03
(5) SECONDARY WIRE CHOPPING				
ELECTRICAL ENERGY	KW HR	60.0000	0.010500	0.63
			SUBTOTAL	0.63
(6) AIR SEPARATION				
ELECTRICAL ENERGY	KW HR	9.0000	0.010500	0.09
			SUBTOTAL	0.09
* TOTAL PROCESS ENERGY				1.05
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	38.0000	0.010500	0.40
			SUBTOTAL	0.40
* TOTAL POLLUTION CONTROL ENERGY				0.40
SPACE HEATING				
NATURAL GAS	CU. FT.	300.0000	0.001000	0.30
			SUBTOTAL	0.30
* TOTAL SPACE HEATING ENERGY				0.30
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				1.75



SUMMARY

	Million Btu per ton of product
Process energy	1.05
Pollution control energy	.40
Space heating	.30
Total energy	1.75

FIGURE 15. - Copper: Copper wire chopping.

Figure 16 and table 15 present a flowsheet and an energy analysis of copper wire incineration for removal of insulation. Incineration requires 1.67 million Btu, most of which is consumed in the afterburner. If the insulation contains PVC, a serious air pollution problem arises, requiring the use of wet scrubbers and treatment of the effluent. Consequently, this method of scrap preparation is being replaced by other methods, such as chopping.

TABLE 15. - Copper: Copper wire incineration

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION OF WIRE				
TRUCK	TON MI	100.0000	0.002400	0.24
RAIL	TON MI	49.0000	0.000670	0.03
			SUBTOTAL	0.27
(2) WIRE INCINERATION				
DISTILLATE FUEL OIL	GAL	0.1000	0.139000	0.01
ELECTRICAL ENERGY	KW HR	7.2000	0.010500	0.08
			SUBTOTAL	0.09
* TOTAL PROCESS ENERGY				0.36
AIR POLLUTION CONTROL				
DISTILLATE FUEL OIL	GAL	9.4000	0.139000	1.31
			SUBTOTAL	1.31
* TOTAL POLLUTION CONTROL ENERGY				1.31
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				1.67

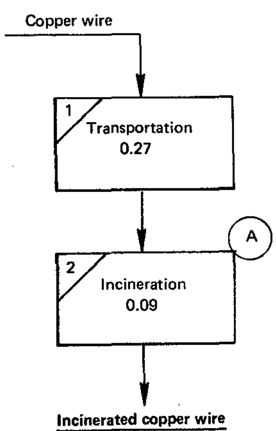


FIGURE 16. - Copper: Copper wire incineration.

SUMMARY

	Million Btu per ton of product
Process energy	0.36
Pollution control energy	1.31
Space heating	.00
Total energy	1.67

Bulky, low-density scrap is compressed into small bales to facilitate handling. The electric energy requirement for baling is less than 0.05 million Btu per ton. For briquetting, the electric energy requirement is on the order of 0.10 million Btu per ton.

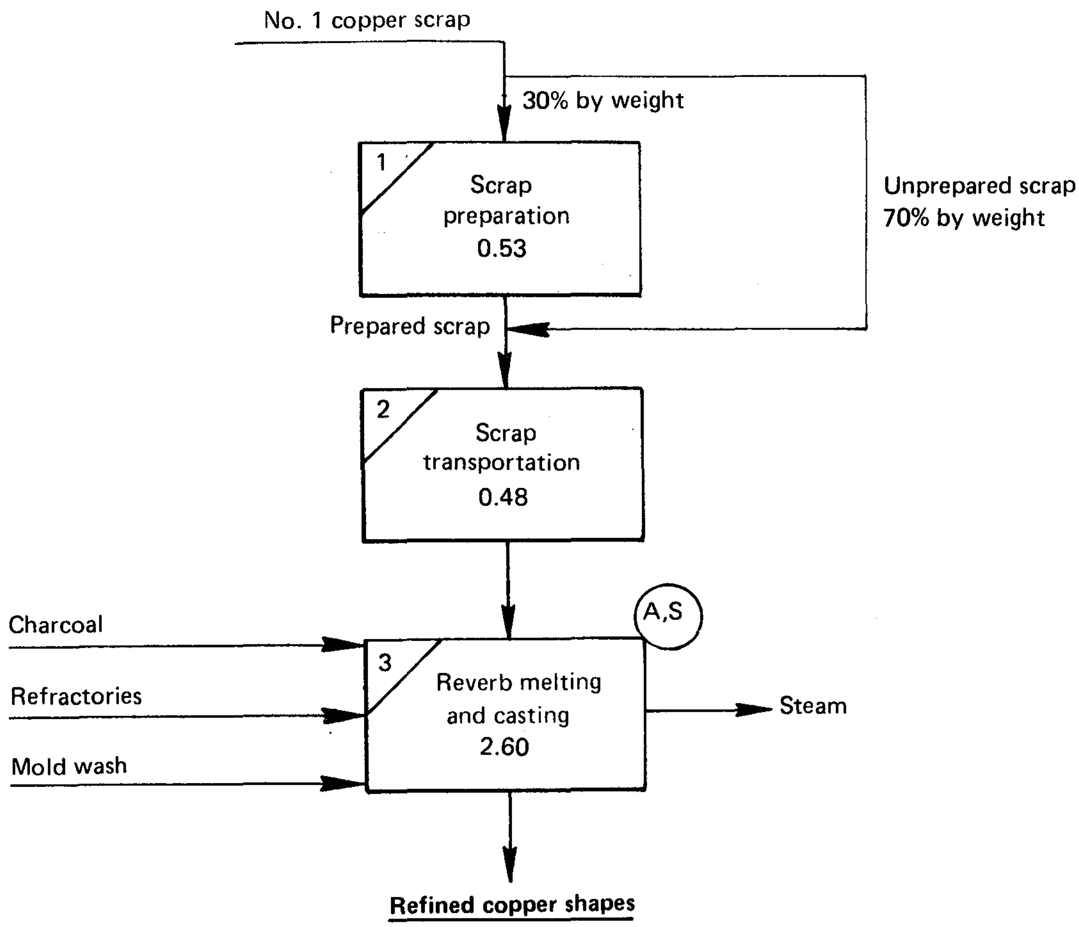
Another scrap processing step is the removal of insulation and lead sheathing from electrical conductors, such as cables, by stripping machines or by hand. This process requires less than 0.01 million Btu per ton. Large pieces of scrap are cut by pneumatic cutters, electrical shears, and/or manually operated shears. The energy requirements for these operations is also low (less than 0.01 million Btu per ton).

Reverb Melting No. 1 Copper Scrap

Figure 17 and table 16 show the recycling scheme and energy requirements for processing No. 1 scrap by reverb melting. Based upon field visits, and for purposes of the analysis, it is assumed that 30% of the scrap feed is chopped copper wire. Recycling No. 1 scrap by this method requires 3.81 million Btu per ton of refined copper shapes, such as billets, cakes, etc. Of this, about 95% is process energy; the remainder represents pollution control and space heating energy.

TABLE 16. - Copper: Reverb melting No. 1 copper wire scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) SCRAP PREPARATION				
SCRAP - WIRE CHOPPING	NET TON	0.3000	1.750000	0.53
			SUBTOTAL	0.53
(2) SCRAP TRANSPORTATION				
TRUCK	TON MI	200.0000	0.002400	0.48
			SUBTOTAL	0.48
(3) REVERB MELTING AND CASTING				
NATURAL GAS	CU. FT.	3400.0000	0.001000	3.40
STEAM(WASTE HEAT CREDIT)	LB	-850.0000	0.001400	-1.18
ELECTRICAL ENERGY	KW HR	20.0000	0.010500	0.21
MOLD WASH	NET TON	0.0024	3.000000	0.01
REFRACTORY	NET TON	0.0040	26.600000	0.11
CHARCOAL	NET TON	0.0020	25.000000	0.05
			SUBTOTAL	2.60
* TOTAL PROCESS ENERGY				3.61
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
			SUBTOTAL	0.05
* TOTAL POLLUTION CONTROL ENERGY				0.05
SPACE HEATING				
NATURAL GAS	CU. FT.	150.0000	0.001000	0.15
			SUBTOTAL	0.15
* TOTAL SPACE HEATING ENERGY				0.15
* TOTAL ENERGY PER NET TON OF PRODUCT				3.81



SUMMARY

	Million Btu per ton of product
Process energy	3.61
Pollution control energy	.05
Space heating	.15
Total energy	3.81

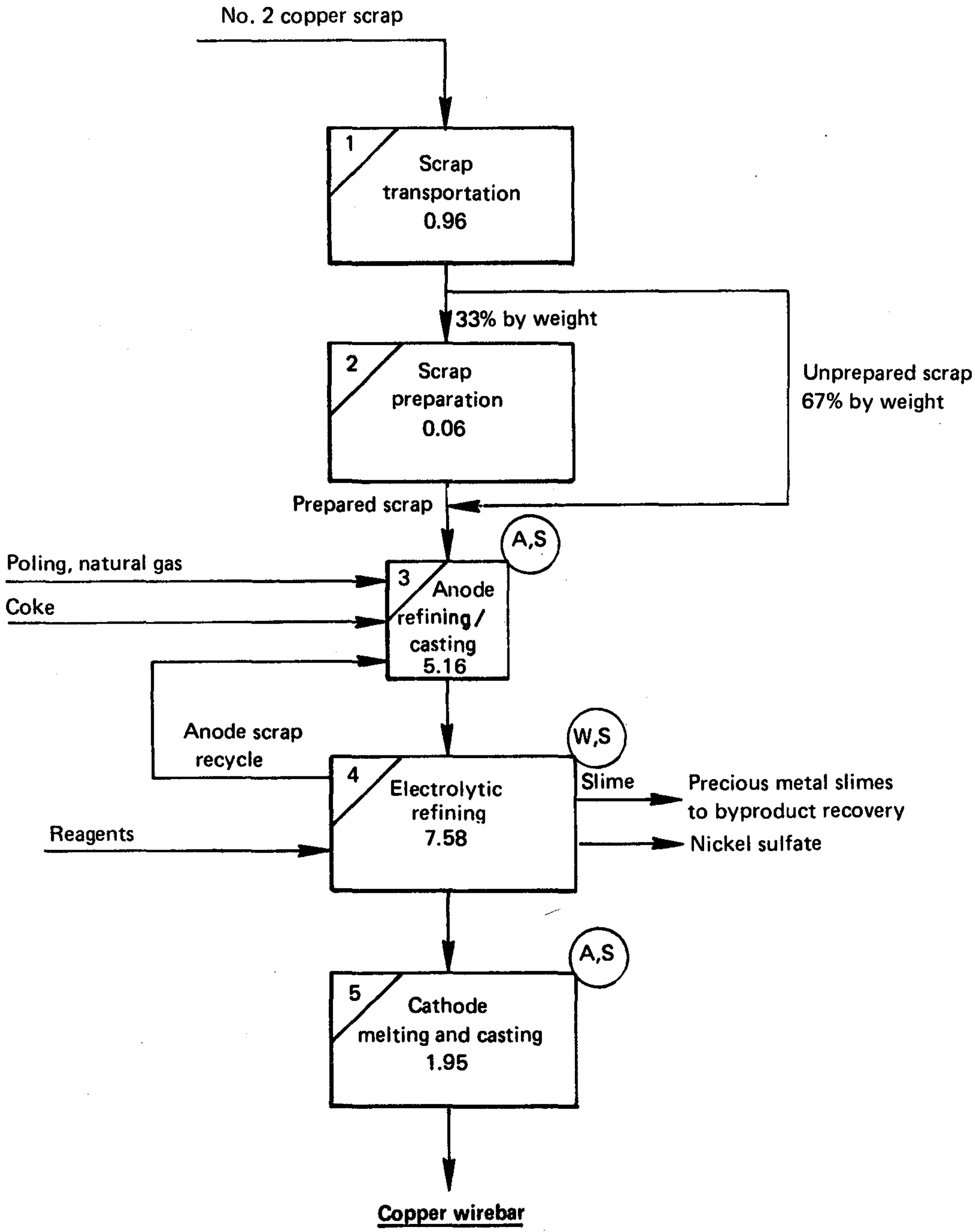
Recycling No. 2 Copper Scrap

Figure 18 and table 17 present the recycling scheme and energy requirements for recycling No. 2 copper scrap. Scrap preparation energy includes electrical energy used in baling loose copper scrap and the fuel consumed in operating mobile material handling equipment, such as tow trucks. For this analysis, it is assumed that a third of the scrap is baled.

TABLE 17. - Copper: Recycling No. 2 copper scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) SCRAP TRANSPORTATION				
TRUCK	TON MI	400.0000	0.002400	0.96
			SUBTOTAL	0.96
(2) SCRAP PREPARATION				
ELECTRICAL ENERGY	KW HR	0.5000	0.010500	0.01
DISTILLATE FUEL OIL	GAL	0.3600	0.139000	0.05
			SUBTOTAL	0.06
(3) ANODE REFINING & CASTING				
DISTILLATE FUEL OIL	GAL	41.0000	0.139000	5.70
NATURAL GAS, POLING	CU. FT.	660.0000	0.001000	0.66
METALLURGICAL COKE	NET TON	0.0090	31.500000	0.28
ELECTRICAL ENERGY	KW HR	24.8000	0.010500	0.26
STEAM(WASTE HEAT CREDIT)	LB	-1250.0000	0.001400	-1.74
			SUBTOTAL	5.16
(4) ELECTROLYTIC REFINING (BATTELLE)	MM BTU	7.5750	1.000000	7.58
			SUBTOTAL	7.58
(5) CATHODE MELTING (BATTELLE)	MM BTU	1.9470	1.000000	1.95
			SUBTOTAL	1.95
* TOTAL PROCESS ENERGY				15.71
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	19.6000	0.010500	0.21
			SUBTOTAL	0.21
* TOTAL POLLUTION CONTROL ENERGY				0.21
SPACE HEATING				
DISTILLATE FUEL OIL	GAL	9.7000	0.139000	1.35
			SUBTOTAL	1.35
* TOTAL SPACE HEATING ENERGY				1.35
* TOTAL ENERGY PER NET TON OF PRODUCT				17.27

Total process energy requirements are 15.71 million Btu per ton of copper wirebar. Air pollution control energy accounts for 0.21 million Btu per ton of copper wirebar, and space heating accounts for an additional 1.35 million Btu per ton. Total energy requirements are 17.27 million Btu per ton of copper wirebar. Results from an earlier study (1) sponsored by the Bureau of Mines have been used in determining energy requirements for electrolytic refining and cathode melting.



SUMMARY

	Million Btu per ton of product
Process energy	15.71
Pollution control energy	.21
Space heating	1.35
Total energy	17.27

FIGURE 18. - Copper: Recycling No. 2 copper scrap.

Recycling Low-Grade, Copper-Bearing Scrap

Figure 19 and table 18 represent the processing scheme and energy requirements for recycling low-grade, copper-bearing scrap. Based on field visits, the copper-bearing charge can typically vary between 25% and 35% copper. It is assumed for the purpose of this analysis that the charge contains 30% copper. The scrap preparation step is assumed to incorporate pelletizing of fine materials and materials handling with one-quarter of the scrap feed being pelletized. Based on plant visits, pelletizing is estimated to require 0.54 million Btu per ton pelletized. Energy requirements amount to 42.42 million Btu per ton copper wirebar, 39.70 million Btu of which represents process energy, 1.37 million Btu is pollution control energy, and 1.35 million Btu is space heating. Since industry sources indicated that refractory usage per ton of product was very small in copper blast furnaces, refractory usage was considered to be negligible in this analysis. As with the processing of No. 2 copper, estimates of the energy requirements for electrorefining and cathode melting are based on an earlier study (1).

Recycling Brass and Bronze Scrap to Brass and Bronze Ingot

Figure 20 and table 19 present the recycling scheme and energy requirements for processing brass and bronze ingots. An 85:5:5:5 red brass alloy has been chosen as a representative product since it accounts for more than half of the brass alloys produced. Scrap preparation energy includes briquetting loose copper scrap and fuel for forklift trucks used in the plant. Based on conversations with plant operating personnel, it is assumed that 30% of the scrap is briquetted. The process energy required is 5.86 million Btu per ton alloy (85:5:5:5); this figure does not include the energy content of alloying elements. Air pollution control energy accounts for 0.91 million Btu, and space heating, for 0.32 million Btu, making a total energy requirement of 7.09 million Btu per ton alloy (85:5:5:5). For other major grades of brasses and bronzes, the energy analyses would not be expected to be significantly different.

Although an attempt is made by the smelter in selecting the scrap to be charged to minimize addition of expensive alloying elements, tin additions of about 1% product weight are often required. Hence, in alloy scrap recycling there is energy as well as materials conservation not only of the main commodity of interest (copper), but of the alloying elements (for example, tin).

TABLE 18. - Copper: Recycling low-grade, copper-bearing scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) TRANSPORTATION				
RAIL	TON MI	1170.0000	0.000670	0.78
			SUBTOTAL	0.78
(2) SCRAP PREPARATION				
ELECTRICAL ENERGY	KW HR	13.0000	0.010500	0.14
			SUBTOTAL	0.14
(3) CUPOLA SMELTING				
METALLURGICAL COKE	NET TON	0.6400	31.500000	20.16
ELECTRICAL ENERGY	KW HR	277.7000	0.010500	2.92
MILLSCALE (FE OXIDE)	NET TON	0.0280	0.710000	0.02
LIMESTONE	NET TON	0.0550	0.104000	0.01
			SUBTOTAL	23.11
(4) CONVERTER				
DISTILLATE FUEL OIL	GAL	24.7000	0.139000	3.43
ELECTRICAL ENERGY	KW HR	81.9000	0.010500	0.86
SAND (FLUX)	NET TON	0.0170	0.042000	0.00
			SUBTOTAL	4.29
(5) ANODE REFINING				
DISTILLATE FUEL OIL	GAL	8.8000	0.139000	1.22
NATURAL GAS	CU. FT.	234.0000	0.001000	0.23
ELECTRICAL ENERGY	KW HR	11.7000	0.010500	0.12
METALLURGICAL COKE	NET TON	0.0090	31.500000	0.28
			SUBTOTAL	1.85
(6) ELECTROLYTIC REFINING (BATTELLE)	MM BTU	7.5750	1.000000	7.58
			SUBTOTAL	7.58
(7) CATHODE MELTING (BATTELLE)	MM BTU	1.9470	1.000000	1.95
			SUBTOTAL	1.95
* TOTAL PROCESS ENERGY				39.70
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	130.0000	0.010500	1.37
			SUBTOTAL	1.37
* TOTAL POLLUTION ENERGY				1.37
SPACE HEATING				
DISTILLATE FUEL OIL	GAL	9.7000	0.139000	1.35

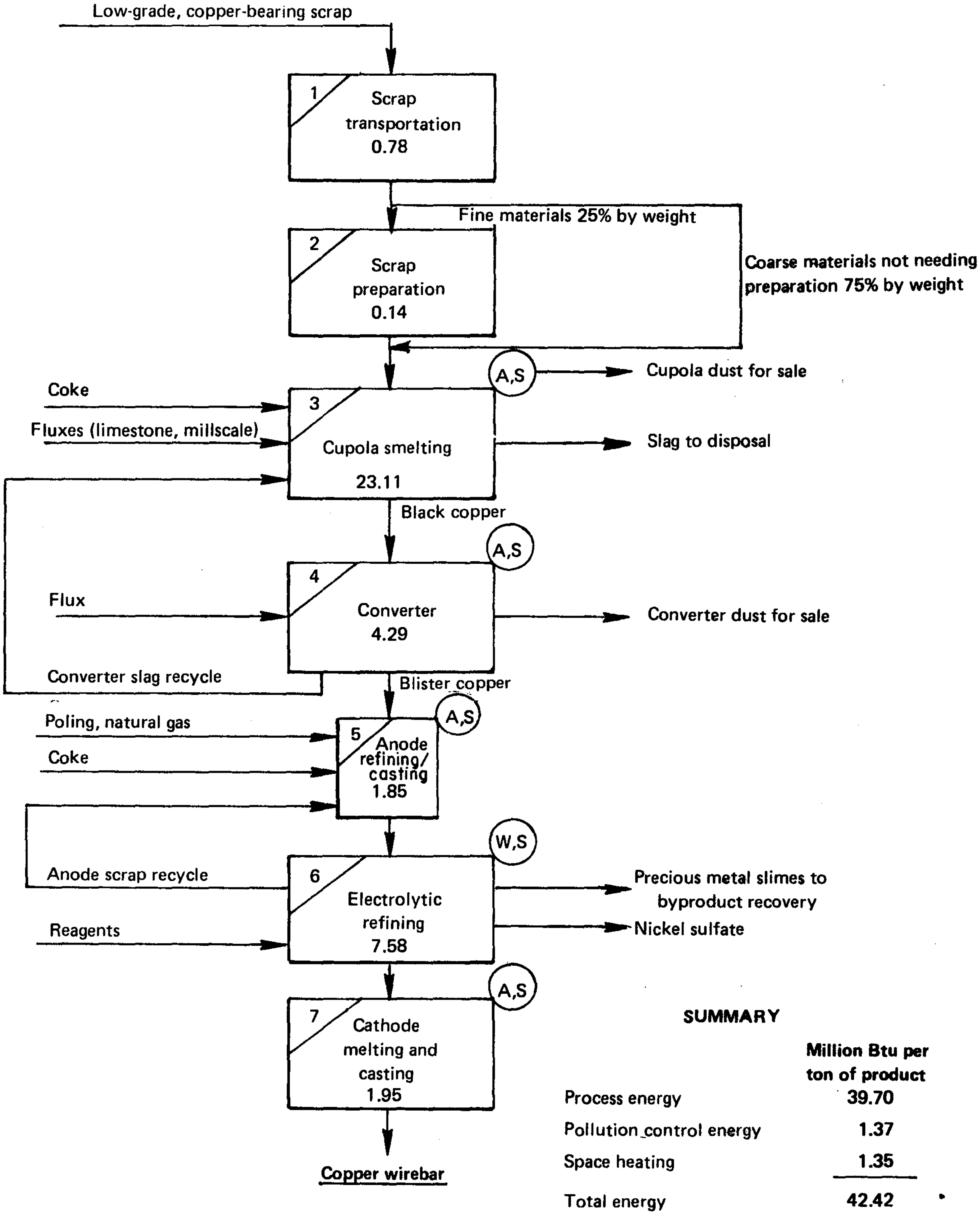
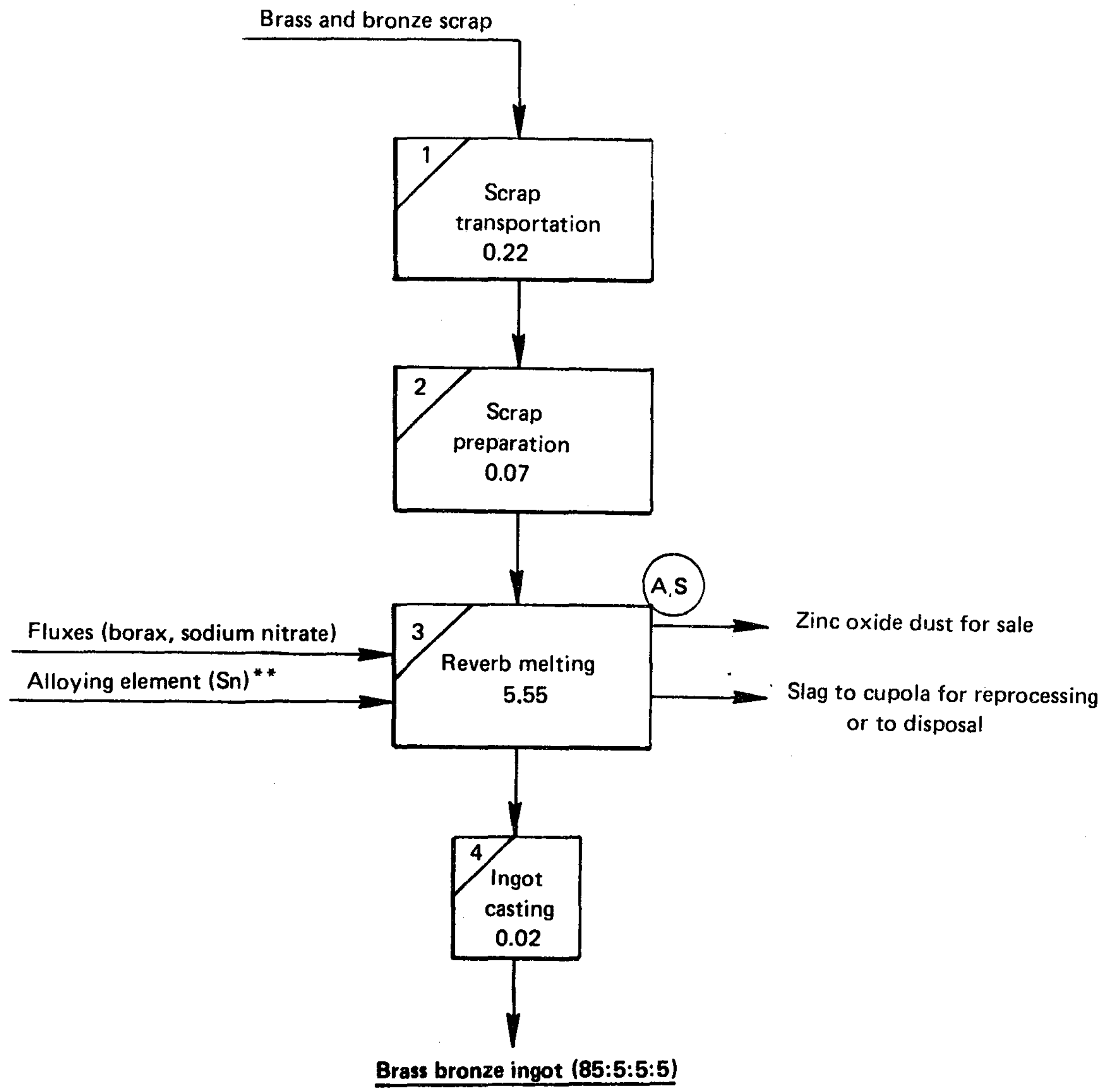


FIGURE 19. - Copper: Recycling low-grade, copper-bearing scrap.

TABLE 19. - Copper: Recycling brass and bronze scrap to brass and bronze ingot (85:5:5:5)

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) TRANSPORTATION				
TRUCK	TON MI	92.0000	0.002400	0.22
			SUBTOTAL	0.22
(2) SCRAP PREPARATION				
ELECTRICAL ENERGY	KW HR	1.7300	0.010500	0.02
DISTILLATE FUEL OIL	GAL	0.3600	0.139000	0.05
			SUBTOTAL	0.07
(3) REVERB MELTING				
NATURAL GAS	CU. FT.	4300.0000	0.001000	4.30
TIN	NET TON	0.0130	**	**
BORAX	NET TON	0.0173	8.600000	0.15
METALLURGICAL COKE	NET TON	0.0070	31.500000	0.22
ELECTRICAL ENERGY	KW HR	60.0000	0.010500	0.63
SODIUM NITRATE	NET TON	0.0060	42.250000	0.25
			SUBTOTAL	5.55
(4) INGOT CASTING				
ELECTRICAL ENERGY	KW HR	2.1800	0.010500	0.02
			SUBTOTAL	0.02
* TOTAL PROCESS ENERGY				5.86
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	87.0000	0.010500	0.91
			SUBTOTAL	0.91
* TOTAL POLLUTION CONTROL ENERGY				0.91
SPACE HEATING				
NATURAL GAS	CU. FT.	323.0000	0.001000	0.32
			SUBTOTAL	0.32
* TOTAL SPACE HEATING ENERGY				0.32
* TOTAL ENERGY PER NET TON OF PRODUCT				7.09

** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE



SUMMARY

	Million Btu per ton of product
Process energy	5.86
Pollution control energy	.91
Space heating	.32
Total energy	7.09

**Energy content of alloying elements is not included in the total process energy.

FIGURE 20. - Copper: Recycling brass and bronze scrap to brass and bronze ingot (85:5:5:5).

Major Heat Losses

The thermal efficiency of reverb furnaces in melting is low, ranging from 17% to 25%. However, in recycling copper scrap these furnaces are used to refine as well as melt with a 24-hour furnace cycle involving 13 hours for charging and melting, about 6 hours for refining, and 5 hours for casting. During the refining and casting portions of the cycle, the furnace operates as a holding furnace and the heat input is used to compensate for the heat loss. Consequently, the overall thermal efficiency in melting, refining, and casting is reduced to 10% to 15%.

About 53% of the heat input to the furnace is carried away as sensible heat in offgas. In the recycling of No. 2 copper, about one-half of this heat is recovered as steam in waste heat boilers; the remaining 47% is available to provide the heat required for melting and refining and to compensate for heat losses from the furnace through the refractory walls, by radiation to the atmosphere, and as sensible heat in the slag. In recycling brass and bronze, generally no heat recovery is practiced.

Research and Development

Potential areas for research and development in copper recycling include the following:

1. Utilizing the plastic waste material from copper wire chopping, either as a recycled plastic product or as a fuel. This can lead to materials/energy conservation as well as eliminating a solid disposal problem.

2. Developing separation techniques to improve utilization of low-quality chopped copper scrap (that is, scrap contaminated with aluminum, zinc, stainless steel, etc.). This material cannot currently be processed by wire chopping. It is treated as low-grade scrap and processed in the blast furnace.

3. Determining the feasibility of recovering waste heat from dust-laden, reverb furnace offgas in the recycling of brass and bronze ingots. The waste heat can be utilized to preheat combustion air or scrap.

4. Modifying burner design in the cathode melting shaft furnace to use alternative fuels, such as No. 2 fuel oil. Operation with modified burners needs to be tested to determine if an acceptable product can be obtained.

5. Improving the electrolytic refining of copper to decrease the 15% to 22% of the anodes that are recycled as scrap. For example, the amount of anode scrap is affected by anode quality, smooth surface, and uniform weight. Current methods for making more uniform anodes include the use of the Hazelett continuous strip casting system (4) involving automatic weight control of anodes which are hung in prefabricated hangars (10-11).

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IRON AND STEEL

Background

Table 20 presents data on and summarizes the role of scrap in the iron and steel industry.

TABLE 20. - Data on iron and steel industry

	Net tons[1]
Secondary raw materials (1976):	
Prompt industrial scrap	22,629,000
Obsolete scrap	18,515,000
U.S. production (1976):	
Raw steel	128,000,000
Iron castings	15,000,000

[1]All figures are rounded to the nearest thousand.

NOTE.--Commodity: Iron and steel.
Primary products: Steel ingots and continuously cast products, iron and steel castings.
Byproducts: None.
Coproducts: None.

Sources: U.S. Bureau of Mines, American Iron and Steel Institute, and Arthur D. Little, Inc., estimates.

Industry

Ferrous scrap processors supplied more than 41 million tons of scrap to American steel mills and foundries in 1976, thereby making them a major supplier of domestic iron units. Ferrous scrap is traded on a worldwide basis. In some recent years, more than 10 million tons of iron and steel scrap have been exported.

Types and Classifications of Scrap

The two main categories of iron and steel scrap are "home" and "purchased" scrap.

Home Scrap.--Home scrap (also known as circulating, revert, in-house, and run-around scrap) is the iron-containing waste material generated during the production of iron castings and semifinished or finished steel, which can be recycled internally (at the plant where it is generated) back to one of the melting furnaces. Such scrap is produced throughout a steel plant or foundry and includes hot metal and steel spills or runnings; ingot and bloom croppings; billet, pipe, and bar ends; plate shearings and sheet trimmings; risers; and rejected old inventory, molds, and stools.

Purchased Scrap.--Purchased scrap is most often obtained from scrap dealers, with smaller amounts of scrap sold directly by scrap generators to scrap consumers. The two categories of purchased scrap are "prompt industrial" and "obsolete." Prompt industrial scrap (also known as new scrap) is material generated by metalworking firms and other users of semifinished steel during the fabrication of their products. Obsolete scrap is also known as old, post-consumer, or country scrap. It is generally made up of parts and equipment which have worn out or become obsolete, such as old automobiles, structural members of demolished buildings and ships, farm machinery, house appliances, railroad equipment, and the like.

A special category of scrap is the ferrous fraction reclaimed from municipal solid waste. This scrap has a potential for recycling in various industries. Reuse in the iron and steel industry is still in the realm of experimentation. Another chapter of this report--Municipal Solid Waste--is devoted to metallic values that can be recovered from municipal solid waste.

Commonly traded grades of scrap generally include both obsolete and prompt industrial scrap. Recognizing that there are many different categories and subcategories of scrap, the major grades of ferrous scrap are as follows:

Low-phosphorus plates and punchings.--This grade consists of steel scrap 0.25 inch and over in thickness, and not over 3 feet in length, which must be free of alloys or any material over 0.05% sulfur, 0.05% phosphorus, and 0.5% silicon.

Electric furnace bundles.--Chemical specifications for this category are similar to those listed above; however, it may include material under 0.25 inch thick, provided the scrap is prompt industrial black plate[14] compressed into bundles approximately 14 by 14 by 20 inches or smaller.

No. 1 heavy melting scrap.--This grade consists of scrap 0.25 inch and over in thickness, not over 18 inches in width, and not over 5 feet in length. It may include heavy forgings, forge butts, billet blooms, slab or bar crops not conforming to chemical analysis required for electric furnace or acid open-hearth use, and pipe ends. This category may not include auto body and fender scrap.

No. 2 heavy melting scrap.--This grade includes wrought iron or steel scrap, black or galvanized, 0.125 inch and over in thickness not over 18 inches in width, and generally not over 3 feet in length. It may include pipe cable not less than 1 inch in diameter and cut to lengths of 3 feet or less, and railroad car sides and light plate cut to 15 by 15 inches or under. Auto body and fender scrap are not included.

[14]Black plate is cold rolled sheet and strip, cleaned and annealed, such as sheet ready for tinning.

<u>No. 1 bundles</u>.--This grade consists of prompt industrial black plate, clippings, or skeletons compressed or hand-bundled to charging box size and weighing not less than 75 pounds per cubic foot. It must be free of paint or protective coating of any kind, and cannot include detinned scrap, electrical sheets, or any material containing more than 0.5% silicon.

<u>No. 2 bundles</u>.--This grade includes body, fender and black plate scrap, or chemically detinned material compressed to charging box size and weighing not less than 75 pounds per cubic foot. Not included in this category are galvanized vitreous enameled stock, painted or laquered sheet stock, tin plate, terneplate, or other metal-coated material. The category may include compressed, uncoated fence wire and light coil springs.

<u>Machine shop turnings</u>.--This grade consists of clean steel or wrought iron turnings free of cast or malleable iron borings, nonferrous metals in a free state, scale, or excessive oil. May not contain badly rusted or corroded stock. Machine shop turnings can be baled into bundles weighing not less than 75 pounds per cubic foot and containing no more than 25% by weight of black sheet scrap for wrapping purposes.

<u>Shredded or fragmented scrap</u>.--Includes the magnetic fraction of shredded automobiles and appliances.

Consumption

All grades of iron and steel scrap traded by dealers, brokers, and other sources are purchased by three types of users--steel plants, iron foundries and miscellaneous users, and manufacturers of steel castings--each one with its own specific mix of grades. Steel plants consume about two thirds of the scrap traded. Although their emphasis is on steel scrap, they buy minor amounts of cast iron scrap. Iron foundries and miscellaneous users purchase roughly 30% of the scrap. They buy most of the iron scrap traded; in addition, foundries purchase about an equivalent tonnage of steel scrap. Manufacturers of steel castings buy the remaining scrap (largely steel scrap), amounting to about 4% of the total.

Table 21 summarizes the characteristics and volumes of ferrous scrap processed and sold to domestic consumers in 1976.

TABLE 21. - Obsolete and prompt industrial iron and steel scrap receipts in 1976

	Net receipts, thousand short tons	Obsolete scrap,[1] %	Prompt industrial scrap,[1] %
Carbon steel:			
Low-phosphorus plate and punchings........	2,536	0	100
Cut structural and plate..................	1,887	70	30
No. 1 heavy melting steel.................	5,890	60	40
No. 2 heavy melting steel.................	2,624	80	20
No. 1 and electric furnace bundles........	7,382	0	100
No. 2 and all other bundles...............	2,749	100	0
Electric furnace 1 foot and under (not bundles)...............................	704	80	20
Railroad rails............................	168	100	0
Turnings and borings......................	1,882	0	100
Slag scrap (70% Fe content)...............	1,333	0	100
Shredded or fragmented....................	3,098	100	0
All other carbon steel scrap..............	4,320	100	0
Ingot mold and stool scrap..................	482	100	0
Machinery and cupola cast iron..............	1,099	100	0
Cast iron borings...........................	1,540	0	100
Motor blocks................................	699	100	0
Other iron scrap............................	1,262	100	0
Other mixed scrap...........................	1,489	100	0
Total...................................	41,144	-	-

[1]Arthur D. Little, Inc., estimates.

Sources: Division of Ferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys, 1976; and Arthur D. Little, Inc., estimates.

Scrap Preparation

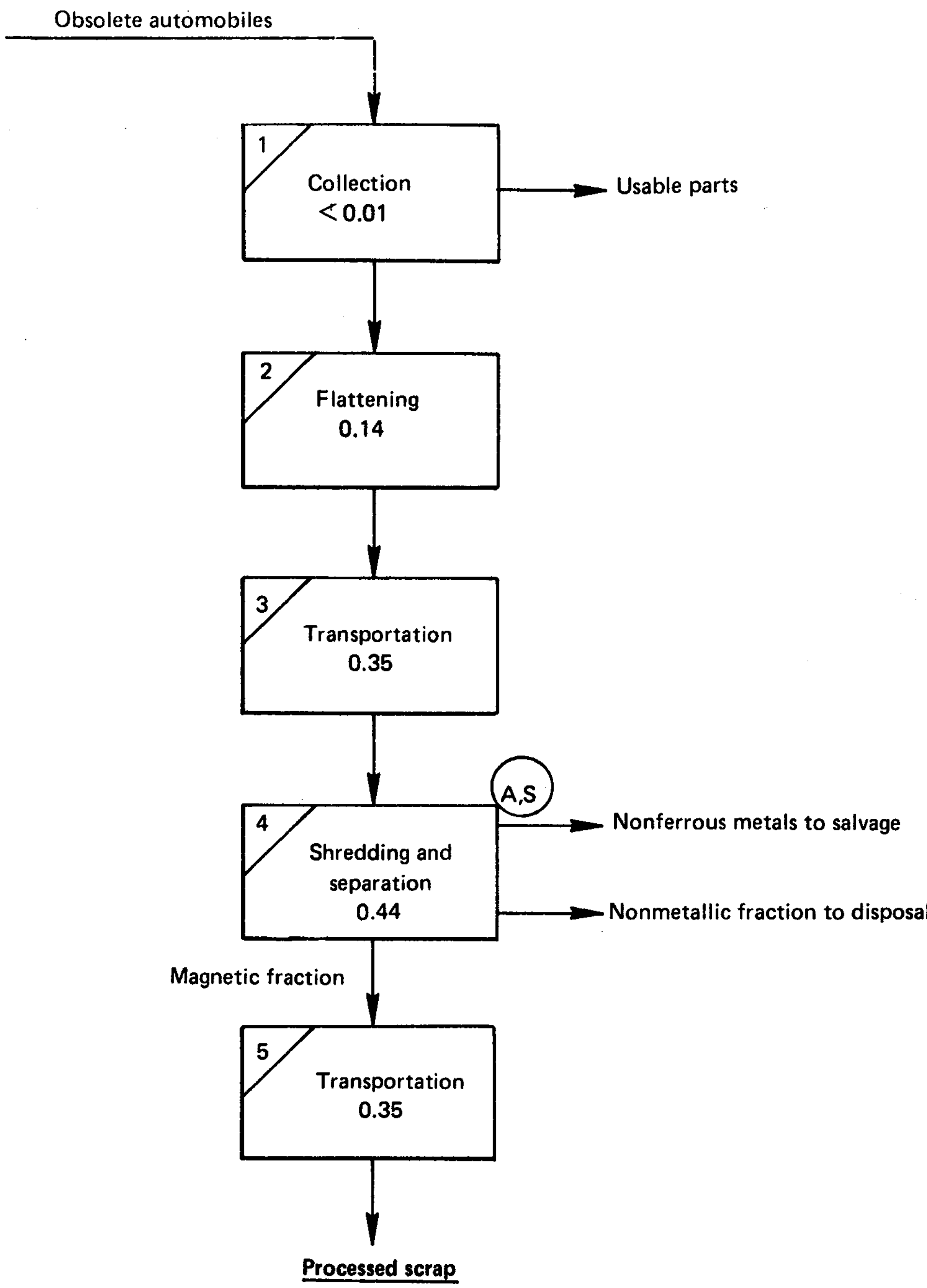
Home Scrap

About one-third of the raw steel produced under current domestic practice is recycled as home scrap. In general, the only processing done to this scrap is to cut it into manageable pieces. Manual oxyacetylene torches are the most widely used equipment for this task. Shears, balers, casting breakers, and mandril rollers are also used. About 70% of the home scrap used is charged to the furnace without any preparation. The scrap is usually stored in large piles onsite until needed. Since this type of scrap presents few problems in collection, transporatation, or sorting, it is nearly always recycled.

Purchased Scrap

Major processing methods are shredding, guillotine shearing, baling, alligator shearing, torch cutting, and crushing, all of which are described below.

A shredder (or hammer mill) has a series of hammers rotating at a fixed distance past a stationary anvil. A shredder accepts automobiles (typically 90% of the feedstock), household appliances, and other light obsolete items (approximately 10% of the feedstock). The process flowsheet is shown in figure 21. Materials to be shredded are fed over the anvil toward the rotating



SUMMARY

	Million Btu per ton of product
Process energy	1.28
Pollution control energy	.00
Space heating	.00
Total energy	1.28

FIGURE 21. - Iron and steel: Automotive scrap preparation by shredding.

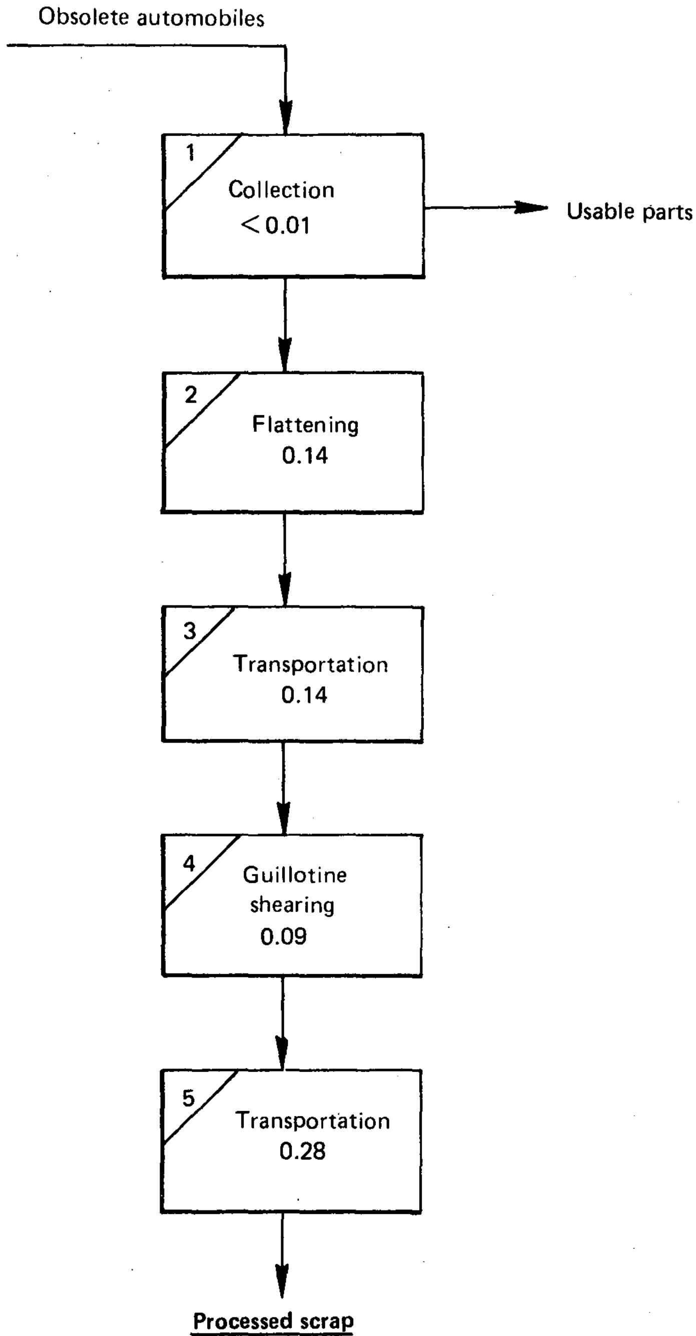
hammers where the impact of the hammer fractures or tears the steel into small pieces. A grate discharge arrangement is used to limit the maximum size of the product. The shredder product is conveyed to a magnet and air separator which produce a clean, high-quality grade of ferrous scrap and a nonmagnetic fraction. The magnetic fraction is shipped to steel mills and foundries; the nonmagnetic fraction containing metallic and nonmetallic materials has been traditionally discarded as solid waste. However, a number of scrap processors have recently begun using some type of dense media separation on the nonmagnetic metallic fraction to recover the aluminum, copper, zinc, and austenitic stainless steel for subsequent resale. Most shredder operators do not perform this separation themselves, but rather ship the nonmagnetic fraction to plants which have installed such processes. The nonmagnetic, nonmetallic fraction contains low-density fibrous plastic, and rubber material collected in cyclones. Although usually landfilled, this material has potential as a fuel, recognizing that polyvinyl chloride (PVC) can cause air pollution control problems. An alternative use currently being explored is the separation of polyurethane and other plastics for recycle.

A guillotine shear has a movable head which descends past a stationary anvil shearing the protruding scrap and producing a large chunk of material. The shears may have a compacting section which compresses the feed material into a log shape prior to shearing. Guillotine shears typically prepare No. 1 and No. 2 heavy melting scrap. They may also be used to reduce the size of large items as a preparation step for further processing with the processing sequences shown in figures 22-23.

A hydraulic baler typically has three perpendicular compression cylinders that sequentially compress light scrap (such as clippings or sheets) into a compact bundle. The processing sequence is shown in figure 24. Balers are available in a wide variety of sizes for various types of scrap.

The alligator shear has a pivoting top blade and cuts scrap sections with the scrap preparation sequence shown in figure 25. These units, generally much smaller than guillotine shears and often fed manually, are used on scrap that is reasonably dense and needs a minimum amount of cutting (for example, rebar, wire ends, cable, and small structural steel). Most often, they prepare smaller materials suitable for foundry use.

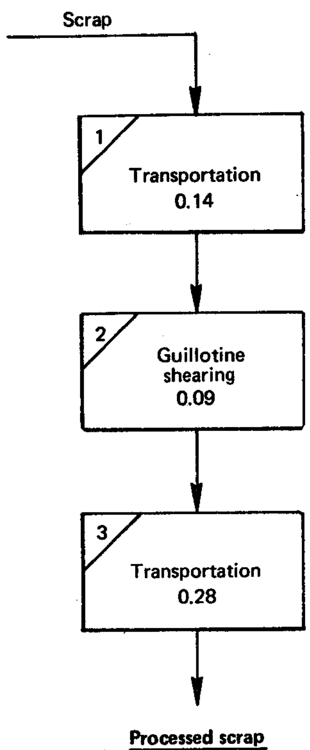
An oxyacetylene torch (figs. 26-27) is used to cut heavy steel scrap and to disassemble large items. Acetylene is used as a pilot light and to initiate the cutting action. Pure oxygen is used to actually cut the steel, as the heat of iron oxidation is sufficient to melt and cut the section. Since torches are usually operated manually, cutting is time-consuming, yet it is one of the few effective ways to cut heavy steel. Torch cutting is seldom used on light scrap.



SUMMARY

	Million Btu per ton of product
Process energy	0.65
Pollution control energy	.00
Space heating	.00
Total energy	0.65

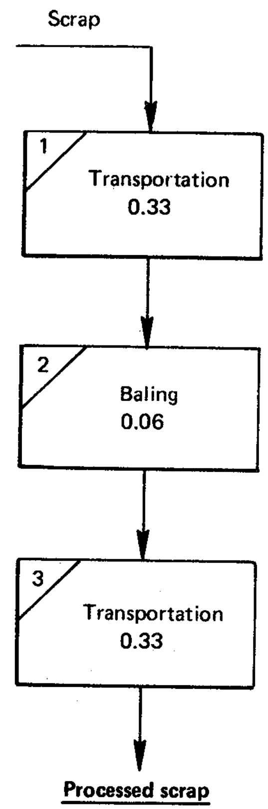
FIGURE 22. - Iron and steel: Automotive scrap preparation by guillotine shearing.



SUMMARY

	Million Btu per ton of product
Process energy	0.51
Pollution control energy	.00
Space heating	.00
Total energy	.51

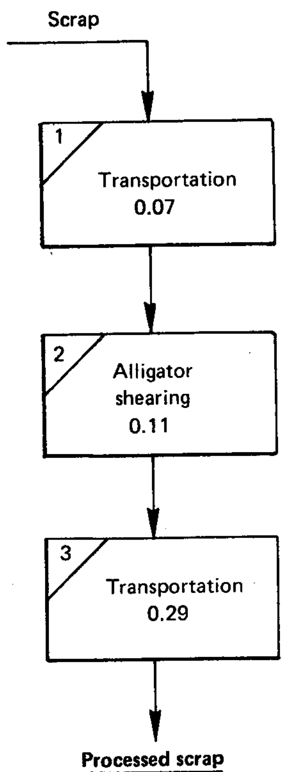
FIGURE 23. - Iron and steel: Scrap preparation by guillotine shearing.



SUMMARY

	Million Btu per ton of product
Process energy	0.72
Pollution control energy	.00
Space heating	.00
Total energy	.72

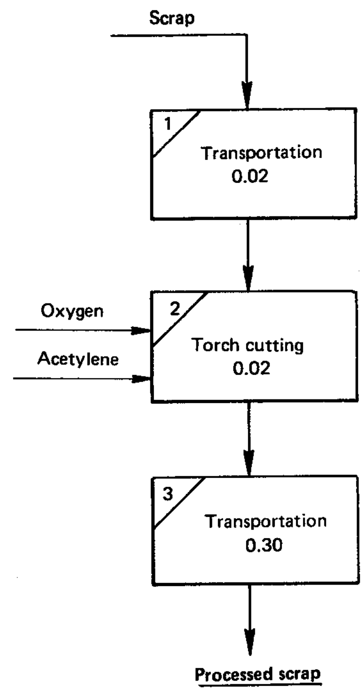
FIGURE 24. - Iron and steel: Ferrous scrap preparation by baling.



SUMMARY

	Million Btu per ton of product
Process energy	0.47
Pollution control energy	.00
Space heating	.00
Total energy	.47

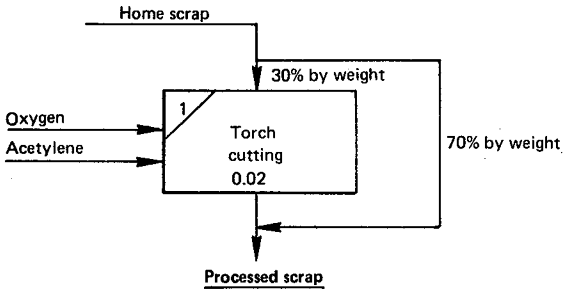
FIGURE 25. - Iron and steel: Ferrous scrap preparation by alligator shearing.



SUMMARY

	Million Btu per ton of product
Process energy	0.34
Pollution control energy	.00
Space heating	.00
Total energy	.34

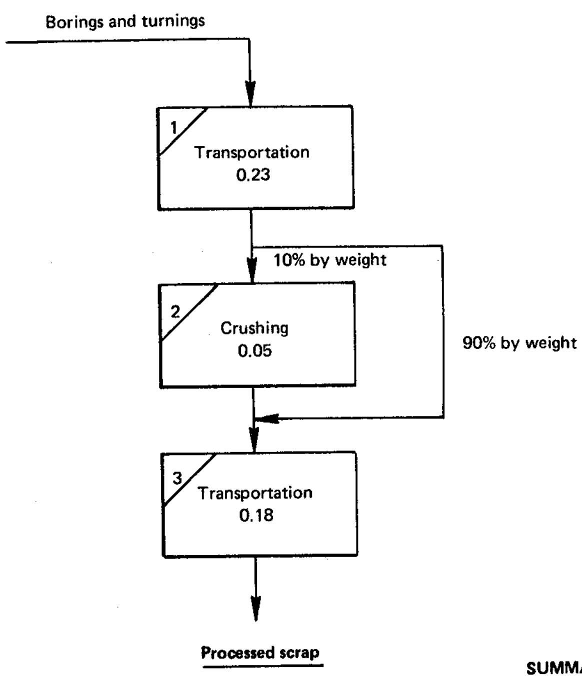
FIGURE 26. - Iron and steel: Purchased scrap preparation by torch cutting.



SUMMARY

	Million Btu per ton of product
Process energy	0.02
Pollution control energy	.00
Space heating	.00
Total energy	.02

FIGURE 27. - Iron and steel: Home scrap preparation by torch cutting.



SUMMARY

	Million Btu per ton of product
Process energy	0.46
Pollution control energy	.00
Space heating	.00
Total energy	.46

FIGURE 28. - Iron and steel: Prompt industrial scrap preparation from borings and turnings (crushing).

A shredder (also known as crusher) for borings and turnings, with the scrap preparation sequence shown in figure 28 (usually a ring-mill or hammer mill), may be used to reduce metal turnings to a manageable size, since uncrushed turnings tangle easily and are difficult to handle. Turnings are not normally de-oiled because the oil film slows down their oxidation under atmospheric conditions and allows for a longer outside storage time.

No processing is performed on a number of loose miscellaneous items, such as rejected fabricated metal products. There is no flowsheet shown for this category. The only step involved in recycling this scrap is transportation.

Other Processing Methods

A number of other preparation techniques are used on various types of scrap. Often a processor will have an abundant supply of a particular type of scrap, which may warrant use of special techniques. Following are examples of such situations:

Cast iron items (motor blocks, machinery parts) often are simply dropped in an enclosed area and break upon impact. This task is performed either by scrap processors or by the melting furnace operator. Flowsheets are not shown for machine cupola cast iron or for motor blocks scrap grade preparation.

Railroad rails can be notched on one side and broken with a sledge hammer. Alternatively, they can be broken in mechanized rail breakers, torch cut, or more commonly reheated and drawn into merchant bars and rebars without being remelted.

Hot or cold briquetting of turnings and borings is sometimes practiced on a small scale.

Blast furnace slag is usually crushed by an independent nearby operator. The magnetic fraction is recovered and returned to the steel mill for use as blast furnace feedstock. About 1.3 million tons of such scrap containing 70% iron was used in the United States in 1976.

Transportation

Prepared scrap, shipped to the consumer either in open railroad cars or by truck, is stored next to the melt shop. Before being used, it must be thawed and dried, if necessary; the presence of ice or water on the scrap often causes dangerous explosions (due to rapid water evaporation) during charging to hot furnaces.

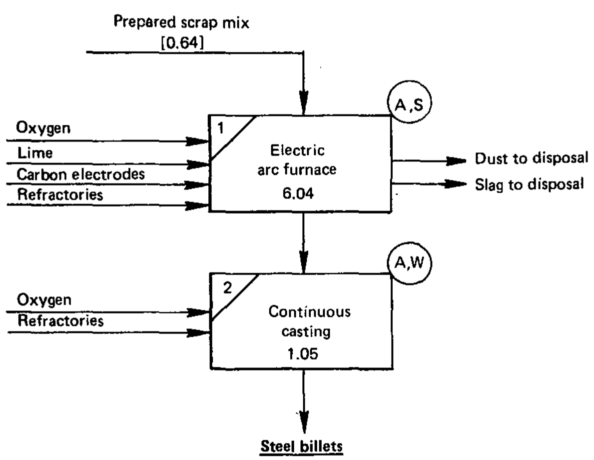
Melting and Refining

Major Processing Methods

Steelmakers and foundrymen are the major users of ferrous scrap. A well-managed melt shop can choose scrap mixes that minimize the amount of refining and chemistry adjustment necessary to meet the specifications of its customers. The major processes by which ferrous scrap is recycled are also found in the major melting and refining processes used in the iron and steel industry: The electric arc furnace (EAF) is used in steelmaking and foundries; the cupola, in foundries; the open hearth (OH), in steelmaking; and the basic oxygen process (BOP and Q-BOP), in steelmaking.

The three steelmaking processes practiced in the United States (EAF, OH, BOP) largely produce the same qualities of carbon steels. The foundry cupola produces gray, malleable, and ductile iron.

Electric furnace operations, as shown in figure 29, are found in steel mills and foundries and are usually based on 100% scrap that is typically a mixture of home and purchased scrap.



SUMMARY

	Million Btu per ton of product
Process energy	8.09
Pollution control energy	.24
Space heating	.00
Total energy	8.33

FIGURE 29. - Iron and steel: Electric arc furnace steelmaking with 100% scrap.

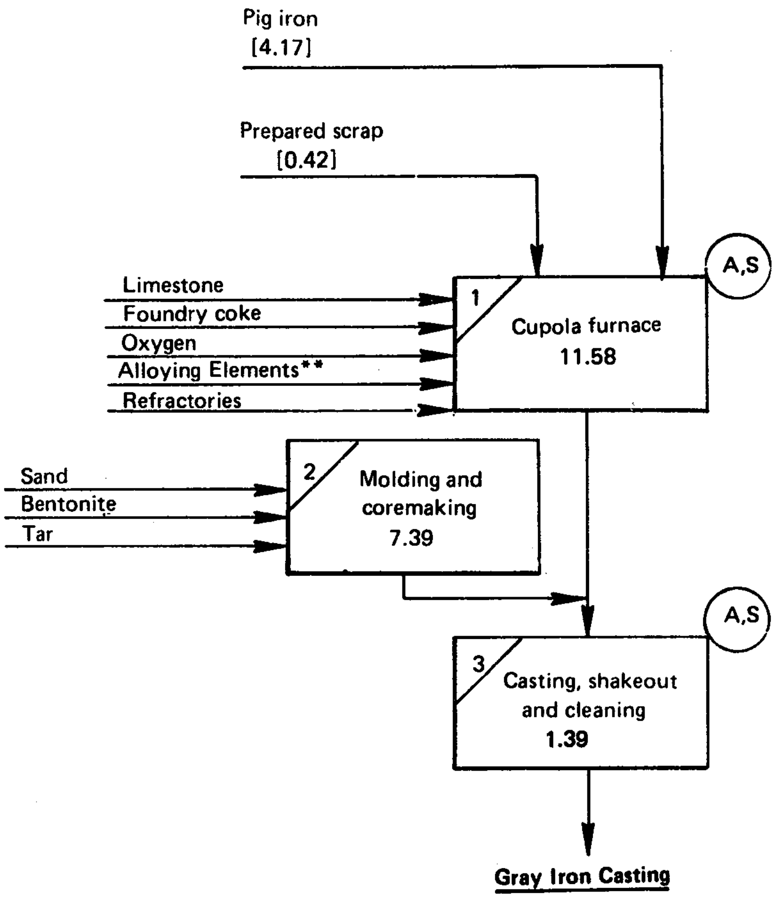
A fair amount of coated products is nearly always present in purchased scrap. Zinc is present in galvanized sheets and wire; a small fraction remains in the slag, but most of it escapes and is entrained as ZnO in the off-gases. Based on plant visits, it is estimated that electric furnace flue dust may contain up to 30% Zn, with an average at about 15%. As a result, 40,000 to 50,000 tons of zinc content in dust are collected every year in electric furnace air pollution control systems. In addition to this, another 5,000 tons of lead are collected in the same dusts, or go to the bottom of the bath and drip through the refractories coming from terneplates and other lead-coating scrap. Although U.S. plants do not recover zinc and lead from such steel dusts, many Japanese plants are doing so routinely. Methods to recover these elements are being periodically reassessed by various governmental and private interests in the United States. Thus, the flowsheets (based on U.S. data for 1976) for electric arc furnaces show no zinc, or other nonferrous metal credits.

Copper, nickel, tin, and other elements that are more noble than iron cannot be eliminated by simple melting and traditional refining techniques in an electric arc furnace. They remain as dissolved impurities in the steel produced. At the end of their useful life, some of the commercial products made from this steel are scrapped and returned to the steelmaker further contaminated with copper wire, solder, and fragments of stainless steel, due to insufficient segregation during scrap preparation. However, not all ferrous items are recycled; concrete reinforcing bars (rebars) and items whose useful life ends too far away from a scrap processor to make this recovery economical, act as a sink for these tramp elements. The present recycling practice, however, has resulted historically in the slow buildup of copper and other impurities in steel. This is of concern to the steelmakers who have less and less leeway to meet increasingly stringent product specifications.

A "heat" or batch of steel of a given grade is made by melting the charge in a steelmaking electric arc furnace. The composition (C, Si, Mn, S, P) is adjusted during a refining period by the combined action of introducing oxygen as by oxygen lancing or addition of iron ore and slag fluxing. After the molten steel is poured into a ladle, final chemistry adjustments are made, and the steel is poured into ingots or into a continuous casting machine. The vast majority of electric furnaces are equipped with baghouses. About 10% use wetscrubbers and less than 5% use electrostatic precipitators.

The cupola (sequence of operations shown in figure 30) is the dominant furnace for producing gray iron used for pipe castings; sanitary ware; automotive, locomotive, and machinery castings; and miscellaneous shapes. The cupola is like a small blast furnace and uses foundry coke instead of metallurgical coke.[15] After tapping into a ladle where the chemistry is adjusted, the molten iron is poured into molds. A wide range of chemical compositions are found in gray iron castings with carbon ranging from 2% to 4%, silicon

[15] Foundry coke is obtained in coke ovens by the same process used to produce metallurgical coke. The only difference is a somewhat longer retention time for the foundry coke, which implies a higher fuel consumption per ton of coke produced for oven under firing.



SUMMARY

	Million Btu per ton of product
Process energy	24.95
Pollution control energy	2.18
Space heating	4.54
Total energy	31.67

**Energy content of alloying elements is not included in the total process energy.

FIGURE 30. - Iron and steel: Gray iron casting by cupola process.

from 0.5% to 3%, and with small amounts of Ni, Cr, Mo, and Cu frequently added. Offgases from a cupola are hot, dirty, and contain about 5% CO. In most cases, the CO is burned in an afterburner with gases cooled by simple radiation or by water sprays, and with particulates collected in systems such as baghouses, high-energy scrubbers, or electrostatic precipitators.

Other Processing Methods for Obsolete Scrap

The open-hearth process is rapidly becoming obsolete because it is at economic disadvantage when compared with either the electric arc furnace (for scrap melting) or the oxygen furnace (for hot metal refining). An energy analysis of the open hearth can be developed using a previous study (1). No further investigation of the open hearth was made during the course of this study.

The oxygen furnace (BOP, top blown, and Q-BOP, bottom blown) is not presented in this study because this furnace has just about the capability to melt the scrap generated in-plant, making the steel mill independent of the purchased scrap market. On balance, it has little additional scrap-melting capability unless modifications are made to the steelmaking process, such as preheating the scrap or using exothermic materials.

Other processing methods for obsolete scrap include the following:

1. Electric arc furnace steelmaking based on directly reduced iron ore and scrap;

2. Electric furnace pig iron reduction combined with the basic oxygen process which has been practiced where low-cost electric power is available, such as in Norway;

3. Electric arc furnaces based on scrap (and/or directly reduced iron) and blast furnace hot metal;

4. Cupola for melting followed by BOF for steelmaking (also known as cupola-BOF duplexing); and

5. Bessemer or Thomas process, which is obsolete in the United States. (This technology had very limited scrap melting ability, being mainly developed for refining of blast furnace hot metal.)

Some induction furnaces are used in iron and steel foundries for melting small to moderate size heats or as holding furnaces. Foundries are beginning to use electric arc furnaces in increasing numbers. These units are conceptually similar to those used in steelmaking, but no significant refining takes place.

It should be noted that not all ferrous scrap is remelted. Three examples are ferrous scrap added to secondary lead blast furnaces as a fluxing agent, ferrous scrap used for copper cementation,[16] and ferrous scrap used to make some standard shapes, especially the use of old railroad rails by splitting them and rolling them directly into rebars. (Although no data are available on the tonnage involved, industry analysts agree that this does not appear to be a widely practiced method in the United States.)

Energy Analysis

The energy analysis is complicated by the fact that purchased scrap goes through a complex network of dealers, brokers, and processors. Tables 22-31 summarize the energy requirements associated with the previously described processing methods. The energy analysis of the melting step is based on a previous study supported by the Bureau of Mines (1). In most instances, materials transportation and handling are the most energy-intensive steps in scrap preparation.

[16]Further discussion of this process can be found in a previous study (1).

TABLE 22. - Iron and steel: Automotive scrap preparation by shredding

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
		0.0000	0.000000	0.00
			SUBTOTAL	0.00
(2) FLATTENING				
DISTILLATE FUEL OIL	GAL	0.9800	0.139000	0.14
			SUBTOTAL	0.14
(3) TRANSPORTATION				
TRUCK	TON MI	146.0000	0.002400	0.35
			SUBTOTAL	0.35
(4) SHREDDING AND SEPARATION				
DISTILLATE FUEL OIL	GAL	0.4140	0.139000	0.06
ELECTRICAL ENERGY	KW HR	36.0000	0.010500	0.38
2110 WELDING ROD	NET TON	0.0001	30.000000	0.00
			SUBTOTAL	0.44
(5) TRANSPORTATION				
TRUCK	TON MI	89.0000	0.002400	0.21
RAIL	TON MI	208.0000	0.000670	0.14
			SUBTOTAL	0.35
* TOTAL ENERGY PER NET TON OF AUTO SCRAP FROM SHREDDING (AUTO SHRED)				1.28

TABLE 23. - Iron and steel: Automotive scrap preparation by guillotine shearing

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
		0.0000	0.000000	0.00
			SUBTOTAL	0.00
(2) FLATTENING				
DISTILLATE FUEL OIL	GAL	0.9800	0.139000	0.14
			SUBTOTAL	0.14
(3) TRANSPORTATION				
TRUCK	TON MI	58.0000	0.002400	0.14
			SUBTOTAL	0.14
(4) GUILLOTINE SHEARING				
ELECTRICAL ENERGY	KW HR	8.3000	0.010500	0.09
			SUBTOTAL	0.09
(5) TRANSPORTATION				
TRUCK	TON MI	71.0000	0.002400	0.17
RAIL	TON MI	166.0000	0.000670	0.11
			SUBTOTAL	0.28
* TOTAL ENERGY PER NET TON OF AUTO SCRAP FORM GUILLOTINE SHEARING				0.65

TABLE 24. - Iron and steel: Scrap preparation by guillotine shearing

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	58.0000	0.002400	0.14
			SUBTOTAL	0.14
(2) GUILLOTINE SHEARING				
ELECTRICAL ENERGY	KW HR	8.3000	0.010500	0.09
			SUBTOTAL	0.09
(3) TRANSPORTATION				
TRUCK	TON MI	71.0000	0.002400	0.17
RAIL	TON MI	166.0000	0.000670	0.11
			SUBTOTAL	0.28
* TOTAL ENERGY PER NET TON OF SCRAP FROM GUILLOTINE SHEARING (GUIL)				0.51

TABLE 25. - Iron and steel: Ferrous scrap preparation by baling

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	139.0000	0.002400	0.33
			SUBTOTAL	0.33
(2) BALING				
ELECTRICAL ENERGY	KW HR	5.6000	0.010500	0.06
			SUBTOTAL	0.06
(3) TRANSPORTATION				
RAIL	TON MI	198.0000	0.000670	0.13
TRUCK	TON MI	85.0000	0.002400	0.20
			SUBTOTAL	0.33
* TOTAL ENERGY PER NET TON OF SCRAP FROM BALING (BALING)				0.72

TABLE 26. - Iron and steel: Ferrous scrap preparation by alligator shearing

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	30.0000	0.002400	0.07
			SUBTOTAL	0.07
(2) ALLIGATOR SHEARING				
ELECTRICAL ENERGY	KW HR	10.0000	0.010500	0.11
			SUBTOTAL	0.11
(3) TRANSPORTATION				
TRUCK	TON MI	77.0000	0.002400	0.18
RAIL	TON MI	161.0000	0.000670	0.11
			SUBTOTAL	0.29
TOTAL ENERGY PER NET TON OF SCRAP FROM ALLIGATOR SHEARING(ALLIG)				0.47

TABLE 27. - Iron and steel: Purchased scrap preparation by torch cutting

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	10.0000	0.002400	0.02
			SUBTOTAL	0.02
(2) TORCH CUTTING				
OXYGEN	CU. FT.	73.0000	0.000150	0.01
ACETYLENE	CU. FT.	5.6000	0.002400	0.01
			SUBTOTAL	0.02
(3) TRANSPORTATION				
TRUCK	TON MI	77.0000	0.002400	0.18
RAIL	TON MI	181.0000	0.000670	0.12
			SUBTOTAL	0.30
* TOTAL ENERGY PER NET TON OF SCRAP FROM TORCH CUTTING (PURCH. TORCH)				0.34

TABLE 28. - Iron and steel: Home scrap preparation by torch cutting

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TORCH CUTTING (0.30 TON)				
OXYGEN	CU. FT.	73.0000	0.000150	0.01
ACETYLENE	CU. FT.	5.6000	0.002400	0.01
			SUBTOTAL	0.02
* TOTAL ENERGY PER NET TON OF HOME SCRAP FROM TORCH CUTTING(HOME TORCH)				0.02

TABLE 29. - Iron and steel: Prompt industrial scrap from borings and turnings (crushing)

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	96.0000	0.002400	0.23
			SUBTOTAL	0.23
(2) CRUSHING (0.10 TON)				
ELECTRICAL ENERGY	KW HR	4.5000	0.010500	0.05
			SUBTOTAL	0.05
(3) TRANSPORTATION				
TRUCK	TON MI	75.0000	0.002400	0.18
			SUBTOTAL	0.18
* TOTAL ENERGY PER NET TON OF PROMPT SCRAP FROM CRUSHED BORINGS & TURN				0.46

TABLE 30. - Iron and steel: Electric arc furnace steelmaking with 100% scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) ELECTRIC ARC FURNACE				
SCRAP - AUTO GUIL	NET TON	0.0103	0.650000	0.01
SCRAP - AUTO SHRED	NET TON	0.0764	1.280000	0.10
SCRAP - ALLIG	NET TON	0.0914	0.470000	0.04
SCRAP - B & T	NET TON	0.1261	0.460000	0.06
SCRAP - BALING	NET TON	0.2534	0.720000	0.18
SCRAP - GUIL	NET TON	0.1956	0.510000	0.10
SCRAP - PURCH. TORCH	NET TON	0.1191	0.340000	0.04
SCRAP - HOME TORCH	NET TON	0.0510	0.020000	0.00
SCRAP - LOOSE & MISC.	NET TON	0.2337	0.460000	0.11
LIME	NET TON	0.0300	5.450000	0.16
LIMESTONE	NET TON	0.0100	0.104000	0.00
CARBON ELECTRODE	NET TON	0.0060	82.000000	0.49
REFRACTORY	NET TON	0.0130	26.600000	0.35
FERROMANGANESE	NET TON	0.0110	**	**
OXYGEN	CU. FT.	250.0000	0.000150	0.04
FLUORSPAR	NET TON	0.0050	1.590000	0.01
NATURAL GAS	CU. FT.	100.0000	0.001000	0.10
ELECTRICAL ENERGY	KW HR	500.0000	0.010500	5.25
			SUBTOTAL	7.04
(2) CONTINUOUS CASTING				
ELECTRIAL ENERGY	KW HR	25.0000	0.010500	0.26
NATURAL GAS	CU. FT.	605.0000	0.001000	0.61
REFRACTORIES	NET TON	0.0025	26.600000	0.07
OXYGEN	CU. FT.	750.0000	0.000150	0.11
			SUBTOTAL	1.05
* TOTAL PROCESS ENERGY				8.09
AIR POLLUITON CONTROL				
ELECTRICAL ENERGY	KW HR	22.9000	0.010500	0.24
			SUBTOTAL	0.24
WASTE DISPOSAL				
TRUCK	TON MI	0.4500	0.002400	0.00
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.24
SPACE HEATING				
NATURAL GAS	CU. FT.	0.0000	0.001000	0.00
			SUBTOTAL	0.00
* TOTAL SPACE HEATING ERERGY				0.00
* TOTAL ENERGY PER NET TON OF PRODUCT				8.33

** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE

TABLE 31. - Iron and steel: Gray iron casting by cupola process

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) CUPOLA FURNACE				
SCRAP - AUTO SHRED	NET TON	0.0500	1.280000	0.06
SCRAP - B & T	NET TON	0.0472	0.460000	0.02
SCRAP - BALING	NET TON	0.0468	0.720000	0.03
SCRAP - GUIL	NET TON	0.0868	0.510000	0.04
SCRAP - PURCH. TORCH	NET TON	0.0440	0.340000	0.01
SCRAP - MACH. CUP. C.I.	NET TON	0.0624	0.460000	0.03
SCRAP - CAST IRON BORINGS	NET TON	0.0732	0.460000	0.03
SCRAP - MOTOR BLOCKS	NET TON	0.0390	0.460000	0.02
SCRAP - LOOSE & MISC.	NET TON	0.3506	0.460000	0.16
SCRAP - HOME	NET TON	0.8300	0.020000	0.02
PIG IRON	NET TON	0.1800	23.180000	4.17
LIMESTONE	NET TON	0.0750	0.104000	0.01
FOUNDRY COKE	NET TON	0.3000	33.000000	9.90
FERROSILICON	NET TON	0.0300	**	**
FERROMANGANESE	NET TON	0.0150	**	**
REFRACTORIES	NET TON	0.0200	26.600000	0.53
OXYGEN	CU. FT.	600.0000	0.000150	0.09
ELECTRICAL ENERGY	KW HR	100.0000	0.010500	1.05
			SUBTOTAL	16.17
(2) MOLDING AND COREMAKING				
SAND (NEW)	NET TON	0.6500	0.042000	0.03
BENTONITE	NET TON	0.0700	1.200000	0.08
TAR (OIL-BASED BINDERS)	GAL	5.8700	0.160000	0.94
TAR (CARBONACEOUS ADD.)	GAL	26.7000	0.160000	4.27
ELECTRICAL ENERGY	KW HR	16.0000	0.010500	0.17
NATURAL GAS (EQUI)	CU. FT.	1900.0000	0.001000	1.90
			SUBTOTAL	7.39
(3) CASTING, SHAKEOUT AND CLEANING				
REFRACTORIES	NET TON	0.0060	26.600000	0.16
INOCULANTS	LB	5.0000	**	**
OXYGEN	CU. FT.	100.0000	0.000150	0.02
ACETYLENE	CU. FT.	12.0000	0.002400	0.03
NON-METALLIC ABRASIVES	LB	2.0000	0.040000	0.08
METALLIC ABRASIVES	LB	15.0000	0.017500	0.26
2110 WELDING ROD	NET TON	0.0010	30.000000	0.03
ELECTRICAL ENERGY	KW HR	20.0000	0.010500	0.21
NATURAL GAS (EQUI)	CU. FT.	600.0000	0.001000	0.60
			SUBTOTAL	1.39
* TOTAL PROCESS ENERGY				24.95
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	160.0000	0.010500	1.68
NATURAL GAS	CU. FT.	500.0000	0.001000	0.50
			SUBTOTAL	2.18
* TOTAL POLLUTION CONTROL ENERGY				2.18
SPACE HEATING				
ELECTRICAL ENERGY	KW HR	4.0000	0.010500	0.04
NATURAL GAS (EQUI)	CU. FT.	4500.0000	0.001000	4.50
			SUBTOTAL	4.54
* TOTAL SPACE HEATING ENERGY				4.54
* TOTAL ENERGY PER NET TON OF PRODUCT				31.67

** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE

Transportation

Transportation can be accomplished by rail, truck, or barge. The actual means of transportation are dictated by a number of considerations, including freight rates, volume shipped, distances, and vehicle availability. Actual shipping distances vary widely, depending on the type of scrap, market condition, locality, availability of scrap, and the like. For example, in several scrap processing plants a typical incoming distance for shredder scrap is about 100 miles, but it may range from as low as 5 miles to more than 400 miles. Likewise the final shredded product may be consumed a few miles away or shipped more than 300 miles domestically. The final product shipping distance is highly dependent on spot price conditions which vary from day to day. On the average, scrap transportation energy amounts to an estimated 0.46 million Btu per ton of product.

Materials Handling

Materials handling, although less energy-intensive than transportation, has energy requirements similar to those of the other scrap preparation steps. Since this energy is consumed in the scrapyard, it is included with processing energy. Cranes are the most widely used type of equipment for this purpose and can be classified as fixed, traveling, or mobile. In addition, many yards also use forklifts for materials handling, and conveyors for feeding equipment and discharging processed scrap.

Scrap Preparation Operations

The scrap-processing operations are less energy-intensive than those of transporation and materials handling. On a "per ton" basis, crushing or shredding machine shop turnings is the most energy-consuming operation: 0.05 million Btu per ton. However, it is estimated that only 10% of carbon steel turnings are crushed.

Automobile shredding is the only other iron and steel or ferrous scrap preparation process that requires a significant amount of energy. Shredders are equipped with large electric motors with ratings up to 6,000 hp. These motors draw 40% of their rated capacity even when idling, so that a sufficiently fast feeding system is highly desirable. Typically, a shredder requires about 40 kwhr or 0.44 million Btu per ton of shredded ferrous scrap.

Scrap items that undergo little or no processing require an estimated 0.46 million Btu per ton for transportation as mentioned above in the section on transportation. Such items include machine cupola cast iron, motor blocks, cast iron borings, and loose and miscellaneous scrap categories.

Electric Furnace

The electric furnace is becoming increasingly efficient as a result of the increased use of ultra-high-power furnaces to decrease melting time, and use of oxygen lancing to decrease the refining time. Better charging practices reduce the charging time. Thus heat losses and refractory damage due to idle time are decreasing. The present arcing energy required in an electric furnace averages about 500 kwhr per ton or 5.25 million Btu per ton of product.

Cupola

The cupola uses about 375 pounds of very high-quality coke per ton of charge, which translates into 600 pounds of coke per ton of casting owing to the typical low-yield foundry operations. The operating variables shown in table 31 are adapted from a recent study (1).

Major Heat Losses

Ferrous scrap is typically prepared outdoors and does not include any heating process; the heat losses, therefore, occur during melting, refining, and casting. Following is an outline of the major heat losses, as well as the major parameters influencing them.

Electric Furnace

The electric furnace loses heat with the gases coming off the furnace, with the slag, and through the shell. The heat loss through the shell and with the gases is essentially a function of heat time, so that any measure reducing the heat time will reduce these losses on a per-ton basis. Such measures include the use of an ultrahigh power supply, oxygen lancing, and quick modern charging systems. Good scrap segregation and chemical analysis also help bring the heat quickly to target chemistry and temperature. A well-designed air pollution control system finally keeps the quantity of air drawn through the furnace at a minimum.

Cupola

The cupola loses heat with the offgas, with the slag, and through the shell. Due to the nature of this countercurrent process, the heat lost in the offgas is not considerable. However, the offgas contains a small amount of CO that is sometimes oxidized to CO_2 in an afterburner. The heat generated in the latter device is lost, unless a heat recuperating device is installed.

Ladle Drying and Preheating

Ladles are dried and preheated by exposing them to the flame of an oil or natural gas burner. This operation is carried out in the open and is very inefficient, inasmuch as most of the combustion heat is not transferred to the ladle. Some operators are considering enclosing this operation to save energy.

Casting

Ingots must be held for extensive periods of time in soaking pits to insure temperature uniformity before breakdown into billets, blooms, or slabs. Continuous slab or strand casting eliminates ingot soaking and breakdown and thus eliminates this energy-intensive step while improving yield. Consequently, continuous casting is a more energy-efficient method of producing semifinished steel products.

Research and Development

During the course of this study a number of potential research areas emerged:

1. Finding additional uses for the nonmetallic material collected in the shredder cyclones. This material consists of plastics, padding material, dirt, and the like. It is claimed to have a high heating value, but a large PVC content makes incineration impractical because of air pollution control problems. Separating the various plastics by type (polyurethane, etc.) is another possibility that is presently being investigated by the Bureau of Mines at its Metallurgy Research Center in Salt Lake City, Utah.

2. Improving the techniques for sorting the nonferrous metal stream from shredders. Currently, this sorting is largely done by hand. Although dense media separators can classify these materials by type of base metal (Al, Cu, Zn, etc.), they cannot distinguish between alloys.

3. Tapping new sources of scrap. However, new sources are difficult to identify. One example in which technical difficulties preclude recycling occurs when metals are left in abandoned mines and there is danger to the personnel performing the salvage. Scrap recovered from municipal refuse is another example of a new source of scrap, but a variety of technical and institutional obstacles have yet to be resolved before this material finds a wider use in the steel industry.

4. Counteracting the gradual buildup of the less oxidizable impurities (Cu, Ni, Sn, Mo, As, Cb, and W) as scrap is recycled over and over again. Research in several areas would help alleviate this problem:

   a. Improving segregation techniques,

   b. Finding new alloys that contain increased amounts of these residual elements,

   c. Perfecting the use of prereduced pellets in electric furnaces whereby their very low-impurity content has a diluting effect when melting large amounts of purchased scrap,

   d. Developing a method of oxidizing carbonaceous particles and CO to CO_2 at the top of a cupola to eliminate the need for an afterburner or recover the heat values generated in the afterburner, and

   e. Increasing the efficiency of a cupola. For example, there are a number of ways to decrease coke consumption in a cupola such as by preheating the air, injecting fuel (natural gas or oil), and enriching the blast with oxygen.

5. Improving the casting practice in a foundry to increase the yield, which will make a more energy-efficient operation.

Reference

1. Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4--Energy Data and Flowsheets, High-Priority Commodities). BuMines Open File Rept. 80-75, 1975, 192 pp.; available for consultation at Bureau of Mines facilities in Albany, Oreg., Avondale, Md., Reno and Boulder City, Nev., Rolla, Mo., Salt Lake City, Utah, Tuscaloosa, Ala., and Twin Cities, Minn.; and at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 245 759.

LEAD

Background

Table 32 gives data on the secondary lead industry.

TABLE 32. - Data on secondary lead industry

	Net tons[1]
Secondary raw materials (1976):	
Prompt industrial scrap (recovered lead)	100,000
Obsolete scrap (recovered lead)	570,000
Secondary U.S. production (1976)	670,000

[1]All figures are rounded to the nearest thousand.

NOTE.--Commodity: Lead.
Primary products: Hard lead, soft lead, remelt lead.
Byproducts: None.
Coproducts: None.

Source: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys, 1976.

Types and Classifications of Scrap

Lead scrap can be classified into the following categories: Battery plate and separator scrap (old battery scrap and battery manufacturers' scrap), drosses and skimmings, and general lead scrap (solder, babbitt, cable covering, type metal, and demolition sources).

Battery plate and separator scrap is by far the most significant of these categories with the major portion derived from old automobile batteries. Drosses and skimmings, which emanate primarily from tetraethyl lead and battery manufacturing operations, also contribute significantly to the total lead scrap. About 78% of the total secondary lead and lead alloys recovered in 1976 consisted of old scrap. (Table 33 shows details of the breakdown of lead-base scrap categories.)

TABLE 33. - Lead scrap consumption by smelters and refiners in 1976

Lead-base scrap	Consumption, thousand net tons recovered lead	Obsolete scrap,[1] %	Prompt industrial scrap, %
Battery plate and separator scrap	445	90	10
Prompt industrial scrap: Drosses and residues	105	0	100
Other scrap:			
Cable covering	45	100	0
Antimonial lead	27	100	0
Soft lead	28	100	0
Type metals	11	100	0
Common babbitt	6	100	0
Solder	3	100	0
Total	670	-	-

[1]Arthur D. Little, Inc., estimates based on percentage in each category for 1974 from Lead Chapter from Bureau of Mines 1974 Minerals Yearbook.

Sources: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys; and Arthur D. Little, Inc., estimates.

Products

The major products produced in the secondary lead industry are refined lead (soft lead), antimonial lead (hard lead), and remelt lead. Refined lead is produced from scrap from which elements like Sb, Cu, Sn, and As have been removed by a variety of techniques to a level consistent with the end-use of the metal. Antimonial lead is produced largely from battery plate and separator scrap. It contains 2% to 7% Sb and small controlled quantities of As, Cu, and Sn. Remelt lead, containing 96% to 99% elemental lead, is melted general lead scrap. Small quantities of secondary lead also report as lead alloys like solder and babbitt. In 1976 about 52% of secondary lead was in the form of antimonial lead, and about 35% was soft lead.

Scrap Preparation

In this analysis, secondary lead scrap is classified into three groups: Whole battery scrap, including prompt whole battery scrap (battery plate and separator scrap); prompt industrial scrap, such as drosses, skimmings, and lugs; and other scrap, such as cable sheathings and old appliance parts.

Whole battery scrap is customarily decased by one of two methods--sawing or guillotining--to produce battery plate and separator scrap. A power conveyor is used to move batteries from a storage platform or trailer to either a vertical or horizontal saw blade. In the decasing operation the connectors and posts of the battery section are sawed loose from the case. Guillotining is accomplished in almost the same manner, except the batteries are laid on their side and the tops are sheared off. The batteries are then lifted by hand, turned over, and hit against a striker bar to allow the plates, separators, and acid to fall onto a vibrating conveyor which feeds into a storage bin. 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 with the resulting crushed material then being fed to an air separator where metallic posts and connectors are separated from the casing material. The battery cases are crushed to facilitate loading and removal. The scrap prepared from this operation is called plate and separator scrap. This energy analysis considers the sawing technique, recognizing that the differential energy requirements between sawing and guillotining are small.

According to some industry representatives, 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 (2), consists of acid removal by cracking the whole battery before charging it to the smelting furnace. However, since this scheme is not practiced in the United States, it is excluded from this analysis.

Prompt industrial scrap (excluding whole battery scrap) needs no preparation before processing in the furnaces. Most of the general lead scrap like cable sheathing also requires little preparation. In this analysis it is assumed that no energy is consumed in preparing general lead scrap, except for transportation.

Smelting and Refining

Major Processing Methods

Basically, lead scrap is treated by three major smelting schemes: Blast furnace, reverb/blast furnace combination, and pot melting.

Blast Furnace

The blast furnace is the workhorse of the secondary lead industry and is shown in figure 31. It is similar in construction to the cupola used in the iron industry. The secondary lead blast furnace has cross-sectional areas ranging from 5 to 16 square feet at the tuyeres and has water-jacketed smelting zones. The shaft above the water jacket is refractory-lined. The charge, entering at the top of the furnace, 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 using a siphon tap. 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 found in the slag, matte, and dust.

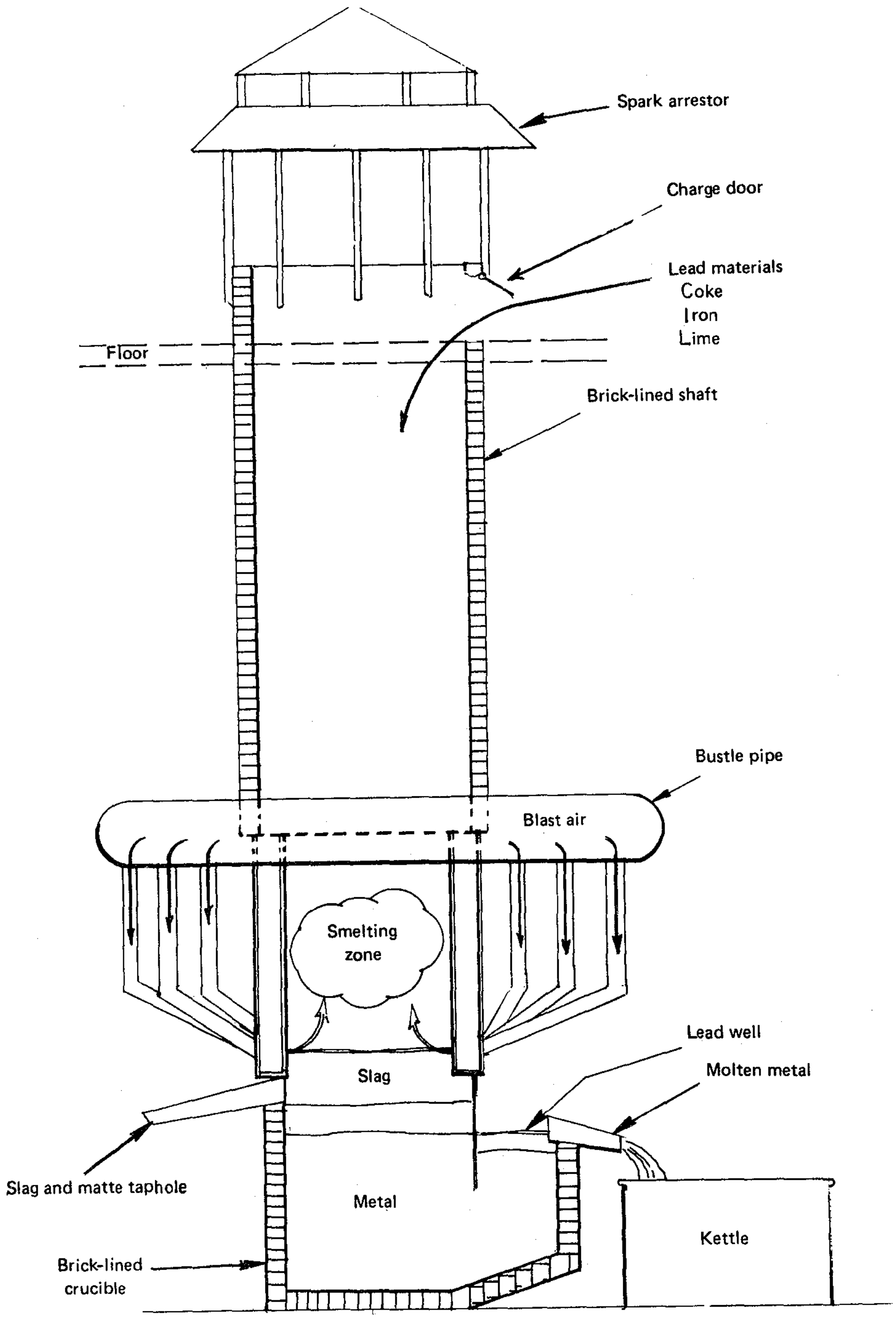


FIGURE 31. - Secondary lead blast furnace.

Reverb/Blast Furnace

The reverb furnace scheme involves a reverb furnace which processes most of the incoming lead scrap, while the blast furnace is used largely to recover lead values from the reverb furnace slag. The reverb furnace is a refractory-lined, shallow-hearth, rectangular structure that is fired from one end with natural gas or oil. It is side-charged. Offgases from the furnace are cooled from 1,400°-2,100° F to 250°-300° F by radiation and water cooling. The dust in offgases is collected in baghouses and recycled. The reverb furnace produces a low antimony lead (less than 1% Sb) and a high antimony slag (5% to 9% Sb, 65% to 90% Pb). 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 includes from 2% to 7% Sb.

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 NaOH, S, and $NaNO_3$, with alloying elements, such as Cu, Sn, Sb, and As, are added to the kettle charge to refine the lead and produce customer specification product. 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.

Pot Melting

Pot melting involves melting general lead scrap in an indirectly fuel-fired cast iron kettle. This process is used whenever the quality of lead is unimportant (96% to 99% Pb), for example, boat keels and weights. Lead recovery in this process is over 90%. Pot melting operations handle very small quantities of lead compared with other smelting schemes described above.

All three of the major processing schemes are discussed in the energy analysis.

Other Processing Methods

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% to 80% Pb and therefore has to be treated by a blast furnace at another smelter to recover the lead. Because a reverb furnace is not a complete lead-recycling process scheme in itself, it was not analyzed independently in this study, but energy requirements are found in the reverb/blast furnace scheme shown in figure 35.

The recent introduction of maintenance-free batteries has brought into the market a certain amount of new 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.

Energy Analysis

Lead energy analyses are presented for the following: Producing hard lead by the blast furnace process; producing hard and soft leads by the reverb/blast furnace scheme; and pot melting general lead scrap.

Since industry sources indicated that refractory usage was small per ton of product, it is not shown in this analysis. Any scrap iron consumed in the blast furnace process is lost as slag. Therefore, it is assigned an energy value of 18 million Btu per ton--a figure obtained from an earlier study (1).

Producing Hard Lead by Blast Furnace Process

Energy diagrams and analyses are presented in figures 32-34 and tables 34-36. Figures 32-33 and tables 34-35 represent scrap preparation and transportation analyses. Figure 34 and table 36 represent the smelting, refining, and casting segments of the blast furnace process.

TABLE 34. - Lead: Preparing broken battery scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
TRUCK (100.0 MILES)	TON ML	100.0000	0.002400	0.24
			SUBTOTAL	0.24
(2) BATTERY BREAKING				
ELECTRICAL ENERGY	KW HR	10.0000	0.010500	0.11
			SUBTOTAL	0.11
* TOTAL PROCESS ENERGY				0.35
WATER POLLUTION CONTROL				
LIME	NET TON	0.0300	8.500000	0.26
			SUBTOTAL	0.26
SOLID WASTE DISPOSAL				
TRUCK	TON MI	5.0000	0.002400	0.01
			SUBTOTAL	0.01
* TOTAL POLLUTION ENERGY				0.27
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				0.62

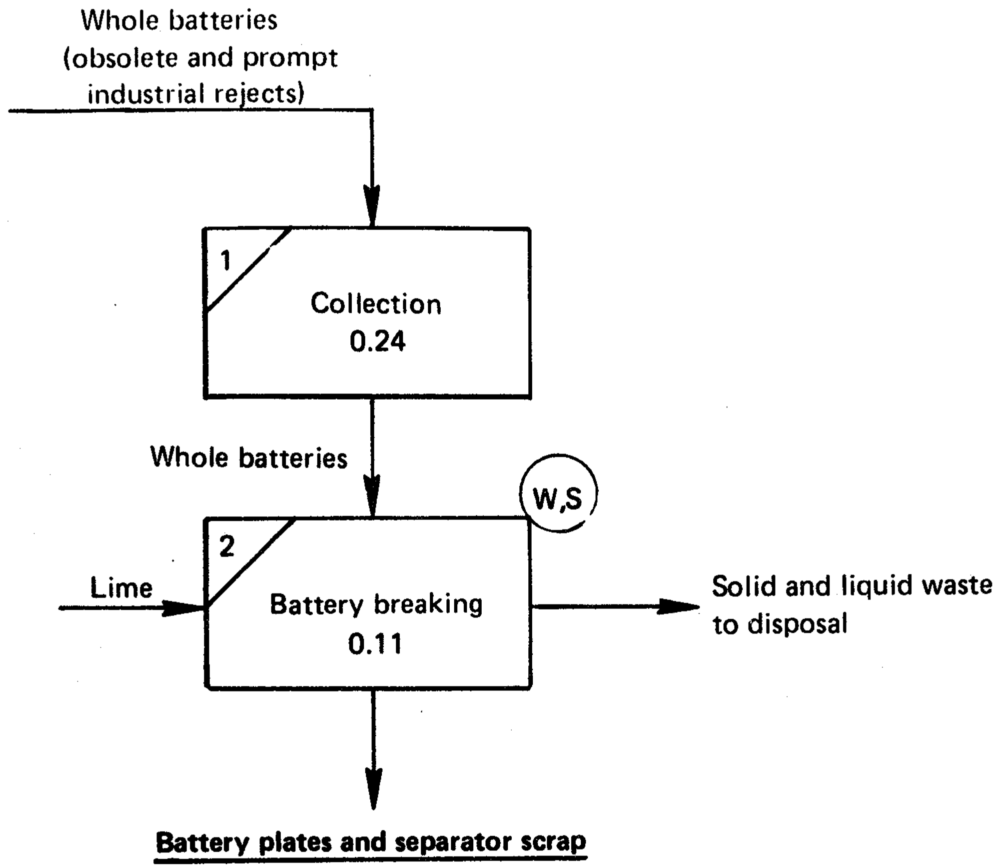
TABLE 35. - Lead: Preparing prompt industrial and general scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
TRUCK (100.0 MILES)	TON ML	100.0000	0.002400	0.24
			SUBTOTAL	0.24
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				0.24

TABLE 36. - Lead: Producing hard lead by blast furnace process

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) BLAST FURNACE				
BROKEN BATTERY SCRAP	NET TON	1.1000	0.620000	0.68
PROMPT INDUSTRIAL SCRAP	NET TON	0.2000	0.240000	0.05
GENERAL LEAD SCRAP	NET TON	0.1000	0.240000	0.02
SCRAP IRON	NET TON	0.1100	18.000000	1.98
LIMESTONE	NET TON	0.0100	0.104000	0.00
SAND	NET TON	0.0100	0.042000	0.00
FOUNDRY COKE	NET TON	0.0900	33.000000	2.97
ELECTRICAL ENERGY	KW HR	30.0000	0.010500	0.32
PROPANE	LB.	0.3000	0.021500	0.01
GASOLINE	GAL	0.5000	0.125000	0.06
DISTILLATE FUEL OIL	GAL	0.5000	0.139000	0.07
			SUBTOTAL	6.16
(2) KETTLES				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
NATURAL GAS	CU. FT.	1100.0000	0.001000	1.10
FOUNDRY COKE	NET TON	0.0005	33.000000	0.02
ARSENIC TRIOXIDE	NET TON	0.0002	**	**
CAUSTIC SODA	NET TON	0.0020	29.900000	0.06
TIN	NET TON	0.0010	**	**
NITER (NANO3)	NET TON	0.0030	42.250000	0.13
ANTIMONY METAL	NET TON	0.0004	**	**
COPPER (SCRAP)	NET TON	0.0000	**	**
			SUBTOTAL	1.36
(3) CASTING				
ELECTRICAL ENERGY	KW HR	7.0000	0.010500	0.07
			SUBTOTAL	0.07
* TOTAL PROCESS ENERGY				7.59
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	65.0000	0.010500	0.68
NATURAL GAS	CU. FT.	1300.0000	0.001000	1.30
			SUBTOTAL	1.98
SOLID WASTE DISPOSAL				
TRUCK	TON MI	3.0000	0.002400	0.01
			SUBTOTAL	0.01
* TOTAL POLLUTION CONTROL ENERGY				1.99
SPACE HEATING				
NATURAL GAS	CU. FT.	70.0000	0.001000	0.07
			SUBTOTAL	0.07
* TOTAL SPACE HEATING ENERGY				0.07
* TOTAL ENERGY PER NET TON OF PRODUCT				9.65

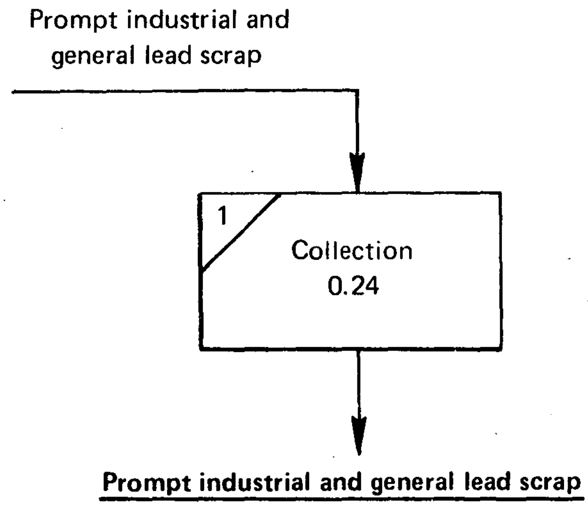
** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE



SUMMARY

	Million Btu per ton of product
Process energy	0.35
Pollution control energy	.27
Space heating	.00
Total energy	.62

FIGURE 32. - Lead: Preparing broken battery scrap.

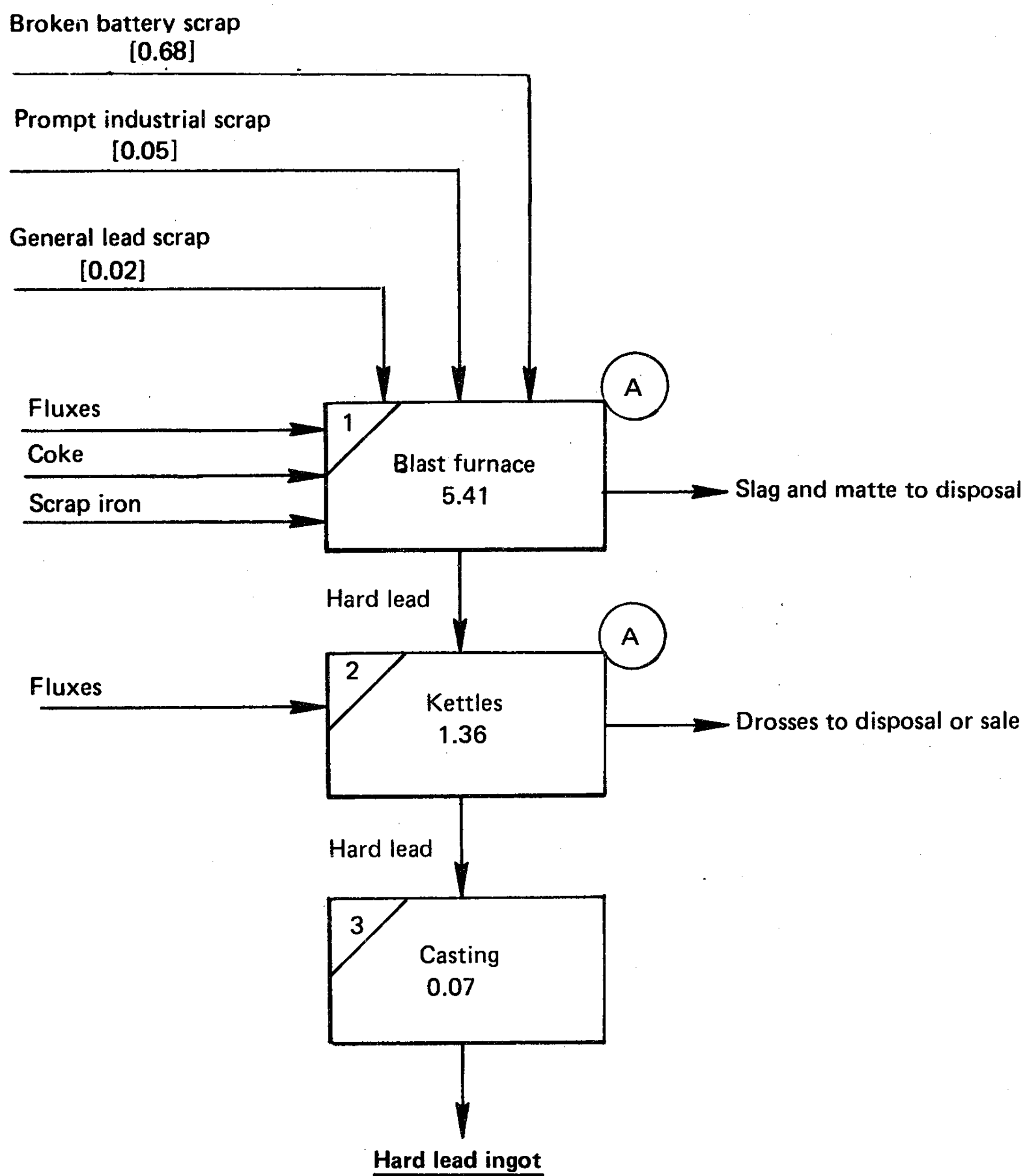


SUMMARY

	Million Btu per ton of product
Process energy	0.24
Pollution control energy	.00
Space heating	.00
Total energy	.24

FIGURE 33. - Lead: Preparing prompt industrial and general lead scrap.

Distribution of energy required in the blast furnace is approximately as follows: Coke accounts for 31% of the total energy; kettle fuel, 12%; scrap iron, 21%; and pollution control, 21%. The total energy requirement of the blast furnace process is 9.65 million Btu per ton of lead.



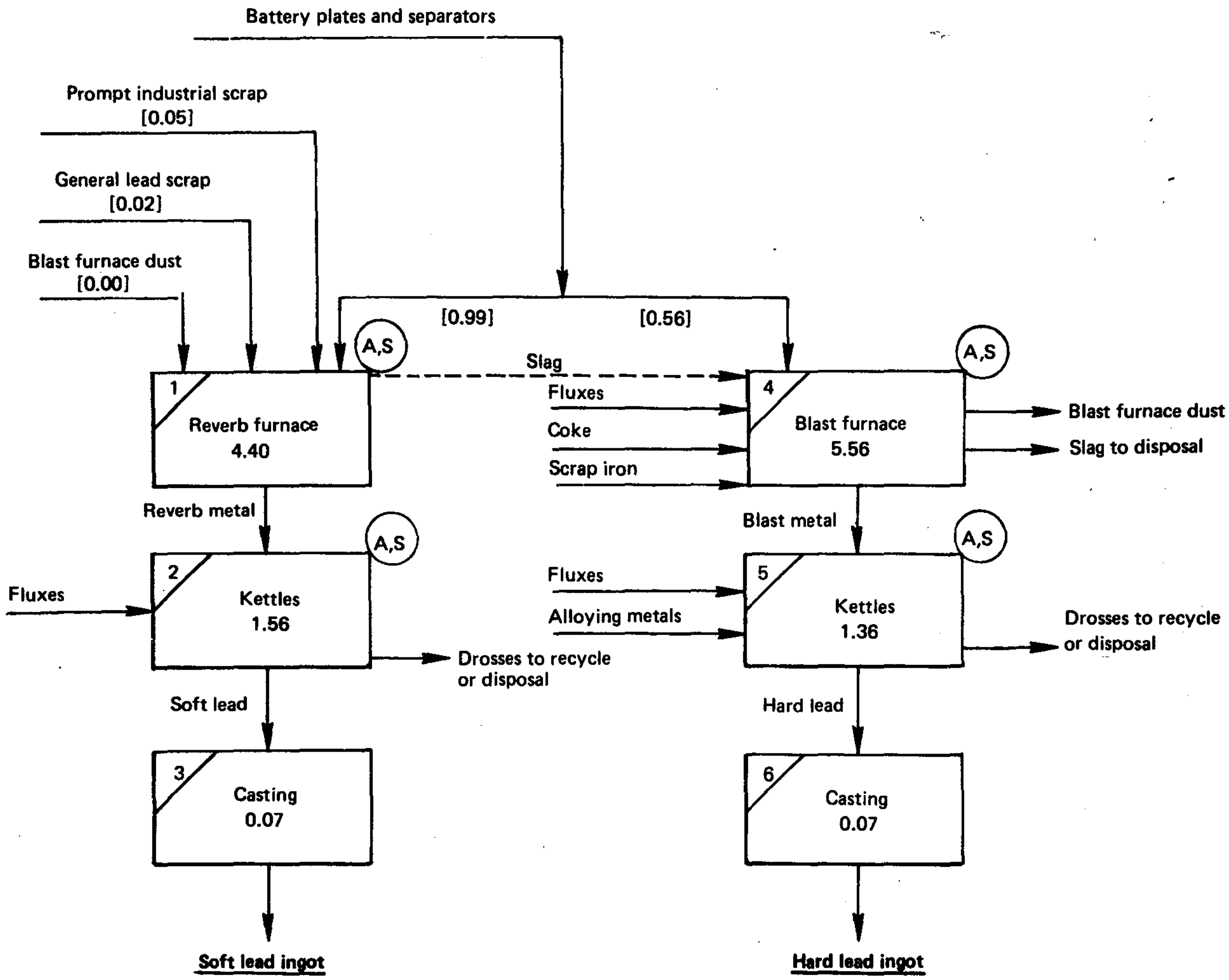
SUMMARY

	Million Btu per ton of product
Process energy	7.59
Pollution control energy	1.99
Space heating	.07
Total energy	9.65

FIGURE 34. - Lead: Producing hard lead by blast furnace process.

Producing Hard and Soft Lead by Reverb/Blast Furnace Scheme

The energy diagrams and analysis are shown in figures 32-33, and 35 and tables 34-35 and 37. Tables 34-35 and figures 32-33 represent scrap preparation and transportation analyses. Figure 35 and table 37 represent the process scheme that produces both hard and soft lead. Steps 1-3 in table 37 represent the production of soft lead by the reverb section of the process, and steps 4-6 in table 37 represent hard lead production by the blast furnace section. The energy content of lead in the reverb slag transferred to the blast furnace is assumed to be zero in this analysis.



SUMMARY

	Million Btu per ton of product
Process energy	7.09
Pollution control energy	.89
Space heating	.07
Total energy	8.05

SUMMARY

	Million Btu per ton of product
Process energy	7.55
Pollution control energy	1.99
Space heating	.07
Total energy	9.61

FIGURE 35. - Lead: Producing secondary lead by reverb/blast furnace process.

TABLE 37. - Lead: Producing secondary lead by reverb/blast furnace process

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) REVERBERATORY FURNACE				
BROKEN BATTERY SCRAP	NET TON	1.6000	0.620000	0.99
PROMPT INDUSTRIAL SCRAP	NET TON	0.2000	0.240000	0.05
GENERAL LEAD SCRAP	NET TON	0.1000	0.240000	0.02
BLAST FURNACE DUST	NET TON	0.1000	0.000000	0.00
NATURAL GAS	CU. FT.	4000.0000	0.001000	4.00
ELECTRICAL ENERGY	KW HR	25.0000	0.010500	0.26
PROPANE	LB.	0.3000	0.021500	0.01
GASOLINE	GAL	0.5000	0.125000	0.06
DISTILLATE FUEL OIL	GAL	0.5000	0.139000	0.07
			SUBTOTAL	5.46
(2) KETTLES				
NATURAL GAS	CU. FT.	1300.0000	0.001000	1.30
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
CAUSTIC SODA	NET TON	0.0020	29.900000	0.06
NITER (NANO3)	NET TON	0.0030	42.250000	0.13
ALUMINUM	NET TON	0.0006	**	**
ZINC	NET TON	0.0014	**	**
FOUNDRY COKE	NET TON	0.0005	33.000000	0.02
			SUBTOTAL	1.56
(3) CASTING				
ELECTRICAL ENERGY	KW HR	7.0000	0.010500	0.07
			SUBTOTAL	0.07
* TOTAL PROCESS ENERGY				7.09
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	85.0000	0.010500	0.89
			SUBTOTAL	0.89
* TOTAL POLLUTION CONTROL ENERGY				0.89
SPACE HEATING				
NATURAL GAS	CU. FT.	70.0000	0.001000	0.07
			SUBTOTAL	0.07
* TOTAL SPACE HEATING ENERGY				0.07
* TOTAL ENERGY PER NET TON OF PRODUCT				8.05

** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE

TABLE 37. - Lead: Producing secondary lead by reverb/blast furnace process--Continued

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(4) BLAST FURNACE				
BROKEN BATTERY SCRAP	NET TON	0.9000	0.620000	0.56
REVERBERATORY SLAG	NET TON	0.6000	0.000000	0.00
SCRAP IRON	NET TON	0.1000	18.000000	1.80
FOUNDRY COKE	NET TON	0.1000	33.000000	3.30
LIMESTONE	NET TON	0.0100	0.104000	0.00
SAND (SILICA SAND)	NET TON	0.0100	0.042000	0.00
ELECTRICAL ENERGY	KW HR	30.0000	0.010500	0.32
PROPANE	LB.	0.3000	0.021500	0.01
GASOLINE	GAL	0.5000	0.125000	0.06
DISTILLATE FUEL OIL	GAL	0.5000	0.139000	0.07
			SUBTOTAL	6.12
(5) KETTLES				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
CAUSTIC SODA	NET TON	0.0020	29.900000	0.06
NATURAL GAS	CU. FT.	1100.0000	0.001000	1.10
NITER (NANO3)	NET TON	0.0030	42.250000	0.13
ARSENIC TRIOXIDE	NET TON	0.0002	**	**
TIN	NET TON	0.0010	**	**
ANTIMONY METAL	NET TON	0.0004	**	**
FOUNDRY COKE	NET TON	0.0005	33.000000	0.02
			SUBTOTAL	1.36
(6) CASTING				
ELECTRICAL ENERGY	KW HR	7.0000	0.010500	0.07
			SUBTOTAL	0.07
* TOTAL PROCESS ENERGY				7.55
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	65.0000	0.010500	0.68
NATURAL GAS	CU. FT.	1300.0000	0.001000	1.30
			SUBTOTAL	1.98
SOLID WASTE DISPOSAL				
TRUCK	TON MI	3.0000	0.002400	0.01
			SUBTOTAL	0.01
* TOTAL POLLUTION CONTROL ENERGY				1.99
SPACE HEATING				
NATURAL GAS	CU. FT.	70.0000	0.001000	0.07
			SUBTOTAL	0.07
* TOTAL SPACE HEATING ENERGY				0.07
* TOTAL ENERGY PER NET TON OF PRODUCT				9.61

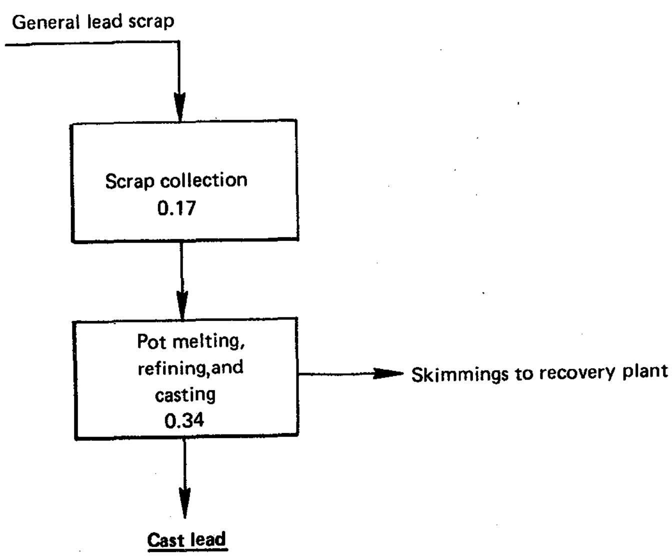
** = THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE

Analysis of this process is based on the production of 1 ton of soft lead for each ton of hard lead. This is approximately the average distribution of hard to soft lead for the industry for the reverb/blast furnace scheme. Energy requirements in the soft lead section of the flowsheet are distributed approximately as follows: Reverb furnace fuel accounts for 55% of the total energy; kettle fuel, 17%; and pollution control, 11%. The total energy requirement of the soft lead section is 8.05 million Btu per ton of soft lead.

The distribution of energy required in the hard lead section of the flowsheet is approximately as follows: Coke accounts for 35% of the total energy; scrap iron, 19%; kettle fuel, 12%; and pollution control, 21%. Total energy required to produce hard lead is estimated at 9.61 million Btu per ton of hard lead.

Pot Melting Lead Scrap

The energy analysis for this scheme is presented in figure 36 and table 38. Pot melting is essentially a one-step melting operation and practically all the energy is consumed in this step. Pot melting lead requires only 0.61 million Btu per ton of lead and is strictly a low-temperature melting scheme that involves no smelting reactions, slag formation, or refining steps. In contrast, the blast furnace and reverb/blast furnace process schemes require 8 to 10 million Btu per ton of lead and involve melting, reduction, smelting, slag formation, and refining operations. Therefore, these process schemes consume much more energy than pot melting. However, lead produced in pot melting is of much lower quality than that produced by the other two process schemes.



SUMMARY

	Million Btu per ton of product
Process energy	0.51
Pollution control energy	.00
Space heating	.10
Total energy	.61

FIGURE 36. - Lead: Producing cast lead by pot melting process.

TABLE 38. - Lead: Producing cast lead by pot melting process

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) COLLECTION				
TRUCK (70.0 MILES)	TON ML	70.0000	0.002400	0.17
			SUBTOTAL	0.17
2) POT MELTING REFINING AND CASTING				
NATURAL GAS	CU. FT.	340.0000	0.001000	0.34
			SUBTOTAL	0.34
* TOTAL PROCESS ENERGY				0.51
POLLUTION CONTROL ENERGY				
ELECTRICAL ENERGY	KW HR	0.0000	0.010500	0.00
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.00
SPACE HEATING				
NATURAL GAS	CU. FT.	100.0000	0.001000	0.10
			SUBTOTAL	0.10
* TOTAL SPACE HEATING ENERGY				0.10
* TOTAL ENERGY PER NET TON OF PRODUCT				0.61

Major Heat Losses

Major areas of heat losses in the various secondary lead process schemes are outlined below.

Blast Furnace

The blast furnace offgas temperature is as high as 600° to 800° F. Further, these gases are heated to between 1,200° and 1,400° F by a high-energy (about 1 million Btu per ton of lead) afterburner to complete combustion of CO, coke particles, etc. These gases are then cooled by radiation and external water-cooled towers to a temperature level of 275° to 300° F to make them suitable for baghouse cleaning. Therefore, all the heat in the offgases as well as that supplied by the afterburner is lost. In fact, heat losses in offgases account for the largest loss in the blast furnace process. In comparison, heat losses to slag, matte, and metal are small. Shell heat losses (including those in water cooling of the furnace melting zone) are also small in comparison.

Reverb Furnace

Just as in the case of the blast furnace, the offgases leaving the reverb furnace between 1,400° and 2,100° F are cooled by radiation and water-cooled towers before going to the baghouse. This accounts for the principal heat loss in the reverb furnace.

Pot Furnace

The pot melting of lead scrap has heat efficiency in the 10% to 15% range. Because of the indirect heating in this process scheme, a significant amount of heat is lost in the combustion gases. The efficiency of this system is somewhat improved by utilizing a small metal heel before melting a new charge, since the heel provides for transfer of heat by conduction and thermal connection to the new charge while it is melting.

Refining Kettles

The two principal forms of heat loss in the kettles are combustion products and radiation losses. The heat loss in the combustion products is by far the most important.

Research and Development

Potential areas of research and development in the secondary lead industry are as follows:

1. Developing a process scheme to treat the dust produced from the reverb and blast furnaces. In present practice, dust produced in the furnaces is recycled. However, it reduces the smelting capacities of the furnaces and is also a potential health hazard because of its chloride content. Reduction in the recirculating load of dust will also affect energy savings. Therefore, research is required to either pelletize the dust before charging to the furnaces, or treat the dust separately by hydrometallurgical or pyrometallurgical techniques to recover its lead values.

2. Developing an afterburner for the blast furnace process that does not use natural gas or oil. Examples include the use of an oxygen-based system or catalytic combustion system. Developing and implementing such a system could reduce energy use by 10% to 15% in the blast furnace scheme.

3. Charging whole battery scrap to the furnaces. This has been given limited study in Europe, and very little concrete data are available on the success or failure of this system. If successful, this system would reduce the handling of battery scrap. Charging whole battery scrap to the furnaces could also reduce the energy consumed in the process schemes, especially if the whole battery scrap includes plastic-cased batteries.

4. Utilizing furnace offgases to preheat furnace charge or preheating combustion air. This scheme, if successful, could save a significant amount of heat lost in the blast furnace and reverb offgases. The heat lost in the refining kettle offgases could also be utilized in this scheme.

5. Recovering the plastic from plastic-cased batteries as a salable byproduct. Some work in this area has been done by the Bureau of Mines.

References

1. Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4--Energy Data and Flowsheets, High-Priority Commodities). BuMines Open File Rept. 80-75, 1975, 192 pp.; available for consultation at Bureau of Mines facilities in Albany, Oreg., Avondale, Md., Reno and Boulder City, Nev., Rolla, Mo., Salt Lake City, Utah, Tuscaloosa, Ala., and Twin Cities, Minn.; and at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 245 759.

2. Mackey, T. S., and S. Bergsoe. Smelting of Unbroken Batteries. Pres. at the 106th Ann. Meeting, AIME, Atlanta, Ga., Mar. 9, 1977, 21 pp.

NICKEL AND NICKEL ALLOYS

Background

Little information is publicly available on the amounts of nickel-containing materials traded in the United States. The most comprehensive data are those published by the Bureau of Mines. Consumption, stock variations, and imports of broad categories of nickel products are reported in thousand pounds of nickel content in its Mineral Industry Survey monthly reports (2). The Bureau of Mines information was supplemented by conversations with industry experts in order to derive the numbers shown in table 39.

TABLE 39. - Data on secondary nickel industry

	Net tons[1]
Secondary raw materials (1976):[2]	
Old scrap	23,000
New scrap	34,500
U.S. production (1976)[3]	128,000

[1]All figures are rounded to the nearest hundred. All tons are net tons of nickel-bearing alloys unless otherwise indicated.
[2]Includes superalloys, nickel-copper alloys, other high-nickel alloys, and electroplating materials.
[3]Primary and secondary industries.

NOTE.--Commodity: Nickel and nickel alloys.
Primary products: Nickel and nickel alloy ingots.
Byproducts: None.
Coproducts: None.

Source: Bureau of Mines estimates.

Scrap preparation procedures and smelting techniques used in the secondary nickel industry are usually considered proprietary. The following energy analysis reflects the authors' best judgment on industry practice. Two scrap preparation flowsheets (turnings and solids) and two melting flowsheets (double vacuum melting of superalloys and single air induction melting of other alloys) have been selected. Other processes such as electric arc furnace and duplex electric arc furnace/argon oxygen decarburization (AOD) process are also briefly discussed.

Types and Classifications of Scrap

Nickel alloys may be classified in the following broad categories, recognizing that some alloys may fall into several of these groups (1).

Superalloys.--Superalloys exhibit high strength at high temperatures and are typically used in gas turbine engines. The nickel content can range from 20% to 80%. Typical nickel-base alloys are the Inconels, Hastelloys, and

Waspaloy.[17] Scrap superalloy takes the form of machine turnings and solids, such as turbine blades, disks, casting stubs and sprues. The aerospace industry generates most of the industrial superalloy scrap.

High-Nickel Alloys and Heating Element Alloys.--A number of nickel alloys are used in corrosion- or oxidation-resistance applications. The nickel content ranges from 20% to 100%. Prompt industrial scrap is generated at metalworking operations and obsolete scrap results from discarded industrial equipment.

Pure Nickel, Nickel-Copper Alloys.--Pure nickel scrap is generated in electroplating operations. Although the nickel used for plating is generally lost for recycling purposes, there are other ways in which the platers generate scrap. As the nickel anodes become depleted, the efficiency of the operation decreases so that spent anodes are removed from the bath when their weight reaches 15% to 20% of their initial weight. Since some nickel also accumulates on the racks holding the plated parts, both spent anodes and old racks are recycled as scrap. Other types of pure nickel scrap include sheet clippings, pipes, plates, and tubes from the petrochemical industry and from medical equipment. Pure nickel scrap belongs to the category termed "solids" which can be transported in boxes or in 55-gallon drums. It represents only a small percentage of the total nickel available for recycling.

Monels.--Monels are largely wrought alloys containing about two-thirds nickel and one-third copper. New scrap consists of clippings and trimmings, with less than 10% turnings. Obsolete scrap originates primarily at industrial plants in the form of tanks, heat exchanger tubes, valves, etc. Although cupronickels are not considered in this study, the recycling methods are similar to those used for Monels.

Miscellaneous.--There are a number of special alloys, such as thermocouple alloys and magnets, which are also recycled. Because either the volume is small or supply erratic, such alloys are not considered further in this study.

Other nickel scrap materials include residues, grinding swarf, sludges, and spent catalysts. These materials are either discarded or treated on an individual basis, and thus are not considered further in this study.

Contamination Problems

Superalloy scrap presents much the same contamination problems as titanium scrap, with two differences: (1) Tool bits left in superalloy turnings are not a problem because the bits dissolve during the melting and refining steps and can be tolerated in the final product, and (2) there is a much greater variety of superalloys, and an established market for obsolete superalloy scrap, including some alloys that are no longer in use.

Other nickel alloy scraps present much the same contamination problems as stainless steel, which is discussed in a later chapter.

[17]Reference to trade names is for identification only and does not imply endorsement by the Bureau of Mines.

Scrap Preparation

Superalloy Scrap

Superalloy scrap enjoys a worldwide market, with imports to the United States from most industrialized countries and exports predominantly to Japan and Germany. Depending upon its degree of cleanliness and segregation, prepared superalloy scrap either goes back to superalloy smelters or to the stainless steelmakers.

Turnings

As shown in figure 37, machine turnings or "chips" are transported by truck or railroad car to the processing plant, where they are crushed in a ring-type or hammer mill crusher. A representative sample of the lot is taken, quartered down to 15 to 20 pounds, and melted in a laboratory induction furnace. The resulting melt is cast into an ingot, which is cut and identified either by X-ray spectrography, optical emission spectrography, atomic absorption, or other suitable analytical techniques. The chips then are cleaned in a vapor degreaser (such as trichloroethylene). To meet customer specifications, the cleaned superalloy chips are screened to remove the dust and fines, which are sold to nickel refineries. The screened chips undergo a complete magnetic separation: A cross-belt magnet removes tramp iron, tool steel, chrome steel, and other highly magnetic contaminants. A high-intensity electromagnet removes very weak magnetic substances, such as austenitic stainless steels. After taking a final sample for quality control, the chips are loaded into boxes or 55-gallon drums for shipment to the customer.

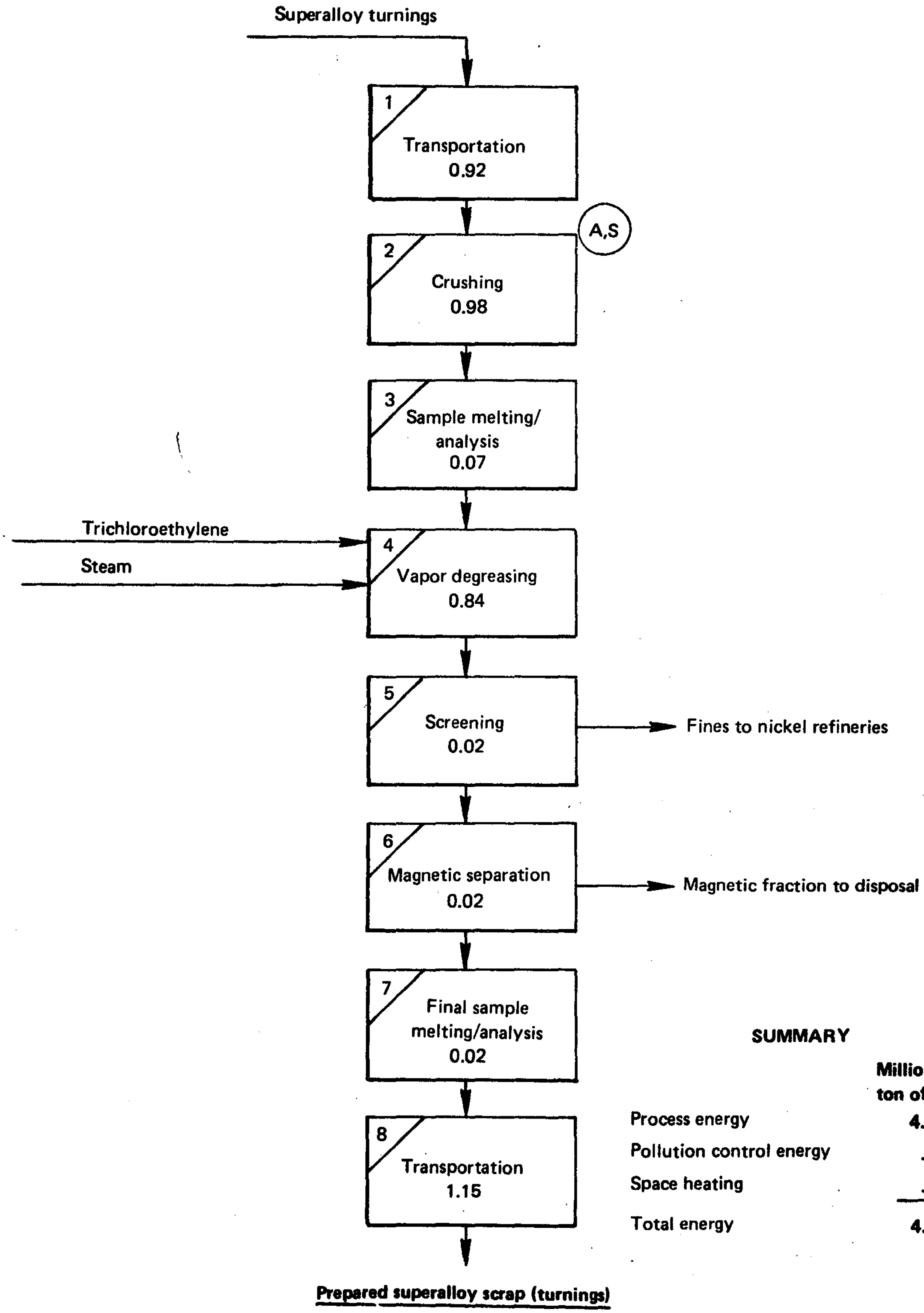
In addition, some turnings often consist of intermixed grades that do not find a ready market with U.S. superalloy melters. Such turnings find an outlet in the stainless steel industry and on foreign markets.

Solids

As shown in figure 38, solids are visually inspected and magnetically separated from tramp ferromagnetic pieces. The alloy type of each piece is recognized from such indications as shape, origin, response to spark, acids, or spectrography as needed. Heavy pieces are cut with a plasma torch; the scrap surface is cleaned by sand blasting. A wet scrubber collects the grit with resulting sludge most often landfilled. The superalloy solids are sent to the customer in boxes or in 55-gallon drums.

High-Nickel Alloys and Heating Element Alloys

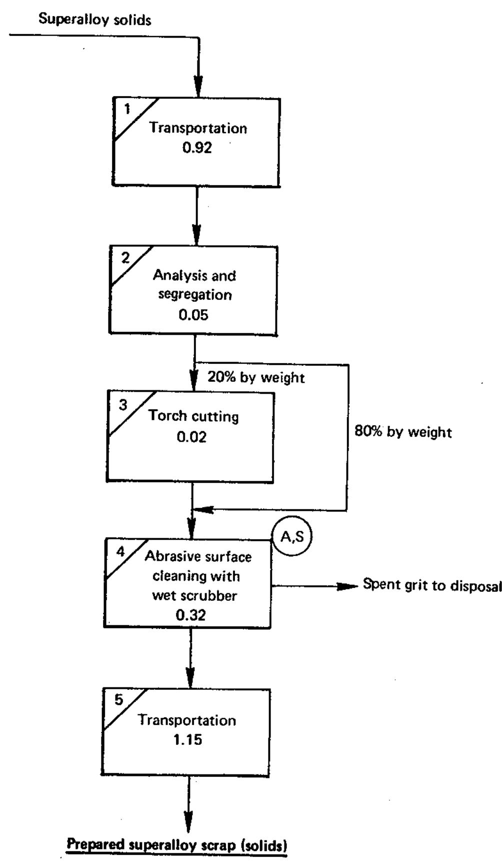
These scrap materials are processed and recycled in the same fashion as are stainless steels (as discussed in the next chapter).



SUMMARY

	Million Btu per ton of product
Process energy	4.02
Pollution control energy	.00
Space heating	.00
Total energy	4.02

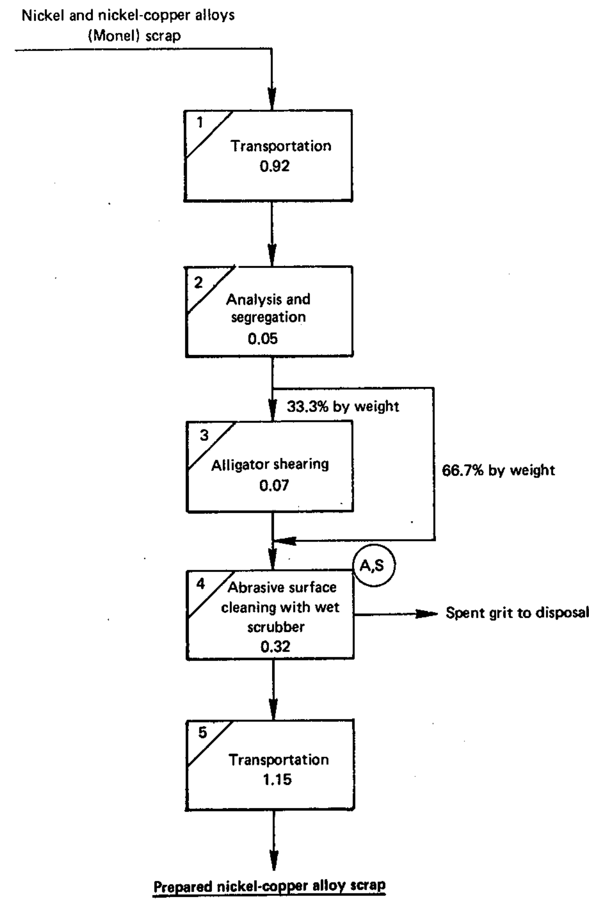
FIGURE 37. - Nickel alloys: Preparing nickel alloy scrap from superalloy turnings.



SUMMARY

	Million Btu per ton of product
Process energy	2.46
Pollution control energy	.00
Space heating	.00
Total energy	2.46

FIGURE 38. - Nickel alloys: Preparing nickel alloy scrap from superalloy solids.



SUMMARY

	Million Btu per ton of product
Process energy	2.51
Pollution control energy	.00
Space heating	.00
Total energy	2.51

FIGURE 39. - Nickel alloys: Preparing nickel and nickel-copper (Monel) scrap from solids.

Pure Nickel, Nickel-Copper Alloys

Pure Nickel Scrap

Pure nickel scrap usually undergoes very little preparation. Used holding racks coated by nickel electroplating operations are broken in alligator shears, which causes the nickel to peel off in the form of small flakes. Anodes and used chemical plant parts may show some surface corrosion, which is removed by sand or steel grit blasting. A wet scrubber collects the grit, which is landfilled. The prepared nickel scrap is consumed by a variety of operations. A few sophisticated scrap processors melt such scrap in a coreless air induction furnace. Nickel from plating operations may be cast into anodes and returned to the platers. Otherwise, this nickel may be sent as "shot" to iron foundries, or to ferrous or nonferrous melt shops as an alloying element. Since it originates in small and sporadic quantities from a variety of sources, the supply of pure nickel scrap is not reliable enough to be used by superalloy melters.

Monels

Monels are hand segregated by grade, such as K-Monel and S-Monel, and, if necessary, tested for composition (for example, acid and spark). They are then cut to size in alligator shears and packed in 55-gallon drums. The same flowsheet applies for pure nickel and Monels and is shown in figure 39.

Melting and Refining

Major Processing Methods

Superalloys Meant for Critical Applications

Purchased scrap as well as home scrap must be carefully identified. Some such scrap consumers premelt all scrap in a vacuum induction furnace, as shown in figure 40, to obtain a representative sample by taking a button from the solidified material, which is then analyzed. If necessary, new metals and alloys are added to the scrap to meet the chemical specifications and maximum permissible proportion of scrap in the final product as specified by contractual relationships between melter and customer. A second vacuum melting step of the prepared charge then follows. The flowsheet for this operation is shown in figure 41.

Other Alloys Meant for Less Critical Applications

These are either melted in an air induction furnace or in an electric arc furnace. The latter furnace may accommodate a flux, which both protects the melt and exerts some refining action. In the case of air induction melting, a flux may be melted in a separate furnace and poured on top of the ingot to protect it. The air pollution control system consists of an air-collecting hood and a baghouse. Solid wastes consist of the dust collected in the bags and minor amounts of fluxes when these are used. Figure 42 shows an air induction furnace process, the most common processing method.

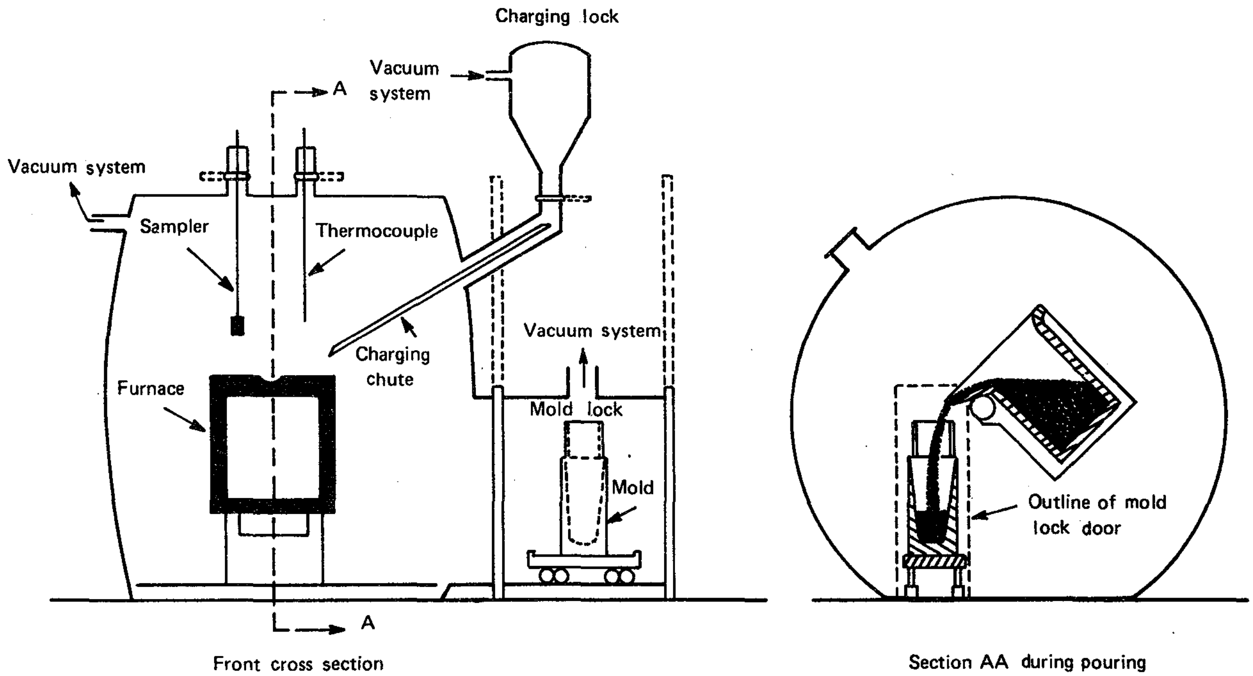
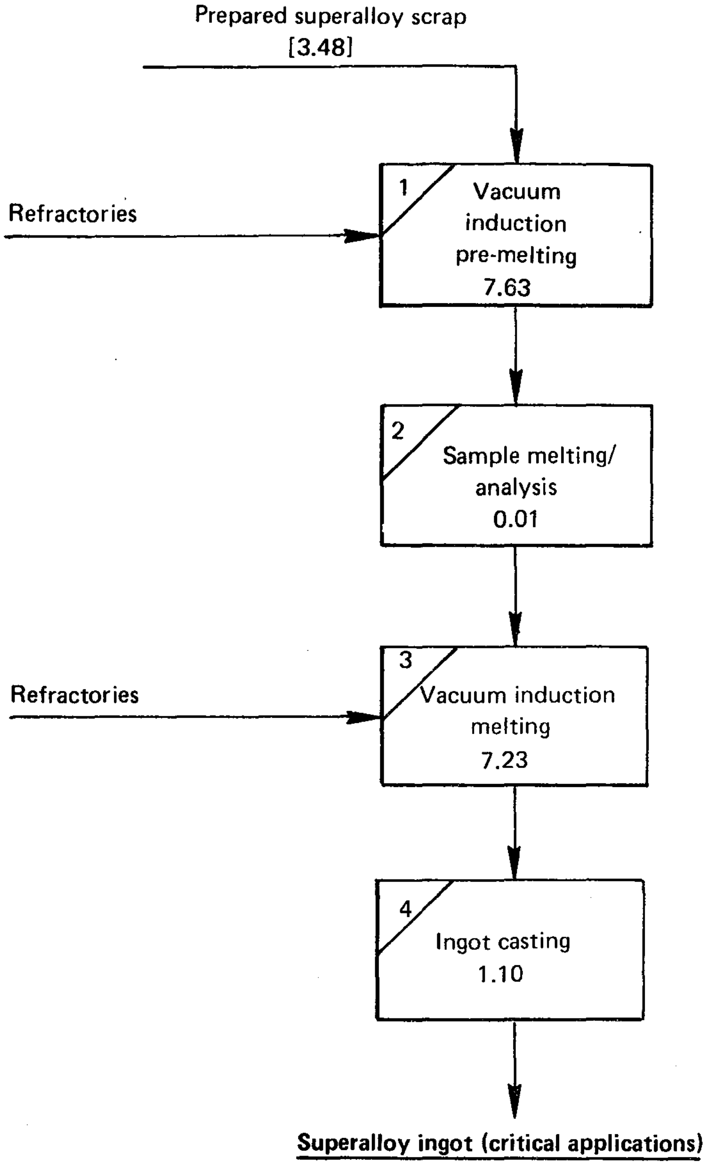


FIGURE 40. - Vacuum induction furnace. *(Courtesy, United States Steel Corp.)*

Other Processing Methods

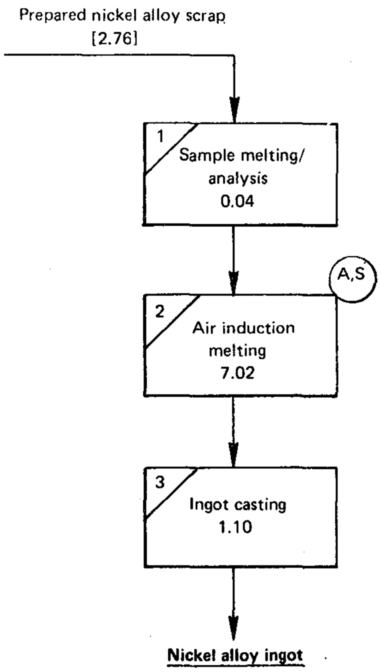
A few high-nickel alloys--A-286, for example--can be made in a duplexing operation consisting of electric furnaces and argon-oxygen decarburization (AOD) vessels much like those used in making stainless steel. There have been instances in which it has proved economical to separate the superalloys into their individual constituents. Proprietary techniques are used that combine pyrometallurgy and hydrometallurgy. These are complex methods that need constant research and reevaluation. There is no commercial process presently in the United States to separate superalloys into their components.



SUMMARY

	Million Btu per ton of product
Process energy	19.45
Pollution control energy	.00
Space heating	.00
Total energy	19.45

FIGURE 41. - Nickel alloys: Superalloy ingotmaking by double vacuum induction melting.



SUMMARY

	Million Btu per ton of product
Process energy	10.92
Pollution control energy	.16
Space heating	.00
Total energy	11.08

FIGURE 42. - Nickel alloys: Nickel alloy ingotmaking by air induction melting.

Some high-nickel scrap and residues representing 5% to 15% of the total nickel scrap are purchased by nickel refineries. Such scrap can be used in any one of a variety of processes found in a nickel refinery, depending on scrap grade, process economics, final product specifications, and so on.

Energy Analysis

The energy analysis shown here was estimated on the basis of plant visits and telephone conversations. Tables 40-44 show the energy requirements associated with the flowsheets shown on figures 37-42, respectively.

The energy required in handling, processing, and transporting the scrap represents about 2.46 million Btu per ton for solids and 4.02 million Btu per ton for turnings. The main item is transportation; the average distance from generation to processing is an estimated 600 miles, either by truck or by rail. From processor to melter, it is estimated that the scrap moves an average of an additional 1,200 miles, mostly by rail. The pollution control energy involved in landfilling the spent grit collected in the wet scrubber of the surface cleaning machine is negligible.

The main energy user is the melt shop since one melting step requires roughly 0.3 kwhr per pound, or 6.3 million Btu per ton. All three types of furnaces--vacuum induction, air induction, and electric arc--require about the same amount of energy. Obviously the process energy required to melt a ton of ingot does not depend upon the ratio of scrap to new metal.

TABLE 40. - Nickel alloys: Preparing nickel alloy scrap from superalloy turnings

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	300.0000	0.002400	0.72
RAIL	TON MI	300.0000	0.000670	0.20
			SUBTOTAL	0.92
(2) CRUSHING				
ELECTRICAL ENERGY	KW HR	93.0000	0.010500	0.98
			SUBTOTAL	0.98
(3) SAMPLE MELTING/ANALYSIS				
ELECTRICAL ENERGY	KW HR	6.8000	0.010500	0.07
			SUBTOTAL	0.07
(4) VAPOR DEGREASING				
TRI-CHLORO-ETHYLENE	GAL	0.7500	0.100000	0.08
STEAM	NET TON	0.2700	2.800000	0.76
			SUBTOTAL	0.84
(5) SCREENING				
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
			SUBTOTAL	0.02
(6) MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
			SUBTOTAL	0.02
(7) FINAL SAMPLE MELTING/ANALYSIS				
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
			SUBTOTAL	0.02
(8) TRANSPORTATION				
TRUCK	TON MI	200.0000	0.002400	0.48
RAIL	TON MI	1000.0000	0.000670	0.67
			SUBTOTAL	1.15
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				4.02

Table 43 shows the energy requirement of the superalloy melting and remelting sequence. For ease in making the energy analyses for recycling, it is assumed the charge consists of 100% scrap, recognizing that virgin materials are often used. These results can be used to estimate energy required to produce any particular superalloy made from scrap. However, no single grade represents more than a few percent of the market, with chemical specifications varying widely from one alloy grade to another. This situation differs from that of other commodities (for example, carbon steel) where chemical specifications for the more common grades do not change the energy requirement to any significant extent.

TABLE 41. - Nickel alloys: Preparing nickel alloy scrap from superalloy solids

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	300.0000	0.002400	0.72
RAIL	TON MI	300.0000	0.000670	0.20
			SUBTOTAL	0.92
(2) ANALYSIS AND SEGREGATION				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
			SUBTOTAL	0.05
(3) TORCH CUTTING (0.20 TON)				
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
			SUBTOTAL	0.02
(4) ABRASIVE SURFACE CLEANING				
ELECTRICAL ENERGY	KW HR	30.0000	0.010500	0.32
			SUBTOTAL	0.32
(5) TRANSPORTATION				
TRUCK	TON MI	200.0000	0.002400	0.48
RAIL	TON MI	1000.0000	0.000670	0.67
			SUBTOTAL	1.15
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				2.46

TABLE 42. - Nickel alloys: Preparing nickel and nickel-copper (Monel) scrap from solids

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	300.0000	0.002400	0.72
RAIL	TON MI	300.0000	0.000670	0.20
			SUBTOTAL	0.92
(2) ANALYSIS AND SEGREGATION				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
			SUBTOTAL	0.05
(3) ALLIGATOR SHEARING (0.33 TON)				
ELECTRICAL ENERGY	KW HR	6.6700	0.010500	0.07
			SUBTOTAL	0.07
(4) ABRASIVE SURFACE CLEANING				
ELECTRICAL ENERGY	KW HR	30.0000	0.010500	0.32
			SUBTOTAL	0.32
(5) TRANSPORTATION				
TRUCK	TON MI	200.0000	0.002400	0.48
RAIL	TON MI	1000.0000	0.000670	0.67
			SUBTOTAL	1.15
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				2.51

TABLE 43. - Nickel alloys: Superalloy ingotmaking by double vacuum induction melting

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) VACUUM INDUCTION PRE-MELTING				
SCRAP - SUPERALLOY TURN.	NET TON	0.4060	4.020000	1.63
SCRAP - SUPER ALLOY SOLID	NET TON	0.7520	2.460000	1.85
ELECTRICAL ENERGY	KW HR	694.8000	0.010500	7.30
REFRACTORIES	NET TON	0.0080	26.600000	0.21
NATURAL GAS	CU. FT.	116.0000	0.001000	0.12
			SUBTOTAL	11.11
(2) SAMPLE MELTING/ANALYSIS				
ELECTRICAL ENERGY	KW HR	1.0000	0.010500	0.01
			SUBTOTAL	0.01
(3) VACUUM INDUCTION MELTING				
ELECTRICAL ENERGY	KW HR	660.0000	0.010500	6.93
REFRACTORIES	NET TON	0.0070	26.600000	0.19
NATURAL GAS	CU. FT.	110.0000	0.001000	0.11
			SUBTOTAL	7.23
(4) INGOT CASTING				
NATURAL GAS	CU. FT.	100.0000	0.001000	0.10
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
INGOT MOLDS & STOOLS	NET TON	0.0400	24.500000	0.98
			SUBTOTAL	1.10
* TOTAL ENERGY PER NET TON OF PRODUCT				19.45

Other nickel alloys and Monels are commonly prepared from 100% scrap. The corresponding scrap requirement is shown in table 44. There is no air pollution control in the case of vacuum melting. The baghouse associated with air induction melting furnaces requires 15 kwhr per ton (0.16 million Btu per ton) of ingot. The baghouse associated with an arc furnace would require about 20 kwhr per ton of ingot (0.21 million Btu per ton).

None of the processes described involves any significant space heating energy. Scrap is normally processed outdoors or in nonheated buildings; melt shops are not usually heated.

N. TABLE 44. - Nickel alloys: Nickel alloy ingotmaking by air induction melting

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) SAMPLE MELTING/ANALYSIS				
SCRAP - NICKEL ALLOYS	NET TON	1.1000	2.510000	2.76
ELECTRICAL ENERGY	KW HR	4.0000	0.010500	0.04
			SUBTOTAL	2.80
(2) AIR INDUCTION MELTING				
ELECTRICAL ENERGY	KW HR	640.0000	0.010500	6.72
REFRACTORIES	NET TON	0.0070	26.600000	0.19
NATURAL GAS	CU. FT.	110.0000	0.001000	0.11
			SUBTOTAL	7.02
(3) INGOT CASTING				
NATURAL GAS	CU. FT.	100.0000	0.001000	0.10
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
INGOT MOLDS & STOOLS	NET TON	0.0400	24.500000	0.98
			SUBTOTAL	1.10
* TOTAL PROCESS ENERGY				10.92
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	15.0000	0.010500	0.16
			SUBTOTAL	0.16
* TOTAL POLLUTION CONTROL ENERGY				0.16
* TOTAL ENERGY PER NET TON OF PRODUCT				11.08

Major Heat Losses

All nickel alloys scrap preparation is conducted at room temperature, with two minor exceptions: The degreasing of superalloy chips, which uses steam; and the induction melting of sampled chips, which can be minimized by implementing a more rigorous segregation procedure at the source of scrap generation. There is, therefore, no major heat loss involved in scrap separation.

The melting operations are the only steps where significant amounts of heat are lost from the furnaces. Reducing these losses is a matter of furnace design, for example, improved power supplies, refractories, and charging systems.

Research and Development

Following is a list of potential research areas:

1. Develop a method to descale and clean the inner face of nickel alloy tubes used in high temperature and corrosion-resistant applications, as a way of upgrading such scrap items;

2. Develop rapid and accurate scrap-identification methods, so that the number of melting steps can be kept to a minimum in all instances;

3. Develop a reliable method, as a complement to scrap recycling, to recover the metal values contained in such often-wasted materials as grinding swarf and sludge. Although some companies offer such services, this impact still seems limited and significant amounts of metal values are lost;

4. Reevaluate and develop economical methods by which superalloys can be separated into their individual components; and

5. Develop superalloy melting techniques that allow for a larger amount of refining to take place, for example, by the use of appropriate fluxes. Some techniques such as electroslag remelting may be adapted from other sectors of extractive metallurgy. In this fashion, one might be able to produce an ingot to specification in a single melting step.

References

1. Savage, R. New Developments in Nickel Alloys and Stainless Steel. Iron Age, v. 33, No. 43, 1977, pp. 36-37.

2. U.S. Bureau of Mines. Nickel. Mineral Industry Surveys, Monthly and Annual, 1976.

STAINLESS STEEL

Background

Table 45 presents data on the stainless steel industry.

TABLE 45. - Data on secondary stainless steel industry

	Net tons[1]
Secondary raw materials (1976):	
Stainless steel scrap	[2]379,000
Carbon steel and low alloy steel scrap	[3]400,000
Superalloy scrap	[3]10,000
U.S. finished stainless steel production (1976)	[4]1,019,000

[1]All figures are rounded to the nearest thousand.
[2]Stainless steel scrap is about equally divided between new and old. The total figure is based on data collected by the Bureau of Mines published monthly in the Mineral Industry Surveys.
[3]Arthur D. Little, Inc., estimates.
[4]Preliminary estimates for net receipts of finished stainless steel products based on American Iron and Steel Institute (AISI) figures. Raw stainless steel and heat-resisting alloys represented 1,684,000 tons, according to AISI. Figures for raw stainless steel alone are not available.

NOTE.--Commodity: Stainless steel.
Products: Stainless steel ingots, strand cast products, and castings.
Byproducts: None.
Coproducts: None.

Sources: Bureau of Mines and Arthur D. Little, Inc., estimates.

Types and Classifications of Scrap

The hundred or so types of stainless steels available to United States customers can be classified into three broad categories--300 series, 400 series, and 200 series.

300 Series.--The 300 series is the most widely used stainless steel. The 18-8 alloys, referring to their chrome and nickel content, respectively, belong to this series. Other elements may be present in varying proportions: Molybdenum in 316 and 317 grades, columbium in 347, and so on. These alloys are nonmagnetic. They find a great variety of uses in the construction industry, kitchen utensils, hospital equipment, chemical plants, refineries, and the aerospace industry.

400 Series.--The 400 series consists of straight chrome grades (10% to 27% Cr) of stainless steel, all of which are magnetic. They contain various amounts of minor additions, but little or no nickel. Some grades are ferritic (very low carbon), while others are martensitic. This series has a variety of applications, such as for decorative purposes, cutlery, and automobile mufflers.

200 Series.--The less common 200 series is nonmagnetic. In this series, manganese is partially substituted for nickel in order to retain the austenitic structure, resulting in a composition containing 3.6% Ni, 16% to 20% Cr, and 5% to 10% Mn.

Stainless scrap is priced according to its metal values. It is, therefore, carefully segregated with particular attention being paid so as not to mix incompatible grades, such as molybdenum-containing and non-molybdenum-containing alloys. A synopsis of the more common groups of stainless steel scrap is listed below (1):

Scrap	Grades
Cr scrap...........	AISI 403, 430, and [illegible]6.
CrMo scrap.........	AISI 501 and 502.
NiCr scrap (18-8)...	AISI 302, 304, 305, 308, 309, 310, and 321.
NiCrMo scrap........	AISI 316 and 317.
NiCrCb scrap........	AISI 347 and 348.
NiCrMn scrap........	AISI 201 and 202.
Mn scrap...........	16-1-17 and other new grades of 1% maximum Ni, 14% to 17% Mn steels.

A considerable amount of stainless scrap is available in the form of turnings at generally lower costs per ton than solid scrap. In addition, many special types of high-nickel-content scrap are available to makers of stainless steel, such as Inconel, Nichrome, valve steels, and others with the nickel content ranging from 20% to 80%.

Contamination Problems

With the increased use of argon-oxygen decarburization (AOD) in making stainless steels, the amount of carbon steel scrap used has increased considerably, resulting in lowered ingot cost and improved heat time. This higher usage of purchased carbon steel scrap has created additional problems outlined below.

In the manufacture of the common grades of austenitic stainless steels, present specifications limit the phosphorus content to 0.05% and sometimes 0.03% maximum, copper and molybdenum to 0.50% maximum, and lead and tin to traces. In the case of common ferritic stainless steels, nickel is also limited to 0.50%. In present methods of stainless steel melting, practically no portion of the above elements is removed. The continued recycling of scrap produced in recent years has caused the P, Cu, Mo, and Sn contents of ingots produced to rise gradually until they are now close to the upper limits presently allowed.

Purchased stainless steel scrap itself may also differ from the problem of residuals associated with poor scrap segregation. The prime source of high-copper residuals has been mixed 18-8 scrap which contains not only Monel scrap, but in some cases pure copper scrap which is also nonmagnetic. Another common source of contaminated stainless steel scrap is refrigerator freezing units, which have soldered joints and copper coils; aircraft engine manifolds, which are usually high in lead content due to absorption of tetraethyl lead from exhaust gases; and soldered sheets. (Lead is undesirable because it attacks furnace refractories.)

Scrap Preparation

Stainless steel scrap can be classified into three physical categories for preparation purposes: Turnings and borings, light scrap, and solids. Turnings and borings are shipped to the recycler in bulk by truck or rail. They are sometimes crushed in rotary crushers to ease handling and shipping. Nonmagnetic grades go through a magnetic separation step. If the grade is unknown, a 20- to 30-pound composite sample is taken and melted in whole or in part in a laboratory induction furnace. A button is taken and analyzed by X-ray spectroscopy. Depending upon the customer's requirements, the crushed turnings may be briquetted in small cylindrical briquettes, typically 5 inches in diameter by 4 inches thick.

Degreasing of turnings can be technically achieved by either simple heating or solvent cleaning. Since heating with partial combustion of grease and oils causes pollution control problems, and since solvent cleaning is generally not economic, degreasing is rarely done. As a result, 5% or 6% by weight of the turnings (loose or briquetted) is typically dirt and oil. The processed turnings are shipped out to the mill in bulk, boxes, or as briquettes. Light scrap and solids are segregated by grade, as recognized from their shape, origin, and response to spark, acids, and magnets. The solids are cut to length by torch or shearing (either alligator or guillotine shears). While light scrap can be kept loose, it is more likely to be baled, with the size depending on customer specifications (for example, a cube 2 feet on each side). There is a growing interest in shredded stainless steel, although presently it represents an insignificant volume.

Very clean, perfectly segregated new scrap can be sheared to small pieces, descaled by steel/grit blasting, and sent to foundries which remelt it. The handling and processing equipment, such as balers, presses, crushers, and shears, is identical to that used in the recycling of plain carbon steels.

Prepared stainless scrap is sent to stainless and alloy steelmakers. It is sold on the basis of its more noble element content (Ni, Cr, Mo), typically under a clause that tramp elements are kept below acceptable limits.

Two other recycled items--stainless steel dust and grinding swarf--are worth mentioning, even though they are not "scrap." Although slag and dust have usually been sent to disposal, a few service companies take the dust and convert it to a reusable product, mostly as pigs of "master alloys." Grinding swarf, a mixture of fine particles consisting of metals and abrasives, can be upgraded and briquetted, pigged, or simply charged to the AOD vessel. There is no commonly accepted practice at present, nor is there any problem-free recycling method, particularly with respect to controlling undesirable tramp elements.

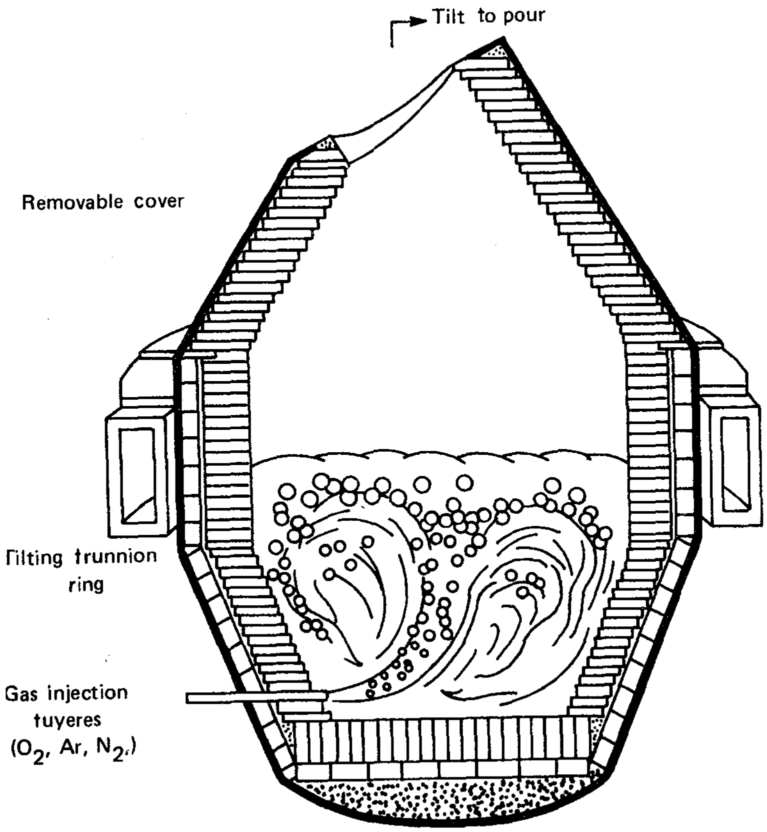


FIGURE 43. - Argon-oxygen decarburization (AOD) vessel.
(Courtesy, Union Carbide Corp.)

Melting and Refining

Stainless steel scrap is purchased entirely by stainless and specialty alloy steel producers. There are no "primary" and "secondary" stainless steel producers. All stainless steel melters use home scrap, purchased scrap, other recycled materials (such as processed flue dust, grinding swarf, and skulls), and virgin materials. The proportions of these various materials in the furnace charge are calculated separately for each heat on a least-cost basis. All produce proprietary or merchant grades of stainless steel, the origin of which is not recognizable.

The major process for making stainless steel is a duplex method which involves melting and initial refining in an electric arc furnace, followed by refining in an AOD vessel as shown in figure 43.

Electric arc furnaces have the capability of melting 100% scrap. In practice, a small amount of virgin material is always used for such reasons as final chemistry adjustment or impurity dilution. The advent of the AOD has permitted the use of carbon steel scrap and high-carbon ferrochrome in the charge. A small part of alloying elements is routinely provided by nickel-base alloy scrap, such as Inconel. This degrading use of high-value alloys occurs either because of market conditions (such as a recession in the aerospace industry) or because the amount of segregation and decontamination that can economically be applied to some scraps is insufficient to meet the specifications of superalloy melters.

The reactions occurring in the AOD vessel are strongly exothermic, so that this process step offers an opportunity to melt another 5% to 10% scrap, if necessary. This scrap, however, can only be home scrap or otherwise perfectly clean and identified scrap. Ferroalloys, silicomanganese, and sometimes pure nickel are added to the bath at the end of the refining period in order to meet product specifications. The melt is commonly poured into ingot molds or into the tundish of a continuous casting machine. Upon solidification, stainless steel can take any of three forms, in decreasing order of production volume, ingots, strand cast products, and castings.

Although most steel producers have switched to the AOD process, a small (less than 10%) quantity of stainless steel is still made entirely in the electric furnace alone. This practice, rapidly becoming obsolete, is characterized by considerably longer heat time, resulting in higher energy consumption and smaller chrome recovery; less flexibility in scrap usage, particularly with respect to carbon and sulfur content; and significantly greater ferrosilicon usage.

Another processing method making a small contribution to stainless scrap use is the induction furnace. These furnaces, generally found in foundries, use only stainless steel scrap and virgin metallics in proportions dictated by the customer specifications and market conditions.

Energy Analysis

The flowsheets and energy tables are presented to reflect that stainless steel recycling consists of two business segments. One segment is in the business of preparing stainless steel scrap, along with other types of scrap and secondary raw materials. The other is in the business of producing semi-finished stainless steel, using recycled stainless steel along with other types of scrap and also virgin raw materials.

Figures 44-46 and tables 46-48 describe the scrap preparation and transportation steps. Two elements distinguish the stainless recycling business from its iron and steel counterparts:

1. Transportation distances for stainless are greater. Between collection and delivery to the customer, the scrap is estimated to travel an average of 700 miles.

2. The energy required to shred, shear, or bale stainless steel is about twice that required to perform the same operations on carbon steel.

There is no pollution control energy associated with stainless scrap processing. Moreover, there are no space heating requirements, since the operations are conducted outdoors or in nonheated buildings.

Figure 47 and table 49 describe the common process for making stainless steel, namely, the electric arc furnace-AOD sequence, in which the major energy user is the arc furnace. This unit is similar to a steelmaking electric furnace. The best modern practice realizes slightly below 5.04 million Btu per ton (480 kwhr per ton) in electric power, with small, low-power units closer to 6.3 million Btu per ton (600 kwhr per ton). The estimated average, based on information gathered during selected field trips undertaken during this study in 1976, is 5.25 million Btu per ton (500 kwhr per ton). The energy numbers shown in conjunction with carbon steel scrap (No. 1 bundles, shredded cans, miscellaneous solids) are derived in corresponding sections of the chapter on iron and steel. The AOD furnace requires no fuel in its operation, while the continuous casting unit is of the type used in steelmaking.

TABLE 46. - Stainless steel: Preparing scrap from turnings

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
RAIL	TON MI	150.0000	0.000670	0.10
			SUBTOTAL	0.46
(2) SHREDDING				
ELECTRICAL ENERGY	KW HR	93.0000	0.010500	0.98
			SUBTOTAL	0.98
(3) BRIQUETTING (0.10 TON)				
ELECTRICAL ENERGY	KW HR	4.6000	0.010500	0.05
			SUBTOTAL	0.05
(4) TRANSPORTATION				
TRUCK	TON MI	100.0000	0.002400	0.24
RAIL	TON MI	300.0000	0.000670	0.20
			SUBTOTAL	0.44
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				1.93

TABLE 47. - Stainless steel: Preparing light scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
RAIL	TON MI	150.0000	0.000670	0.10
			SUBTOTAL	0.46
(2) BALING (0.50 TON)				
ELECTRICAL ENERGY	KW HR	22.0000	0.010500	0.23
			SUBTOTAL	0.23
(3) TRANSPORTATION				
TRUCK	TON MI	100.0000	0.002400	0.24
RAIL	TON MI	300.0000	0.000670	0.20
			SUBTOTAL	0.44
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				1.13

TABLE 48. - Stainless steel: Preparing heavy scrap

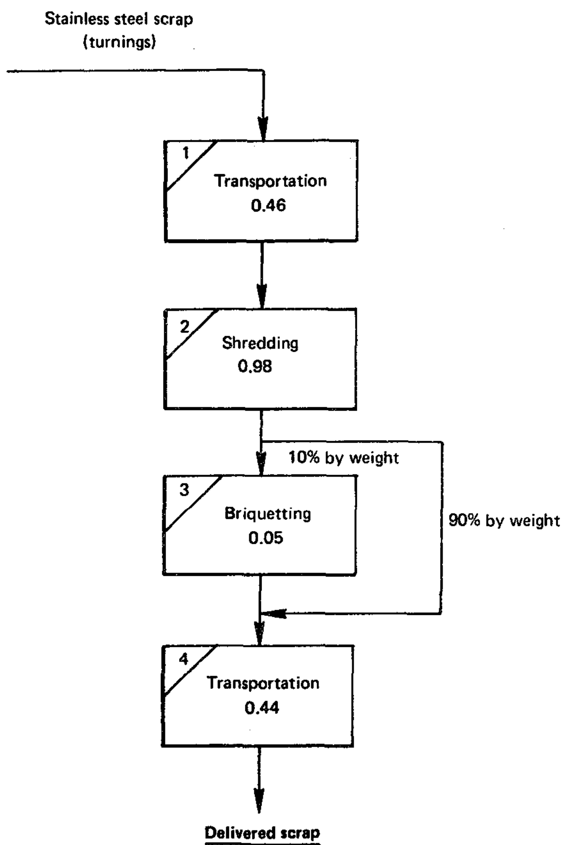
(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	150.0000	0.002400	0.36
RAIL	TON MI	150.0000	0.000670	0.10
			SUBTOTAL	0.46
(2) TORCH CUTTING (0.33 TON)				
OXYGEN	CU. FT.	24.3300	0.000150	0.00
ACETYLENE	CU. FT.	2.1000	0.002400	0.01
			SUBTOTAL	0.01
(3) ALLIGATOR OR GUILLOTINE SHEARING(0.33 TON)				
ELECTRICAL ENERGY	KW HR	6.6700	0.010500	0.07
			SUBTOTAL	0.07
(4) TRANSPORTATION				
TRUCK	TON MI	100.0000	0.002400	0.24
RAIL	TON MI	300.0000	0.000670	0.20
			SUBTOTAL	0.44
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP .				0.98

Because of the additional presence of the AOD, the air pollution control energy used with the AOD furnace is greater than in electric furnace steelmaking. Solid-waste disposal energy is insignificant, as it simply consists of hauling and dumping the slag a few miles away from the plant. Dust collected in the air pollution control system is either dumped along with the slag (conventional practice), or more recently, it is sent to specialized plants that recover the nickel and chrome values by proprietary processes. The total energy required to make a ton of stainless steel is slightly below 10 million Btu, about 10% of which goes to scrap transportation and processing.

TABLE 49. - Stainless steel: Producing strand cast stainless steel billets by argon-oxygen decarburization (AOD)

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) ELECTRIC MELTING FURNACE				
SCRAP - HOME	NET TON	0.3212	0.025000	0.01
SCRAP - S S TURNINGS	NET TON	0.1028	1.930000	0.20
SCRAP - S S LIGHT	NET TON	0.2570	1.130000	0.29
SCRAP - S S SOLIDS	NET TON	0.0257	0.980000	0.03
SCRAP - #1 BUNDLES	NET TON	0.1285	0.720000	0.09
SCRAP - STEEL AUTO-SHRED	NET TON	0.0362	1.280000	0.05
SCRAP - STEEL GUILL	NET TON	0.0152	0.510000	0.01
SCRAP - STEEL MISC.	NET TON	0.0128	0.460000	0.01
GRINDING SWARF	NET TON	0.0257	0.000000	0.00
SCALE	NET TON	0.0257	0.000000	0.00
SCRAP - SUPERALLOYS	NET TON	0.0514	1.000000	0.05
FERROALLOYS	NET TON	0.2827	**	**
ELECTRICAL ENERGY	KW HR	500.0000	0.010500	5.25
REFRACTORY	NET TON	0.0070	26.600000	0.19
GRAPHITE ELECTRODE	NET TON	0.0040	160.000000	0.64
			SUBTOTAL	6.82
(2) AOD REFINING				
LIME	NET TON	0.0590	5.450000	0.32
REFRACTORY	NET TON	0.0200	26.600000	0.53
FERROSILICON	NET TON	0.0280	**	**
SILICOMANGANESE	NET TON	0.0070	**	**
FLUORSPAR	NET TON	0.0050	1.590000	0.01
ARGON	CU. FT.	690.0000	0.000210	0.14
OXYGEN	CU. FT.	910.0000	0.000150	0.14
			SUBTOTAL	1.14
(3) CONTINUOUS CASTING				
ELECTRICAL ENERGY	KW HR	25.0000	0.010500	0.26
NATURAL GAS	CU. FT.	605.0000	0.001000	0.61
REFRACTORY	NET TON	0.0025	26.600000	0.07
OXYGEN	CU. FT.	750.0000	0.000150	0.11
			SUBTOTAL	1.05
* TOTAL PROCESS ENERGY				9.01
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	65.0000	0.010500	0.68
			SUBTOTAL	0.68
WASTE DISPOSAL				
TRUCK	TON MI	0.4500	0.002400	0.00
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.68
SPACE HEATING				
NATURAL GAS	CU. FT.	0.0000	0.001000	0.00
			SUBTOTAL	0.00
* TOTAL SPACE HEATING ENERGY				0.00
* TOTAL ENERGY PER NET TON OF PRODUCT				9.69

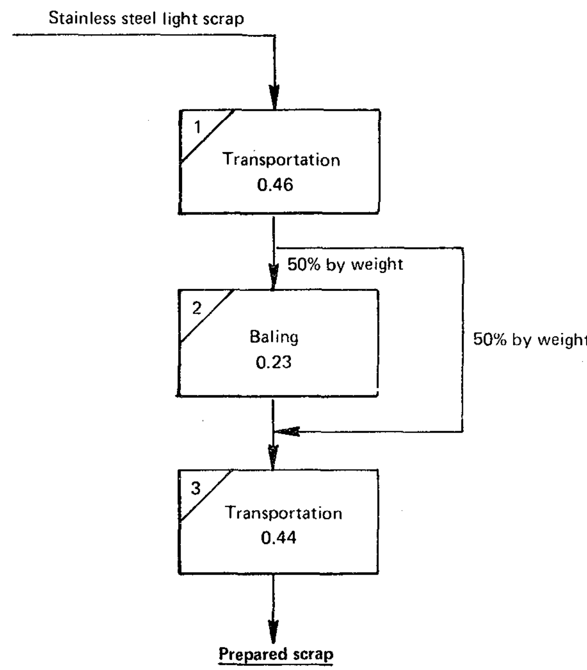
** - THE ENERGY CONTENT OF THESE ALLOYING ELEMENTS IS NOT INCLUDED IN THE TOTAL ENERGY REPORTED IN THIS TABLE



SUMMARY

	Million Btu per ton of product
Process energy	1.93
Pollution control energy	.00
Space heating	.00
Total energy	1.93

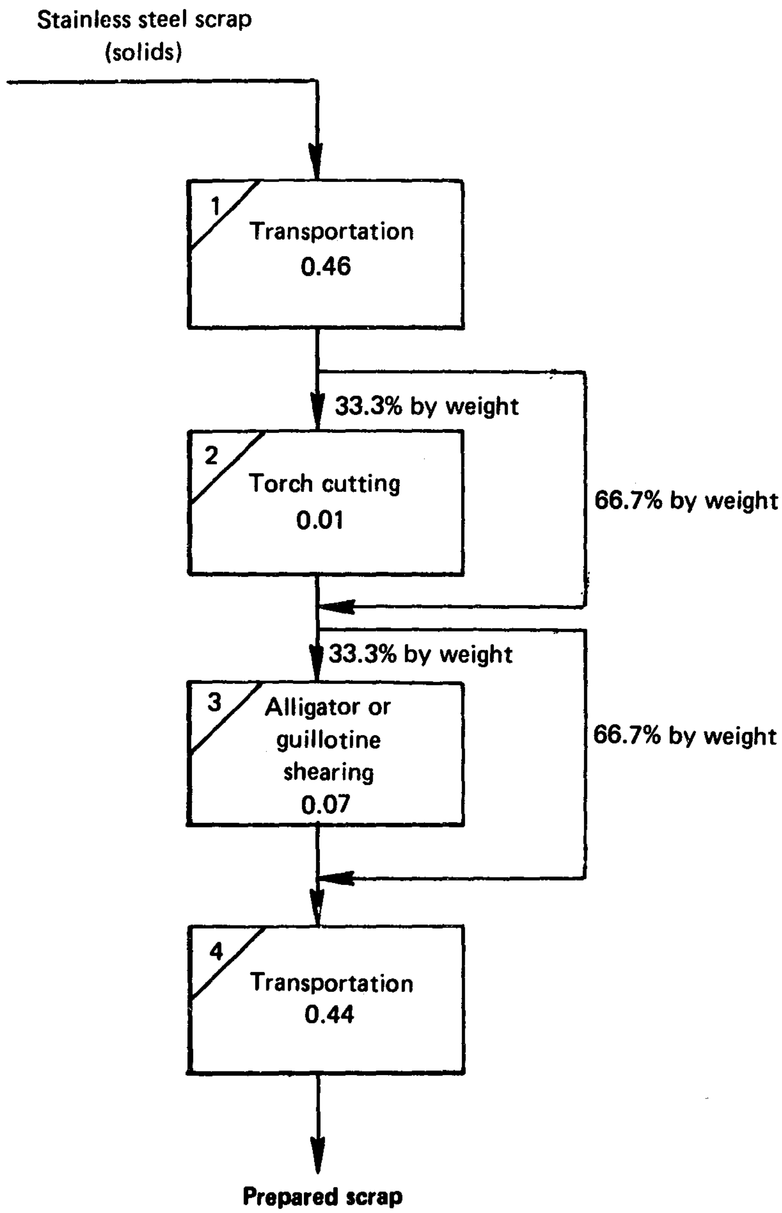
FIGURE 44. - Stainless steel: Preparing scrap from turnings.



SUMMARY

	Million Btu per ton of product
Process energy	1.13
Pollution control energy	.00
Space heating	.00
Total energy	1.13

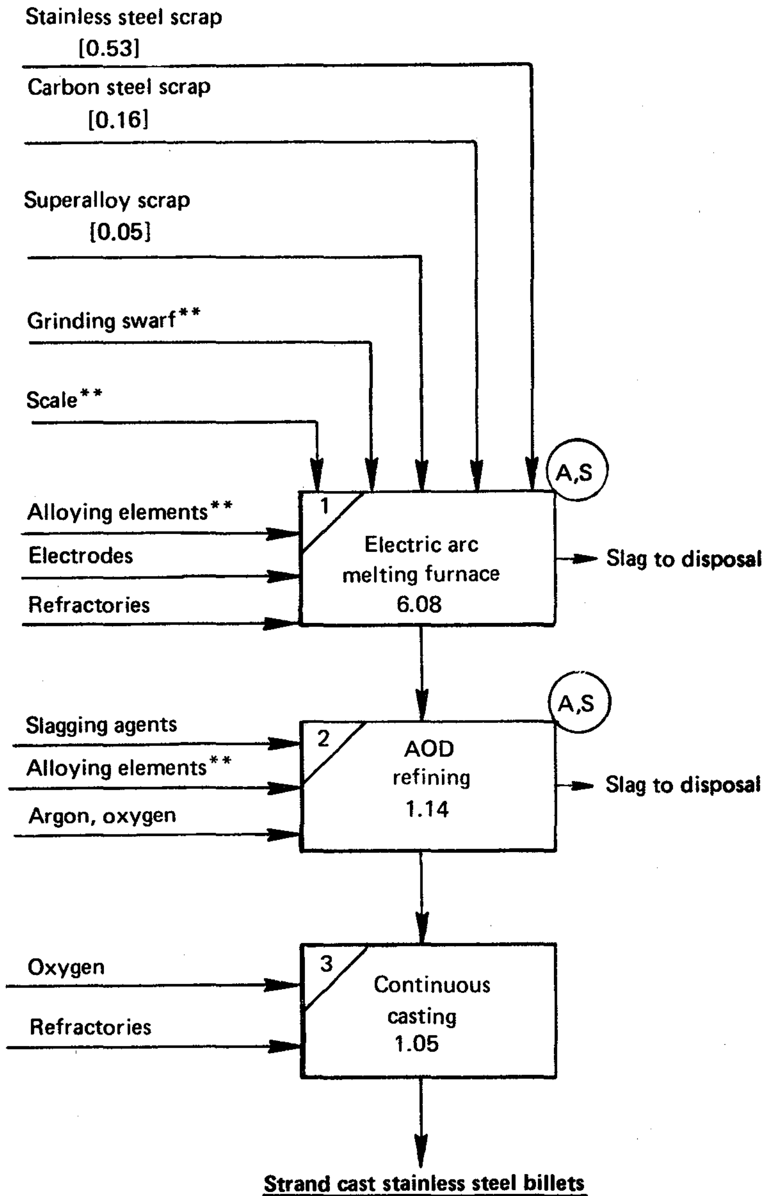
FIGURE 45. - Stainless steel: Preparing light scrap.



SUMMARY

	Million Btu per ton of product
Process energy	0.98
Pollution control energy	.00
Space heating	.00
Total energy	.98

FIGURE 46. - Stainless steel: Preparing heavy scrap.



SUMMARY

	Million Btu per ton of product
Process energy	9.01
Pollution control energy	.68
Space heating	.00
Total energy	9.69

**Grinding swarf, scale, and alloying elements are shown having no energy content.

FIGURE 47. - Stainless steel: Producing strand cast stainless steel billets by argon-oxygen decarburization (AOD).

Major Heat Losses

All stainless steel scrap preparation takes place at room temperature. The heat losses are to be found in the steel mill during melting, refining, and casting. Following is an outline of the major heat losses, as well as the major parameters influencing them.

Electric Furnace, Casting, Ladle Drying, and Preheating

The comments made in the iron and steel chapter of this report concerning these process steps apply to this case as well.

Argon-Oxygen Decarburization (AOD) Vessel

The AOD vessel loses heat through the shell and with the offgas. This gas leaves the mouth of the furnace at a temperature in excess of 3,100° F. It is then cooled by radiation prior to being cleaned, together with the electric furnace offgas. Thought has been given to recovering the heat content of this gas.

Research and Development

Potential areas of research and development in stainless steel scrap recycling are discussed below. Some are presently being explored by private industry; others were examined and found uneconomical in the past but should perhaps be reexamined in light of changing economic conditions. Still others have not yet been explored. The potential areas include--

1. Using prereduced iron pellets in the electric furnace-AOD sequence which would generally require, for economic reasons, that a continuous feeding system on top of the electric furnace be installed. The operating advantages are less contamination of the steel melt, hence a diluting effect on undesirable elements which tend to build up as more and more scrap is being recycled over and over again; and free residual oxygen in the pellets, as these reduced materials are never 100% metallics.

2. Developing a method for cleaning the chips that also recovers the oil. Such a method would suppress the instantaneous generation of hot oil vapor in the electric furnace.

3. Recovering the heat from the AOD offgases. The problem is similar to that of BOP offgases, although on a smaller scale. There may be some potential for scrap preheating, as shown by the Bureau of Mines Metallurgy Research Center at Twin Cities, Minn., on a pilot scale BOP.

4. Improving segregation techniques. This problem is common to most of the scrap industry, which relies tremendously on human judgment and on a slow piece-by-piece inspection procedure.

5. Recycling materials other than traditional scrap, such as grinding swarf, baghouse dust, and slag. The grinding swarf, if properly segregated at

its point of origin, can be treated to recover a very high quantity of metallic values (up to 85%). Current experimental methods include melting and slagging, gravity separation and briquetting in a roll-press, and simple return to the furnace. The baghouse dust is most often landfilled. Research conducted in the past at the Bureau of Mines Metallurgy Research Center at Rolla, Mo., and recent industrial experience have shown the feasibility of recovering the metallic values contained in the dust caught in the baghouse. The slag is usually landfilled in spite of its chrome content. It may be worthwhile investigating ways to recover such values.

6. Taking advantage of the AOD process to melt more scrap by optimizing the use of the exothermic oxidation reactions taking place in the vessel.

7. Increasing the power available to the electric furnaces. Many U.S. units are old and cannot deliver enough arcing power. The result is an extended melting time, with accompanying heat losses.

8. Introducing direct tapping from the furnace into the AOD without any intermediate ladle. Such a practice would increase the yield by reducing the amount of skulls.

9. Introducing continuous casting, which is a well-known way to save energy and to decrease the amount of home scrap being generated.

10. Improving the efficiency of ladle drying and preheating; one possibility is to conduct this operation in an enclosed device.

11. Using better charge preparation methods and charging systems. This will reduce the charging time and thus decrease the furnace heat losses. Briquetting the turnings is an example of such a procedure.

12. Incorporating better engineered pollution control systems. Generally retrofitted air pollution control equipment draws large quantities of air into the furnace, thus having an air-cooling effect on the melt.

Reference

1. Carney, D. J., and E. J. Whittenberger. Raw Materials. Ch. 6 in Electric Furnace Steelmaking. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, v. I, 1963, pp. 175-212.

TIN

Background

Table 50 presents data on the secondary tin industry.

TABLE 50. - Data on secondary tin industry

	Net tons tin content[1]
Secondary raw materials (1976):	
Prompt industrial scrap............................	7,700
Obsolete scrap.....................................	10,500
Secondary U.S. production (1976)......................	18,200

[1]All figures are rounded to the nearest hundred.

NOTE.--Commodity: Tin.
Primary products: Tin metal, tin-based alloys.
Byproducts: None.
Coproducts: Steel scrap.

Sources: Division of Nonferrous Metals, Bureau of Mines; and Arthur D. Little, Inc., estimates.

Types and Classifications of Scrap

Tin scrap can be classified into the following categories: New tin-plated scrap, used tin containers, copper-base scrap, and other tin-bearing scrap, such as solder and babbitt.

Of the tin recycled in 1976, about 85% was processed as an alloy constituent of bronzes, brasses, and other tin-bearing scrap. Some 15% of the recycled tin, mostly from new tin-plated scrap, was processed into tin in a metallic, nonalloy form. Only very small quantities of tin are being recovered from used tin containers. Details regarding this type of scrap are shown in table 51.

TABLE 51. - Tin metal equivalents recovered from various secondary scrap sources in 1976

Process and scrap type	Net tons of tin content recovered	Obsolete scrap, %	Prompt industrial new scrap, %
Tin recovered as tin metal.......	1,870	0	100
Tin recycled in alloy or chemical form:			
Copper-base scrap recycling....	8,690	80	20
Lead- and tin-base scrap recycling.....................	60	60	40
Solder recycling...............	5,500	38	62
Type metal recycling...........	660	100	0
Babbitt recycling..............	440	100	0
Antimonial lead recycling......	470	-	-
Chemicals......................	460	100	0
Miscellaneous..................	10	100	0
Total......................	18,160	-	-

Sources: Division of Nonferrous Metals, Bureau of Mines; and Arthur D. Little, Inc., estimates.

Products

Except for recovery of tin as a metal from new tin-plated scrap and some used tin containers, most tin scrap is recycled as an alloy into a similar classification alloy product. Scrap containing tin solder, for example, is melted and alloyed to produce solder and tin-bearing brass, and bronze scrap is melted and alloyed to produce brass and bronze products. The relevant energy analysis is shown in the chapter on copper. A part of the tin recovered in the secondary tin operation is also converted into tin chemicals, such as $SnCl_2$, $Na_2SnO_3 \cdot 3H_2O$, and $K_2SnO_3 \cdot 3H_2O$. The following analysis undertakes an estimate of energy requirements for recovery of tin from tin-plated scrap.

Scrap Preparation

The primary focus of this analysis is the production of tin metal from new tin-plated scrap. New tin-plated scrap, as received at the tin recovery plant, involves no preparation before the tin recovery processing steps.

Tin Recovery Processes

Major Processing Method

The alkaline chemical process involving leaching and electrowinning is the basis of most tin-recovery operations today in the United States and abroad. The process begins with the charging of tin-plated scrap into large horizontal drums made of perforated steel plate which, in turn, are placed in large treatment tanks for leaching. Rotating the drums insures movement of scrap and solution to effect complete removal of tin. The leaching solution, consisting of NaOH and $NaNO_3$ at about 200° to 210° F, is heated by steam coils. Following detinning, the scrap is rinsed up to four times so that the chemicals are effectively removed. The detinned scrap is compressed into large bales and sold to steel mills as No. 2 scrap bundles for charging, largely to electric arc furnaces, open-hearth, and BOF furnaces. Iron and steel recycling is discussed in the chapter dealing with iron and steel.

A coproduct of the above detinning operation is an aqueous leach solution containing tin. Sodium sulfide is added to this leach solution to precipitate tramp heavy metals, such as lead and zinc. After filtration, the purified leach solution is introduced into a cascade of cells at about 190° F from which tin is recovered by electrowinning. This tin is stripped from the cathode by melting in a gas-fired or electrically heated melting pot. Overall recovery of tin in the process is about 60% to 80%.

Other Processing Method

The aforementioned recovery of tin from tin-plated scrap is considered a batch operation as far as leaching is concerned. Recently, a few companies have developed and commercialized a continuous leaching process which reportedly consumes far less energy than the batch leaching operation. Because of its proprietary nature, however, data on this process are not available, and this scheme is not included in the energy analysis. (When such energy data becomes available, it would have the impact of reducing the energy required for producing No. 2 bundles from tin scrap, while not affecting the energy analysis for the recovery of tin from the byproduct leach solution as presented in this study.)

Energy Analysis

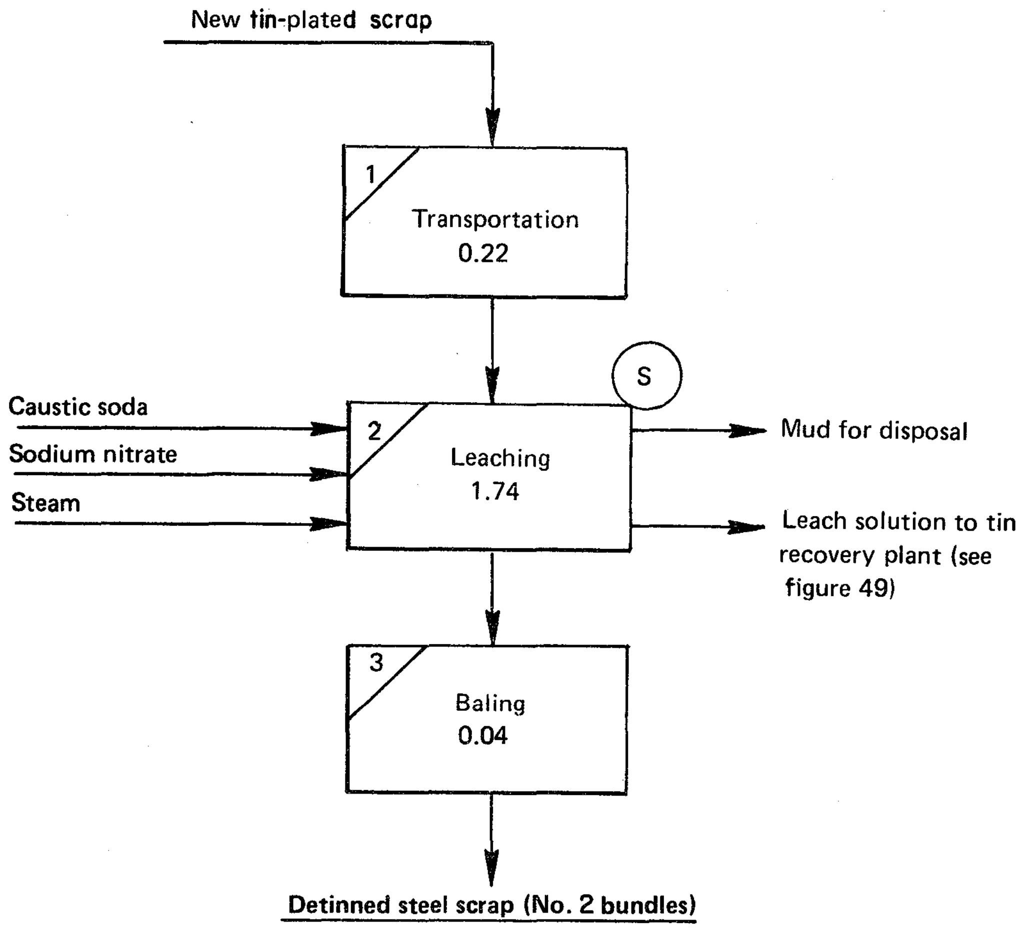
The energy analysis for the batch leaching and electrowinning process is presented in two parts: (1) Detinning new tin-plated scrap and (2) recovery of tin from detinning leach solution.

Detinning New Tin-Plated Scrap

Recovery of clean steel scrap for use in steelmaking from new tin-plated scrap involves several process steps. Because the principal objective of the detinning section is to recover steel scrap, all energy consumed in this section is assigned to the major product which is No. 2 steel bundles. The relevant energy analysis for this step is shown in figure 48 and table 52. Principal energy consumers in the detinning operation are steam heating of the leach solution (requiring about 45% of total detinning energy), electrical energy in leaching and rinsing (requiring about 21%), process material in leaching (requiring about 21%), and transportation (requiring 11%).

TABLE 52. - Tin: Detinning new tin-plated scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) TRANSPORTATION				
RAIL	TON MI	100.0000	0.000670	0.07
TRUCK	TON MI	62.0000	0.002400	0.15
			SUBTOTAL	0.22
(2) LEACHING				
CAUSTIC SODA	NET TON	0.0070	29.900000	0.21
SODIUM NITRATE	NET TON	0.0050	42.250000	0.21
NATURAL GAS	CU. FT.	900.0000	0.001000	0.90
ELECTRICAL ENERGY	KW HR	40.0000	0.010500	0.42
			SUBTOTAL	1.74
(3) BALING				
ELECTRICAL ENERGY	KW HR	4.0000	0.010500	0.04
			SUBTOTAL	0.04
* TOTAL PROCESS ENERGY				2.00
POLLUTION CONTROL ENERGY				
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.00
SPACE HEATING ENERGY				
NATURAL GAS	CU. FT.	15.0000	0.001000	0.02
			SUBTOTAL	0.02
* TOTAL SPACE HEATING ENERGY				0.02
* TOTAL ENERGY PER NET TON OF PRODUCT				2.02



SUMMARY

	Million Btu per ton of product
Process energy	2.00
Pollution control energy	.00
Space heating	.02
Total energy	2.02

FIGURE 48. - Tin: Detinning new tin-plated scrap.

The total energy required in the detinning process is 2.02 million Btu per ton of No. 2 steel scrap. The detinning operation yields a tin-containing leach solution. This solution is assigned a zero energy value and is introduced into the tin recovery section to produce metallic tin.

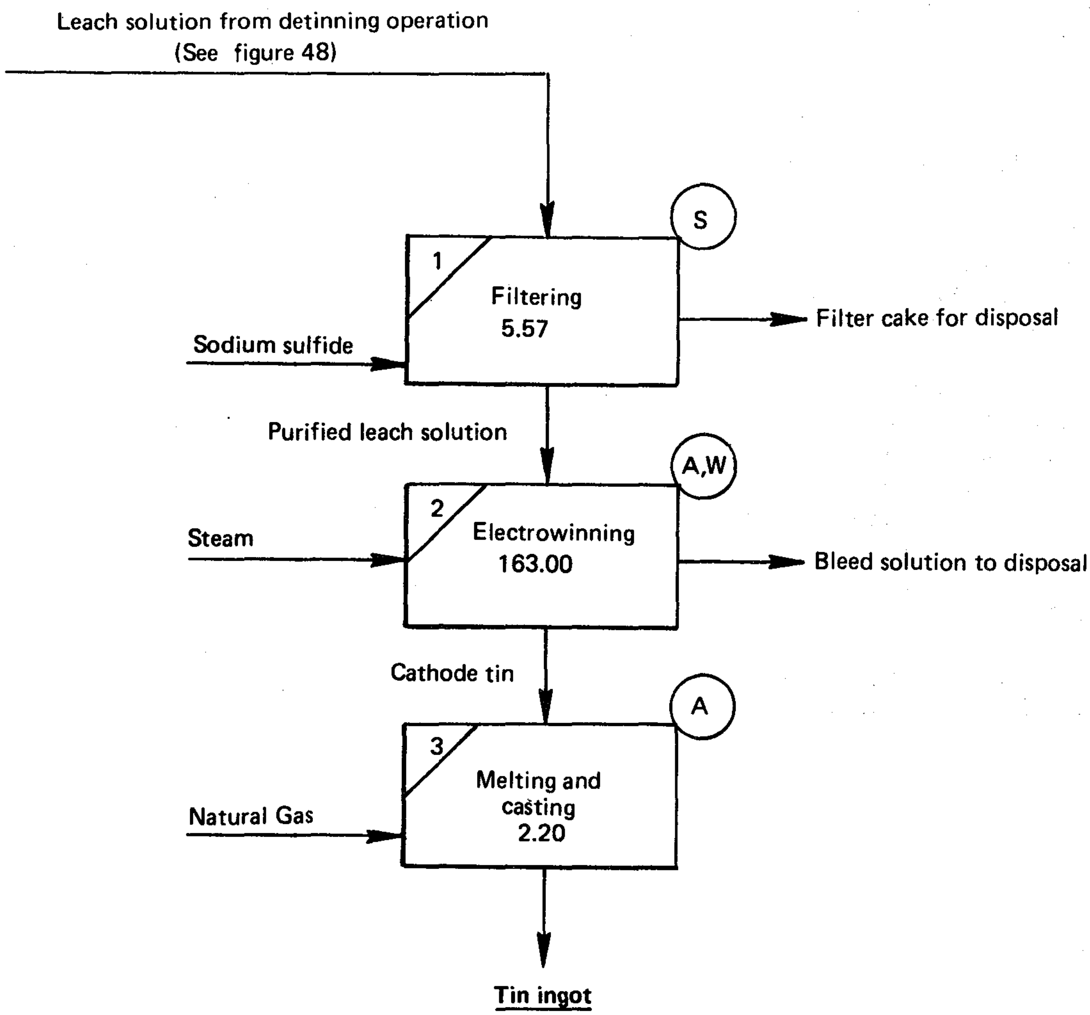
Recovering Tin From Detinning Leach Solution

The energy analysis involving recovery of tin from the detinning leach solution is shown in figure 49 with details presented in table 53. Significant process energy requirements in this process are found in steam heating of the electrowinning solution (58% of the total tin recovery energy), and electrical energy for electrowinning (36%).

TABLE 53. - Tin: Tin recovery from detinning leach solution

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) IMPURITY PRECIPITATION AND FILTERING				
ELECTRICAL ENERGY	KW HR	33.0000	0.010500	0.35
SODIUM SULFIDE	NET TON	0.3000	17.400000	5.22
			SUBTOTAL	5.57
(2) ELECTROWINNING				
ELECTRICAL ENERGY	KW HR	6000.0000	0.010500	63.00
NATURAL GAS	CU. FT.	100000.0000	0.001000	100.00
			SUBTOTAL	163.00
(3) MELTING AND CASTING				
NATURAL GAS	CU. FT.	2200.0000	0.001000	2.20
			SUBTOTAL	2.20
* TOTAL PROCESS ENERGY				170.77
POLLUTION CONTROL ENERGY				
ELECTRICAL ENERGY	KW HR	10.0000	0.010500	0.11
			SUBTOTAL	0.11
* TOTAL POLLUTION CONTROL ENERGY				0.11
SPACE HEATING ENERGY				
NATURAL GAS	CU. FT.	2000.0000	0.001000	2.00
			SUBTOTAL	2.00
* TOTAL SPACE HEATING ENERGY				2.00
* TOTAL ENERGY PER NET TON OF PRODUCT				172.88

The total energy required for this electrowinning step is 172.88 million Btu per ton of tin recovered. As stated earlier, a zero energy value is assigned to the byproduct leach solution produced in the detinning steps shown in figure 40. In the event that another methodology were chosen for calculating the energy requirement, the relevant information can be obtained from tables 52-53.



SUMMARY

	Million Btu per ton of product
Process energy	170.77
Pollution control energy	.11
Space heating	2.00
Total energy	172.88

FIGURE 49. - Tin: Tin recovery from detinning leach solution.

Major Heat Losses

The most significant heat losses in the detinning and tin recovery process are in the open bath leaching, rinsing, and electrowinning sections. The storage and holding of large volumes of leach solution at about 200° F for long periods of time in uninsulated and uncovered leach tanks is the major cause of heat loss. Heat lost in the electrowinning tanks, for similar reasons, is the second highest heat loss area. Heat lost in the melting and casting section, by comparison, is negligible.

Research and Development

The potential areas of research and development in the detinning industry are as follows:

1. Developing a reliable detinning operation with well insulated and covered detinning, rinsing, and electrowinning tanks. This would be the most significant area, both for cost reduction and energy conservation.

2. Developing process schemes to treat municipal solid waste scrap. This scrap is expected to become an important source of tin in the foreseeable future; however, because of the nature of this scrap and its organic coatings, it will require different or modified process schemes for tin recovery from those used for new tin plate scrap.

3. Improving current efficiency in electrowinning. At present, they run only about 40% to 50%.

4. Developing alternate systems of providing heat to the leach solution by an external heat exchanger.

TITANIUM

Background

Table 54 presents data on the secondary titanium industry.

TABLE 54. - Data on secondary titanium industry

	Net tons[1]
Secondary raw materials (1976):	
New scrap	8,400
Obsolete scrap	400
Secondary U.S. production (1976)	([2])

[1]All figures are rounded to the nearest hundred.
[2]Not distinguished from primary production of 21,600 tons.

NOTE.--Commodity: Titanium.
Primary products: Vacuum arc-melted titanium ingots and castings.
Byproducts: None.
Coproducts: None.

Sources: U.S. Bureau of Mines Commodity Data Summaries 1977 and Arthur D. Little, Inc., estimates.

Types and Classifications of Scrap

Titanium and titanium alloys and their scrap are classified into three major categories according to the predominant phase in their microstructure. The alloy types are alpha, beta, and alpha-beta. The most important are alpha-beta alloys; the next most important are the alpha alloys.

Alpha alloys include the unalloyed or low-alloyed titanium grades. They are weldable, nonheat treatable, strong and tough at cryogenic temperatures, more oxidation-resistant than beta or alpha-beta alloys, and relatively difficult to form. Beta alloys are heat treatable, weldable, strong at high temperatures for short times, brittle at cryogenic temperatures, and readily formable at room temperature. Alpha-beta alloys are strong, nonformable, less tough than alpha alloys and, with some exceptions as noted below, are generally difficult to weld. The most important single alloy is the alpha-beta Ti-6Al-4V, with a volume of production comparable to all other alloys combined. Alpha-beta alloys, alpha alloys, and beta alloys and their uses are listed in the following tabulation:

Alloy	Use
Alpha-beta alloys:	
Ti-6Al-4V................	General purpose, forgings, welded fabrications.
Ti-6Al-6V-2Sn............	Aircraft and ordnance parts.
Ti-7Al-4Mo...............	Engine and airframe parts.
Ti-4Al-3Mo-1V............	Parts requiring good formability with high strength.
Ti-8Mn...................	Aircraft skin and structural members.
Ti-8Al-1Mo-1V............	Airframes and turbine applications requiring short-time strength and long-time creep resistance.
Ti-6Al-2Sn-4Zr-2Mo.......	Forgings.
Ti-6Al-2Sn-4Zr-6Mo.......	Forgings requiring high hardenability.
Alpha alloys:	
Unalloyed................	Aerospace, chemical process equipment, and marine uses.
Ti-5Al-2.5Sn.............	Welded, oxidation-resistant, and high-strength parts.
Ti-0.2Pd.................	Special corrosion-resistant applications.
Beta alloys:	
Ti-13V-11Cr-3Al..........	During 1960's, for high-strength airframes and skins, welded pressure vessels, and honeycomb structures.
Ti-8V-8Mo-2Fe-3Al........ Ti-8V-4Mo-6Cr-4Zr-3Al....	Displaces Ti-13V-11Cr-3Al.

In addition to the alloys listed above, a wide range of less common alloy compositions is found in titanium scrap recycling. Therefore, there is a critical need to identify and segregate titanium scrap by specific alloy type to avoid the production of nonspecification ingots.

Physically, titanium scrap is classified into two categories: "Chips" (light) and "solids" (heavy). Although the chemical specifications are the same, the problems and processing methods are different for each category.

Scrap Consumption

Several sources were used for determining the amount of scrap recycled, including published data on the production of ingots (5), production and shipment of mill products (3), consumption of mill products (4), market analyses for secondary titanium metal (1-2), and field trips which resulted in the following estimates on scrap consumption.

Home scrap averages 4% to 5% of total melted ingots. It takes the form of croppings, collars, and turnings.

Prompt industrial scrap is generated in considerable quantities, as only 14% of total ingot production ends up in finished goods. Because of restrictions on contamination of scrap, it is estimated that only 35% of ingot production is recycled to the titanium melting furnaces; 9% is sold to steelmakers as a deoxidizer or as an alloying addition; 20% is exported, principally in the form of contaminated chips; and 2% is sold to aluminum producers as an alloying additive for hardening and grain refining. Finally, 20% is lost as grinding swarf, spent cleaning and pickling solutions, and oxide waste from heat treating operations.

A small amount of obsolete scrap is recycled, mostly from aircraft maintenance operations (about 5%). All alloy types that have been discontinued are of little value for recycling into ingot form, and most of the aircraft incorporating titanium have yet to be retired.

Titanium scrap recycled to the melters consists of solids and chips in a typical ratio of at least 2:1. The implication of this is that most "solids" are recycled to prime quality ingots, whereas a fair amount of "chips" goes to export or to other metallurgical uses.

Contamination Problem

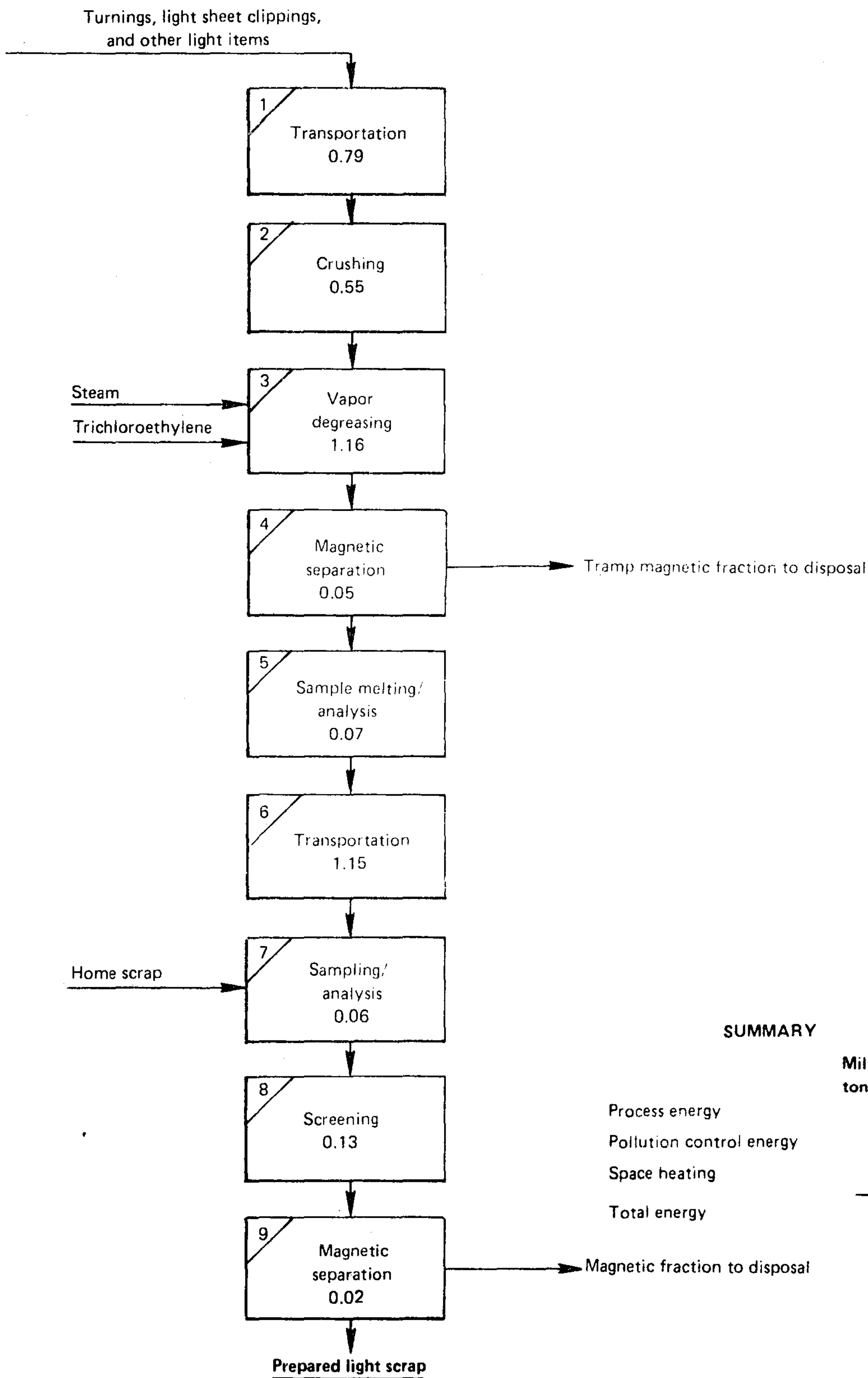
Since there is very little refining action in the melting of titanium scrap to ingot, the scrap must meet very strict standards, especially if the ingots are to be used for aerospace applications. Ordinary contaminants are oxide formation on the surface from exposure to elevated temperatures, hydrocarbons from metalworking lubricants, tramp metals accidentally mixed with the alloys, and fragments of cutting tool bits (usually tungsten carbide). Acceptable levels of impurities are usually measured in parts per million (ppm). Yttrium at concentrations of 1,500 ppm has been added in the past to titanium ingot in the hopes of improving physical properties. As a result, a fair amount of available scrap now contains yttrium. Recently it has been found that yttrium is in fact deleterious, and some fabricators presently require that yttrium be less than 10 ppm in their alloy supply.

Scrap Preparation

The titanium scrap generators are more and more careful to segregate their scrap by alloy grade before shipping to a scrap processor. A major difference from other industry sectors involving scrap preparation is that the melter plays an active role in further processing the scrap it purchases, along with its home scrap. This situation is reflected in the two scrap preparation flowcharts (figs. 50-51).

Light Scrap Preparation

Machine turnings and light sheet clippings are crushed in a hammer mill. This operation improves their handling capability and their packing density for shipping and subsequent briquetting (performed by the melter). The crushed scrap is then solvent-vapor degreased in trichloroethylene. This not only removes the grease, but washes away foreign metal pieces and tramp impurities entrained with the grease. After degreasing, the crushed chips are subjected to magnetic separation to extract any ferrous or ferromagnetic particles that may be present. A representative sample is then taken, and subjected to X-ray spectroscopy so that the lot can be identified. Some of the recovered



SUMMARY

	Million Btu per ton of product
Process energy	3.98
Pollution control energy	.00
Space heating	.00
Total energy	3.98

FIGURE 50. - Titanium: Preparing light scrap.

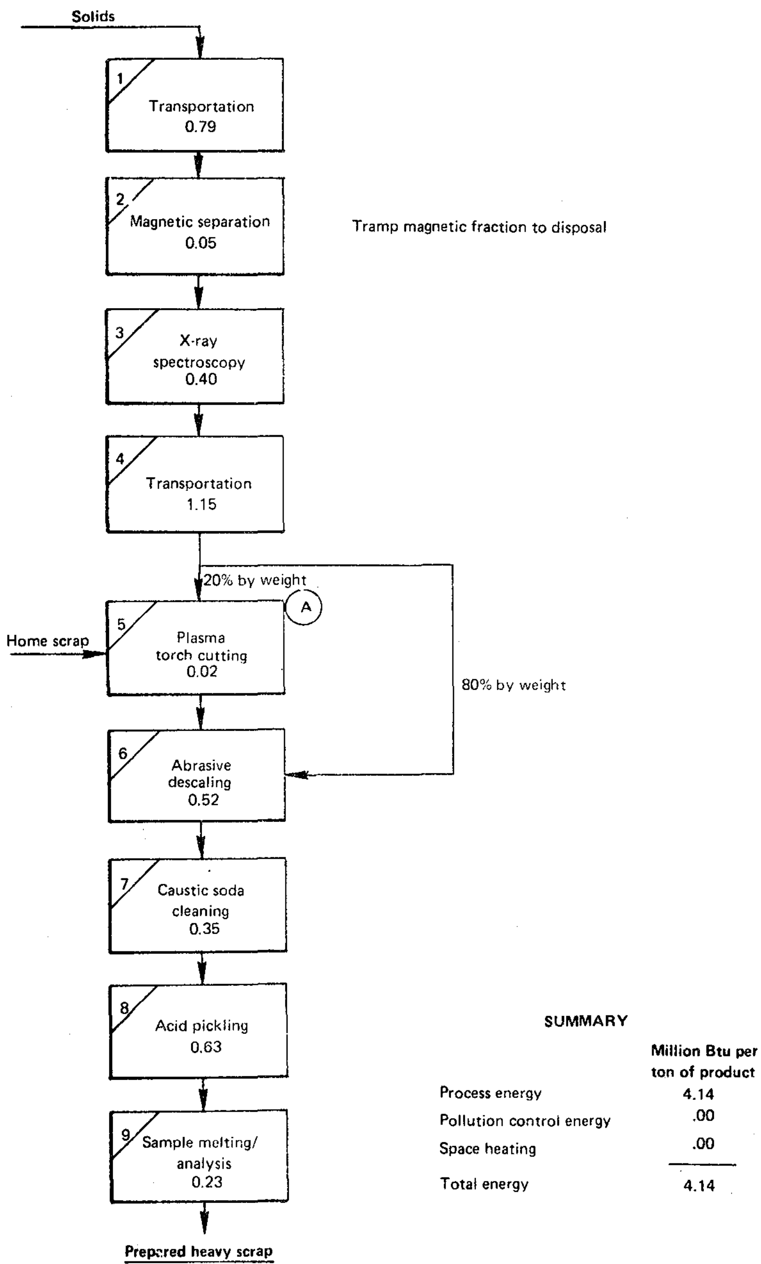


FIGURE 51. - Titanium: Preparing heavy scrap.

light scrap is certified and shipped to melters for recycle back into ingots or castings. The balance is used as either an alloying element or an oxygen scavenger in other metal industries, both domestic and foreign.

Heavy Scrap Preparation

The "solids" are visually inspected and magnetically separated from any tramp ferromagnetic pieces. Each piece of heavy titanium scrap is then individually subjected to X-ray spectroscopy to identify the alloy. Except for pieces that contain unacceptable levels of impurities, the heavy scrap is segregated by grade and shipped to the melters for recycle back to ingots.

The ingot manufacturer receives the certified scrap and processes it farther along with his home scrap. The heavy scrap is cut with a plasma torch, if necessary, descaled by abrasion, cleaned in NaOH, and pickled in HNO_3 with additions of HF. The cleaned heavy scrap is then inspected by spectroscopy and other conventional analytical techniques to make an accurate determination of heavy metals as well as nonmetallics, so that the charge calculations can be made accurately.

Melting and Refining

Major Processing Method

Light scrap is sampled, analyzed, and screened to eliminate the fines and is subjected to a final magnetic separation. It is then ready to be used in

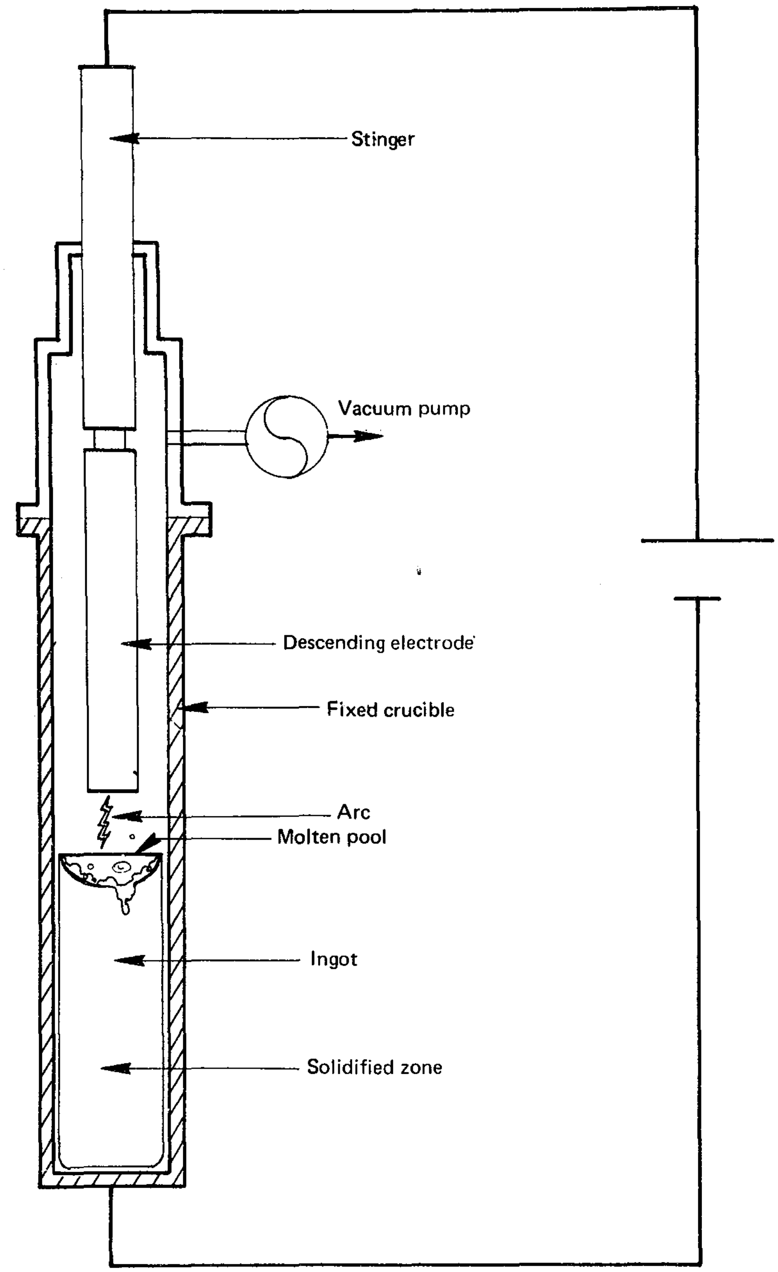


FIGURE 52. - Titanium melting furnace for double or triple vacuum melting.

the charge preparation. Titanium ingots are normally made in consumable electrode vacuum arc furnaces (fig. 52) by either double melting (about 70% of titanium production) or triple melting (about 30%). The electrode contains from zero to 50% scrap, with a national average estimated to be 35%.[18] Very little refining occurs in melting except for some vacuum degassing and some zone refining, which tends to concentrate the impurities on the skin and the top part of the ingot.

The various lots of light scrap are blended with virgin elements, alloys, and sponge into uniform batches of several thousand pounds, which are then briquetted into segments of electrode weighing 40 to 80 pounds. The briquettes, in turn, are then assembled and welded.

The proportions of light scrap being recycled vary with each ingot producer. Some ingot producers believe that the risk of heavy metal contamination from the chips is too high and will not purchase machine turnings for recycle. In most cases, light scrap cannot be briquetted alone, simply because it does not hold together. A sufficient amount of titanium sponge must be mixed with it. The heavy scrap is then assembled with the briquettes, and the electrode is welded together by plasma arc or by any other suitable process, such as electron beam, nonconsumable tungsten electrodes, or titanium wire.

[18]Estimate based on the information gathered during the field visits conducted during this study.

The electrode is first welded to a cap to make a solid electrical connection in the melting furnace. The capped electrode is suspended in the arc furnace which is then sealed and evacuated. An arc is ignited at the base of the electrode and melting is initiated. A pool of molten metal is formed and the metal solidifies into a water-cooled ingot mold.

After the initial vacuum meltdown, only the welded cap from the electrode to the power connection remains. The ingot ends and surfaces are scalped or ground to remove excessive oxides or impurities. The removed material is normally contaminated and is dumped because it only represents a small volume.

The solidified ingot, in turn, becomes an electrode and is remelted. The second melting improves the quality of the ingot by (1) decreasing further the residual levels of volatiles (gases) and (2) by increasing the homogeneity through vertical mixing (deep molten pool). Some ingots are subjected to a third melting to take advantage of these two effects to the utmost. After each remelting, the ingot surface is again conditioned, and the ingot ends are removed as required to meet chemical specifications.

Other Processing Methods

Another approach also being developed for melting titanium scrap to small billets and castings is the use of a nonconsumable electrode vacuum arc furnace. Examples of such processes are the Retech, Inc., Schlienger Rotatrode (rotating electrode) and the Westinghouse "Durarc" (electromagnetically rotating arc).

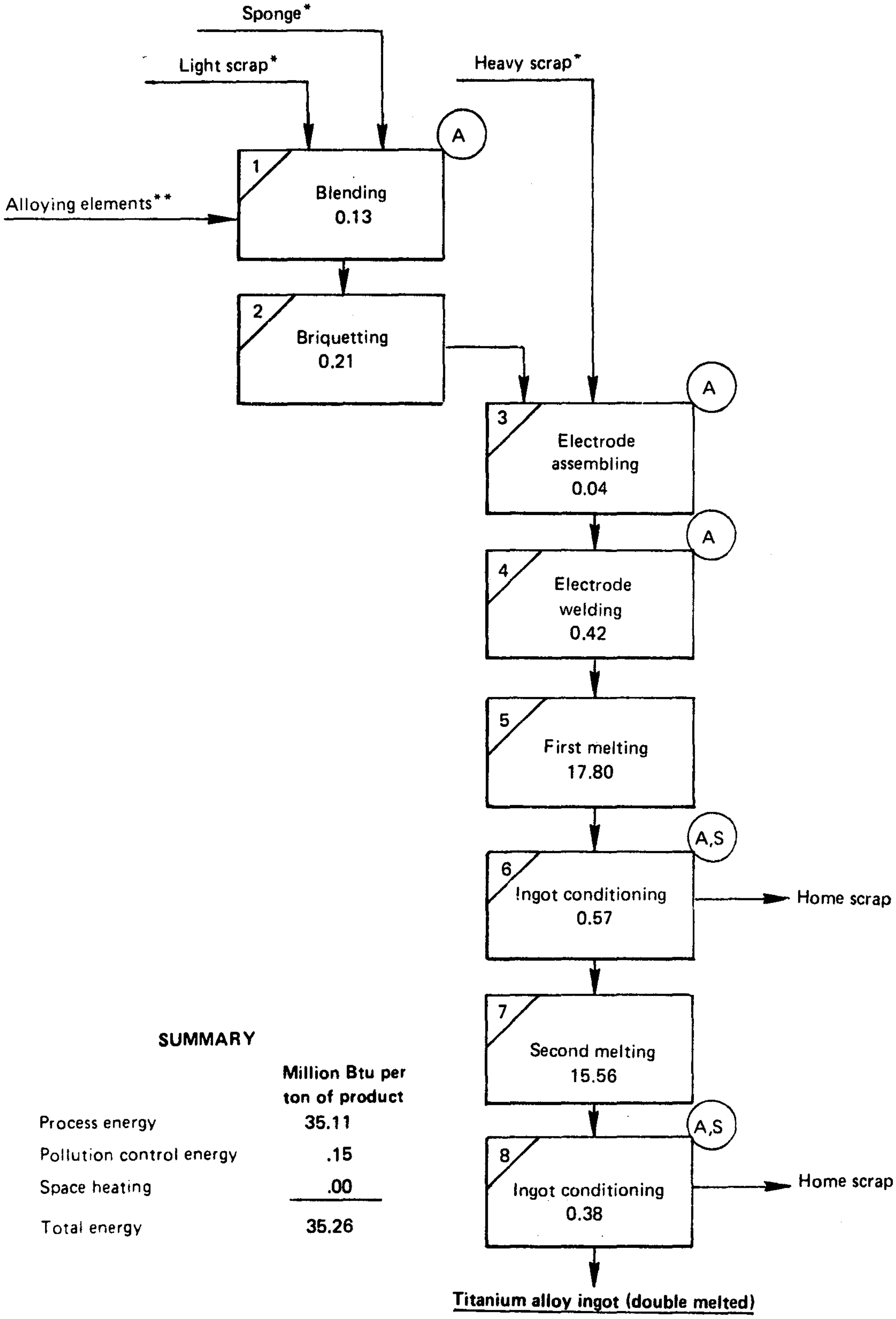
This approach using a nonconsumable electrode has been considered for recovering crushed machine turnings and noncompactable light scrap. The crushed light scrap is side-fed without having to be briquetted. The arc furnace uses a water-cooled copper melting ladle and casting mold. Dense, contaminant particles (tool bit fragments) sink and are entrapped in a titanium skull. A small number of plants operate such furnaces. Nonconsumable arc melting is followed by a conventional consumable electrode remelt to homogenize the product.

This approach is characterized by small capacity, high energy consumption, higher risk of contaminated heats due to the large use of chips, and cheap feedstock because of tramp element contamination.

Pollution Control

No pollution control equipment is generally found in titanium scrap processing operations. At the melting plant, some dust is generated and controlled as follows:

1. During torch cutting and trimming of large pieces, the torch generates a fine oxide dust which is captured by overhead hoods and ducted to a baghouse.



SUMMARY

	Million Btu per ton of product
Process energy	35.11
Pollution control energy	.15
Space heating	.00
Total energy	35.26

*Energy requirements for scrap and sponge excluded on this flowsheet
**Energy content of these alloying elements is not included in the total process energy.

FIGURE 53. - Titanium: Ingotmaking by double melting in vacuum arc furnace.

2. Dust is generated by the handling and tumbling of chips in the blending area. This dust is extremely pyrophoric and is handled with care, for example, in a wet scrubber.

3. Dust is also emitted in the primary melting area from electrode handling. This dust can also be collected by cyclone.

4. The stripping of the ingot from the mold results in the emission of a fine fume containing oxides and residual $MgCl_2$. This fume is captured by overhead hoods and ducted to a high-energy scrubber (for example, 60-inch water pressure drop).

Energy Analysis

Tables 55-57 correspond to figures 50, 51, and 53, respectively. They show the type and amount of energy required at each step from scrap collection to final ingot conditioning. The energy required for handling, processing, and transporting the scrap represents about 4.00 million Btu per ton of scrap. The main energy user under this section is transportation. The average distance from generation to processing is estimated to be 400 miles (mostly by truck). From processor to melter, the scrap moves an average of approximately 1,200 miles (mostly by rail).

Consumable electrode melting requires a fair amount of process energy. The first melting is more energy-intensive than the second because the residual impurities (for example, Mg and $MgCl_2$) must be volatilized. The third melting, when required, consumes as much energy as the second on a "per ton melted basis." Electrode fabrication, double melting, and ingot preparation use about 35 million Btu per ton of final ingot.

The role of scrap is emphasized in figure 54, which shows how the scrap-to-sponge ratio affects the total energy required. Proportions of scrap higher than 50% are not normally attainable for two reasons:

1. Chemically, the sponge dilutes the contaminants present in the scrap; using more than 50% scrap (especially turnings) normally entails a contamination level that is not acceptable, and

2. Physically, the sponge forms a compactable matrix which binds the light scrap together. A proportion of about 20% light scrap in sponge is considered the maximum allowable.

Air pollution controls described earlier require 14 kwhr (0.15 million Btu) per ton of ingot. There is little or no space heating energy required in titanium scrap recycling.

The nonconsumable, rotating, water-cooled, copper electrode process was mentioned earlier. Its main advantage is to bypass the briquetting and welding steps. Accordingly, it permits the use of a larger quantity of light scrap, which is presently often exported. It can be expected to consume at least 20% more electrical energy than a consumable electrode furnace.

TABLE 55. - Titanium: Preparing light scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	300.0000	0.002400	0.72
RAIL	TON MI	100.0000	0.000670	0.07
			SUBTOTAL	0.79
(2) CRUSHING				
ELECTRICAL ENERGY	KW HR	52.3000	0.010500	0.55
			SUBTOTAL	0.55
(3) VAPOR DEGREASING				
TRI-CHLORO-ETHYLENE	GAL	1.5000	0.100000	0.15
STEAM	NET TON	0.3600	2.800000	1.01
			SUBTOTAL	1.16
(4) MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
			SUBTOTAL	0.05
(5) SAMPLE MELTING/ANALYSIS				
ELECTRICAL ENERGY	KW HR	6.8000	0.010500	0.07
			SUBTOTAL	0.07
(6) TRANSPORTATION				
TRUCK	TON MI	200.0000	0.002400	0.48
RAIL	TON MI	1000.0000	0.000670	0.67
			SUBTOTAL	1.15
(7) SAMPLE MELTING/ANALYSIS				
ELECTRICAL ENERGY	KW HR	6.0000	0.010500	0.06
			SUBTOTAL	0.06
(8) SCREENING				
ELECTRICAL ENERGY	KW HR	12.0000	0.010500	0.13
			SUBTOTAL	0.13
(9) MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
			SUBTOTAL	0.02
TOTAL ENERGY PER NET TON OF PREPARED SCRAP				3.98

TABLE 56. - Titanium: Preparing heavy scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) TRANSPORTATION				
TRUCK	TON MI	300.0000	0.002400	0.72
RAIL	TON MI	100.0000	0.000670	0.07
			SUBTOTAL	0.79
(2) MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
			SUBTOTAL	0.05
(3) X-RAY SEPECTROSCOPY				
ELECTRICAL ENERGY	KW HR	38.0000	0.010500	0.40
			SUBTOTAL	0.40
(4) TRANSPORTATION				
TRUCK	TON MI	200.0000	0.002400	0.48
RAIL	TON MI	1000.0000	0.000670	0.67
			SUBTOTAL	1.15
(5) PLASMA TORCH CUTTING(0.20 TON)				
ELECTRICAL ENERGY	KW HR	2.0000	0.010500	0.02
			SUBTOTAL	0.02
(6) ABRASIVE DESCALING				
ELECTRICAL ENERGY	KW HR	50.0000	0.010500	0.52
			SUBTOTAL	0.52
(7) CAUSTIC SODA CLEANING				
CAUSTIC SODA	NET TON	0.0025	29.900000	0.07
STEAM	NET TON	0.1000	2.800000	0.28
			SUBTOTAL	0.35
(8) ACID PICKLING				
NITRIC ACID	NET TON	0.0200	14.200000	0.28
HYDROFLORIC ACID	NET TON	0.0050	14.350000	0.07
STEAM	NET TON	0.1000	2.800000	0.28
			SUBTOTAL	0.63
(9) SAMPLE MELTING/ANALYSIS				
ELECTRICAL ENERGY	KWH	22.0000	0.010500	0.23
			SUBTOTAL	0.23
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				4.14

TABLE 57. - Titanium: Ingotmaking by double melting in vacuum arc furnace

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) BLENDING				
ELECTRICAL ENERGY	KW HR	12.0000	0.010500	0.13
			SUBTOTAL	0.13
(2) BRIQUETTING				
ELECTRICAL ENERGY	KW HR	20.0000	0.010500	0.21
			SUBTOTAL	0.21
(3) ELECTRODE ASSEMBLING				
ELECTRICAL ENERGY	KW HR	4.0000	0.010500	0.04
			SUBTOTAL	0.04
(4) ELECTRODE WELDING(PLASMA ARC)				
ELECTRICAL ENERGY	KW HR	40.0000	0.010500	0.42
			SUBTOTAL	0.42
(5) FIRST MELTING				
ELECTRICAL ENERGY	KW HR	1695.0000	0.010500	17.80
			SUBTOTAL	17.80
(6) INGOT CONDITIONING				
ELECTRICAL ENERGY	KW HR	54.0000	0.010500	0.57
			SUBTOTAL	0.57
(7) SECOND MELTING				
ELECTRICAL ENERGY	KW HR	1482.0000	0.010500	15.56
			SUBTOTAL	15.56
(8) INGOT CONDITIONING				
ELECTRICAL ENERGY	KW HR	36.0000	0.010500	0.38
			SUBTOTAL	0.38
* TOTAL PROCESS ENERGY				35.11
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	14.0000	0.010500	0.15
			SUBTOTAL	0.15
* TOTAL POLLUTION CONTROL ENERGY				0.15
* TOTAL ENERGY PER NET TON OF PRODUCT				35.26

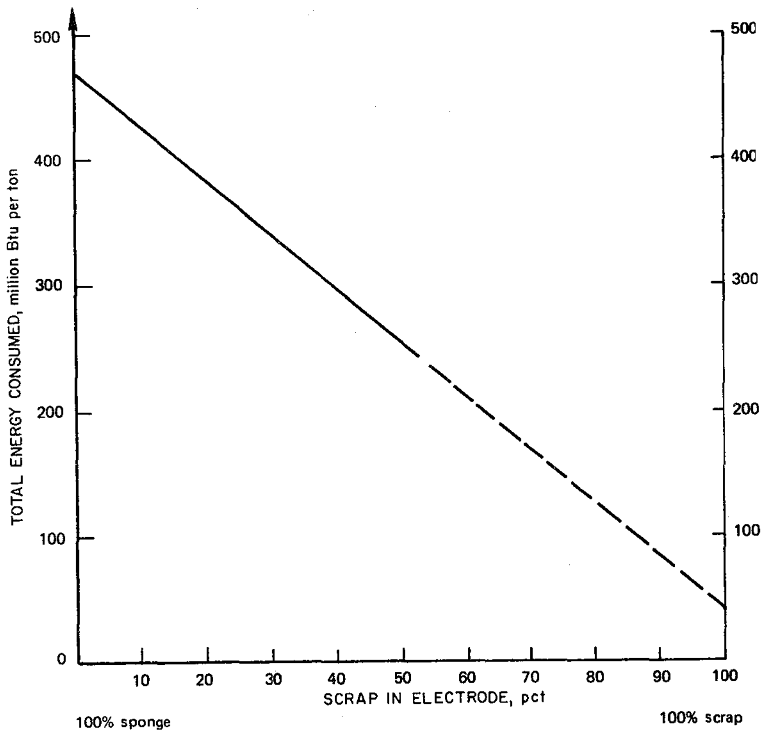


FIGURE 54. - Effect of the percentage of scrap on total energy consumed.

Major Heat Losses

Short of recovering the sensible heat imparted to the water that cools the ingot molds, there is little that can be done by the ingot melters to cut down any heat losses. It should be noted, however, that the number of melting steps has a direct influence on the energy requirement; if one step could be eliminated, an equivalent amount of energy could be saved. Before specifying double or triple melting, consideration should be given as to whether a less energy-intensive method would satisfy the needs of titanium fabricators.

A very minor energy loss is the steam heating of degreasing, cleaning, and pickling solutions. Well-insulated pipes would keep it to a minimum.

Research and Development

Potential areas of research and development for the titanium scrap recycle operations are as follows:

1. Developing a wider range of alloy grades for noncritical applications to permit using scrap directly as secondary mill product stock;

2. Developing melting practices permitting charge mixes with a high proportion of scrap;

3. Developing rapid and efficient alloy identification methods, as excessive reliance on sampling and X-ray spectroscopy is highly energy-consuming;

4. Developing chip cleaning procedures to insure complete removal of tool bits, heavy elements, and nonmetallic particles, thus increasing the acceptability of machine turnings for recycling;

5. Improving the present melting practice to obtain enough refining during the initial melting and avoiding the requirement for double and triple melting schedules; and

6. Developing reliable methods to recover the metal values contained in such wasted materials as grinding swarf, ingot scale, and so on.

References

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ZINC

Background

Table 58 presents data on the secondary zinc industry.

TABLE 58. - Data on secondary zinc industry

	Net tons[1]
Secondary raw materials (1976):	
Prompt industrial scrap (zinc content)...........................	128,000
Obsolete scrap (zinc content).....................................	52,000
Secondary U.S. production (1976)................................	137,000

[1]All figures are rounded to the nearest thousand.

NOTE.--Commodity: Zinc.
Primary products: Slab zinc, zinc dust, zinc oxide, die-cast alloy, and zinc chemicals.
Byproducts: Iron scrap, aluminum scrap.
Coproducts: None.

Source: Division of Nonferrous Metals, U.S. Bureau of Mines, Mineral Industry Surveys, 1976.

Types and Classifications of Scrap

Table 59 shows types of zinc scrap consumed in 1976 for the four broad categories of zinc scrap, namely, galvanizers' scrap, new die-cast scrap, mixed die-cast scrap, and general zinc scrap as further described below.

TABLE 59. - Zinc scrap consumption by smelters and distillers in 1976

Type of scrap	Consumption, tons zinc content	Obsolete scrap,[1] %	Prompt industrial scrap,[1] %
New clippings..................	721	0.0	100.0
Old zinc.......................	8,948	100.0	0.0
Remelt zinc....................	3,248	.0	100.0
Engravers' plates..............	801	100.0	.0
Rod and die scrap..............	5,334	100.0	.0
Diecastings....................	10,881	100.0	.0
Fragmentized diecastings........	14,918	100.0	.0
Remelt die-cast slab...........	7,882	100.0	.0
Skimmings and ashes............	49,397	.0	100.0
Sal skimmings..................	6,614	.0	100.0
Die-cast skimmings.............	4,504	.0	100.0
Galvanizers' dross.............	46,369	.0	100.0
Flue dust......................	5,995	.0	100.0
Chemical residue...............	13,837	.0	100.0
Other..........................	97	.0	100.0
Total......................	179,546	-	-

[1]Arthur D. Little, Inc., estimates based on Zinc chapter for Bureau of Mines 1974 Minerals Yearbook.

Sources: Division of Nonferrous Metals, Bureau of Mines; and Arthur D. Little, Inc., estimates.

Galvanizers' Scrap.--Galvanizers' scrap (primarily drosses, zinc skimmings, sal skimmings and ashes) is by far the largest of the four categories. Zinc skimmings are differentiated from sal skimmings by the fact that the latter consists largely of ZnO contaminated with large quantities of chlorides and fluxes, as well as entrained zinc particles. Zinc skimmings, on the other hand, do not contain the chlorides. In 1976 this broad scrap category provided about 102,000 tons of zinc out of a total of about 180,000 tons. Galvanizers' scrap is classified as prompt industrial scrap.

New Die-Cast Scrap.--New die-cast scrap, classified as prompt industrial scrap, consists of castings discarded as a result of manufacturing defects at the diecasting plant. There are two types of new die-cast scrap. Clean die-cast scrap is well segregated and can be melted at the scrap processing plant to produce a product that meets market specifications. Off-specification die-cast scrap is not so well segregated as clean die-cast scrap and cannot be melted into a product meeting market specifications. It is normally refined and blended to meet market specifications.

Mixed Die-Cast Scrap.--Mixed die-cast scrap, which is classified as obsolete scrap, consists of such products as auto shredders' scrap, old auto parts, and old appliance parts. It forms a substantial portion of the total zinc scrap supply. The scrap from auto shredders is sometimes classified into a separate category, such as auto die-cast scrap.

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

Products

The principal products of the secondary zinc industry are slab zinc, zinc dust, zinc oxide, die-cast alloy, and zinc chemicals. Slab zinc, zinc dust, and zinc oxide are produced from zinc drosses, zinc skimmings, mixed die-cast scrap, and some general zinc scrap, with the product mix depending on the market demand. Die-cast alloy, produced principally from new die-cast scrap, generally contains about 4% Al with smaller quantities of other alloying elements, such as copper, and magnesium. Zinc chemicals, principally $ZnCl_2$, are derived from sal skimmings and ash generated by zinc galvanizers.

A breakdown of secondary zinc products in 1976 is as follows, in net tons: Slab zinc, 52,100; zinc dust, 33,300; zinc oxide, 24,300; and remelt die-cast product, 3,600.

Scrap Preparation

Zinc drosses and zinc skimmings are largely shipped from galvanizing operations in drums or solid blocks to the scrap-consuming plant. There they are charged to the distillation furnace either directly or after first being melted in a separate operation. Some plants dry-mill the zinc skimmings and air-classify to separate the metallic zinc from zinc oxide.

New die-cast scrap and general zinc scrap usually require no preparation before being consumed by a secondary zinc smelter. On the other hand, mixed die-cast scrap and auto die-cast scrap contain a large amount of other ferrous and nonferrous material. Therefore, they are pretreated in a sweating furnace (generally a rotary type) to produce a low-purity zinc product. The zinc product is charged to a distillation furnace either in a molten state or as cast solid. The treatment of sal skimmings for recovery of zinc involves milling and classification. However, because sal skimmings account for a small portion of zinc recycled with an orientation toward chemicals recovery, their treatment is not included in this analysis.

Distillation and Remelting

Major Processing Methods

Basically, zinc scrap is treated by three major schemes: Retort distillation, muffle furnace distillation, and pot melting.

Retort Distillation

The retort distillation scheme (fig. 55) produces slab zinc or zinc dust from prepared (sweated, rich zinc fraction) and unprepared zinc scrap. Three types of retort furnaces are in general use: Stationary, horizontal, and tilting. Stationary retort furnaces are fired with either gas or oil through a port at the bottom of the furnace, and the exhaust gas discharges through a vent in the crown. Horizontal furnaces are similar in construction and size to the stationary retort furnace. The tilting type of retort furnace consists of a large refractory-lined cylindrical steel vessel mounted on trunnions which permit it to be tripped at an angle during charging and discharging.

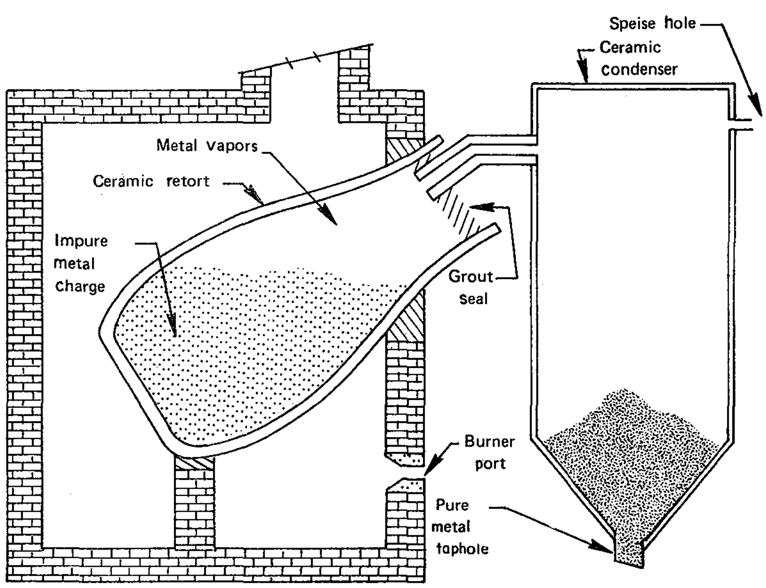


FIGURE 55. - Zinc: Retort distillation furnace. *(Courtesy, Department of Health, Education, and Welfare)*

In each type of retort furnace a graphite or silicon carbide retort is used. There are several retort designs used in industry. One such design, shaped like a bottle and capable of taking a charge of about 4,000 pounds, can be used in the stationary- or tilting-type distillation furnace. Another retort design consists of a cylindrical tube also holding about 4,000 pounds. It can be used only in the horizontal-type distillation furnace. The scrap is charged to the retort which is externally heated by natural gas or oil. The scrap charge is then heated to the boiling point of zinc with the zinc vapors passing through the neck of the retort into a condenser where they are cooled to form either metal or dust, depending on the type of condenser. The condenser used for the production of zinc dust is constructed of steel and is not lined, whereas the condenser for the production of zinc metal is refractory-lined. Zinc recoveries of more than 90% are achieved in the retort distillation process. The solid waste residue from the process is either sold or sent to landfill.

Muffle Furnace Distillation

In the muffle furnace distillation process (fig. 56), heat for zinc vaporization is supplied by gas- or oil-fired burners. The products of combustion transfer heat to the scrap charge by convection, conduction, and radiation through a silicon carbide arch that separates the zinc vapors and the products of combustion. Cold zinc scrap or molten zinc from a sweat furnace is fed into the muffle furnace. The zinc vapors are conducted to a condenser where purified liquid zinc at about 900° F is collected. Alternatively, the condenser is bypassed and the vapors are discharged through an orifice into a stream of air where ZnO is formed and then collected in a baghouse. Such muffle furnaces can produce zinc of 99.8% purity and ZnO of 99.9% purity. Recoveries of more than 90% are usually obtained. Losses occur as entrapped zinc in the unmelted scrap and in the fumes.

Pot Melting

Pot melting of zinc die-cast scrap involves melting either well-segregated or off-specification zinc die-cast scrap in a steel pot furnace. Pot melting is a simple melting scheme in which heat is supplied to the charge by indirect heating. Therefore, fuel efficiency rarely exceeds 20% and is generally in

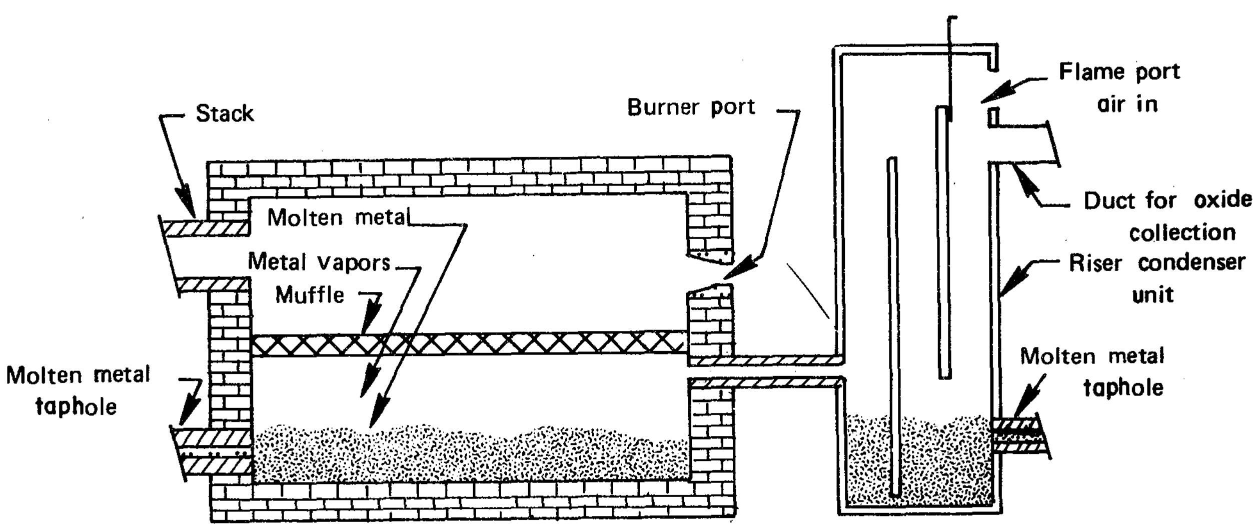


FIGURE 56. - Muffle furnace and condenser. *(Courtesy, Department of Health, Education, and Welfare)*

the 10% to 15% range. Recovery of more than 90% is achieved with losses occurring principally as zinc fumes and skimmings.

Other Processing Methods

A large amount of secondary zinc scrap (principally galvanizers' drosses and skimmings) is treated by the electrothermic distillation process. This process uses resistance-type electric furnaces relying on a flow of current through the charge to generate the energy required for smelting. The process can produce slab zinc or ZnO. Normally, the secondary materials are charged to the furnace along with sintered ore. Since there is only one plant in the United States utilizing this process (St. Joe Minerals Corp.'s smelter in Josephtown, Pa.), an energy analysis was not made for this process in this study. However, an energy analysis for the electrothermic process for primary zinc production has been previously undertaken (1). Rough energy consumption estimates for the production of zinc from secondary zinc scrap by the electrothermic process can be established on the basis of that analysis by selecting the unit operations pertinent to secondary zinc production.

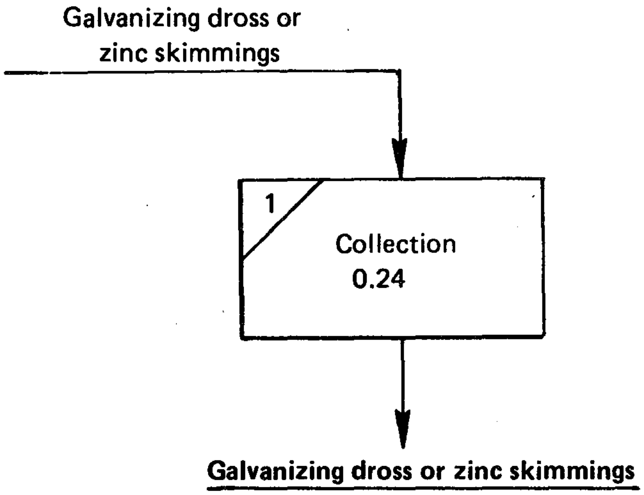
Because distillation of secondary zinc by Larvik electric furnaces (practiced only by Federated Metals plants in the United States) is small compared with that of fossil fuel-heated muffle and retort furnaces, the Larvik furnace energy analysis is not presented in this study. Sal skimmings contain large quantities of NH_4Cl, ZnO, and entrained zinc particles. Treatment of sal skimmings is more akin to a chemical processor with the major emphasis on the production of chemicals and ZnO rather than zinc. Therefore, its analysis was not undertaken in this study.

Energy Analysis

Energy analyses are presented for the following: Scrap preparation; production of zinc dust by the retort distillation process; production of slab zinc by the muffle furnace distillation process; pot melting of clean die-cast scrap; and pot melting of off-specification die-cast scrap. The energy numbers presented are derived from information gathered during plant visits.

Scrap Preparation

Flowsheets and energy tables for scrap preparation are presented in figures 57-60. Figure 57 shows the energy for preparation of drosses and zinc skimmings. The only energy involved is in the transportation of the scrap, which is equivalent to 0.24 million Btu per ton of prepared scrap. A few secondary zinc distillation plants melt the drosses in fuel-fired reverb furnaces before charging to the distillation furnaces. The energy required for scrap preparation in such plants is significantly higher--on the order of about 3.75 million Btu per ton of prepared scrap. This is, however, recovered to a significant extent by reduction in the energy required in distillation. Some plants also dry-mill the zinc skimmings and air-classify to separate the metallic fraction from oxide fraction. In this analysis this treatment is not considered since it has only a limited practice.

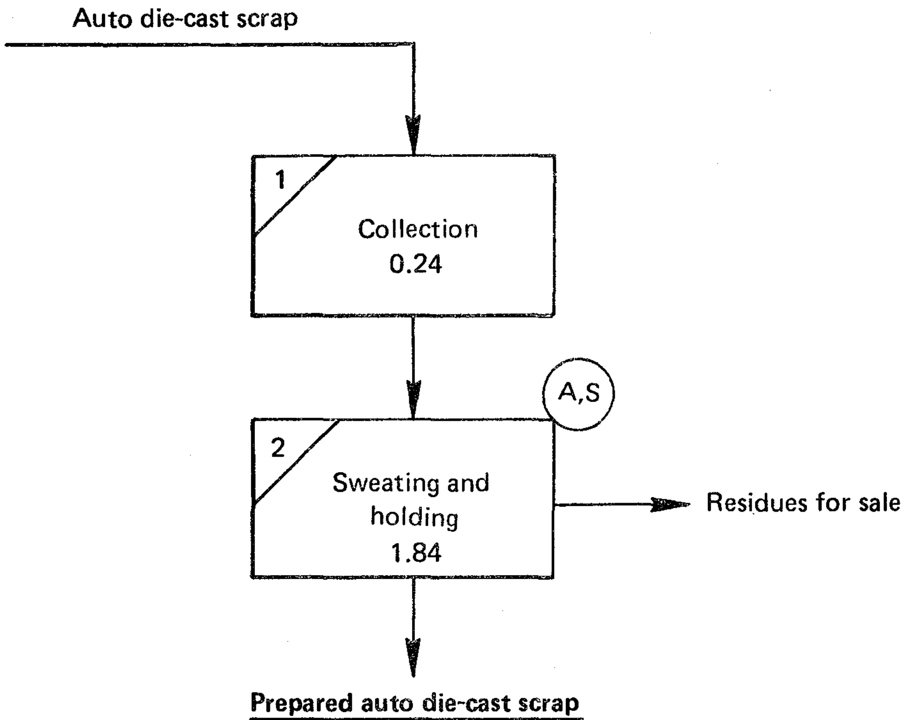


SUMMARY

	Million Btu per ton of product
Process energy	0.24
Pollution control energy	.00
Space heating	.00
Total energy	.24

FIGURE 57. - Zinc: Preparing galvanizing dross or zinc skimmings.

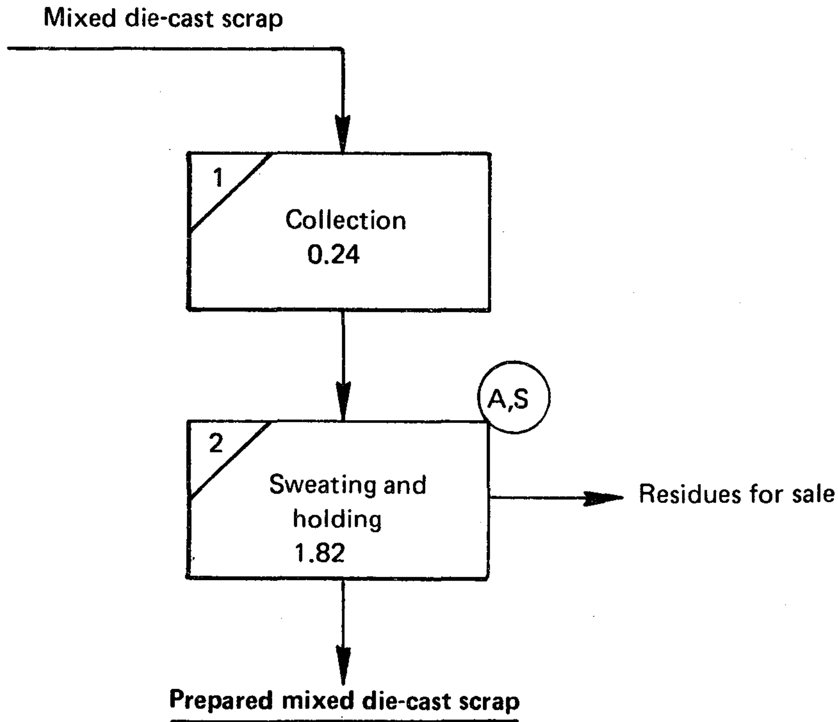
Figure 58 shows that about 4 million Btu of energy is required to prepare 1 ton of sweated zinc from auto die-cast scrap. Most sweating furnaces are of the rotary type and require a high-energy-consuming afterburner as a pollution control device. Breakdown of energy required in the preparation of auto die-cast scrap is approximately as follows: Collection (6% of total energy), sweating and holding (46%), and pollution control (48%).



SUMMARY

	Million Btu per ton of product
Process energy	2.08
Pollution control energy	1.92
Space heating	.00
Total energy	4.00

FIGURE 58. - Zinc: Preparing auto die-cast scrap.



SUMMARY

	Million Btu per ton of product
Process energy	2.06
Pollution control energy	.04
Space heating	.00
Total energy	2.10

FIGURE 59. - Zinc: Producing mixed die-cast scrap.

Energy required for preparation of mixed die-cast scrap is estimated at about 2.10 million Btu per ton of prepared scrap (sweated zinc). About 87% of the total energy required in mixed die-cast scrap preparation is used in the sweating furnace and the molten zinc holding pot. Generally, no afterburner is used on the sweating furnace because of the clean nature of the scrap. For plants that use an afterburner on the sweating furnace, the total energy required for preparation of mixed die-cast scrap is about 4 million Btu per ton of prepared scrap.

New die-cast scrap requires no preparation prior to remelting and refining, except for transportation of the scrap which accounts for about 0.5 to 0.6 million Btu per ton of zinc alloy produced (figs. 61-62).

Producing Zinc Dust by Retort Distillation Process

Flowsheets and energy tables are presented in figures 57-60 and tables 60-63. Figures 57-59 and tables 60-62 represent scrap preparation and transportation analysis; figure 60 and table 63 represent the distillation step of the process. Fuel for distillation accounts for about 92% of the total energy expended in the retort distillation process.

Total energy requirement of the process is 24.01 million Btu per ton of zinc dust. The process can also be adapted to produce slab zinc or ZnO. The energy required to produce slab zinc is the same as that for zinc dust production, except that for slab zinc production the "dust preparation" step--that is, grinding and screening--would not be required but a casting section would be added. The energy requirement for slab zinc production is estimated to be 23.90 million Btu per ton of slab zinc. Production of zinc oxide by the retort distillation process requires the same energy as does zinc dust production; that is, 24.01 million Btu per ton of zinc content in ZnO.

TABLE 60. - Zinc: Preparing galvanizing dross or zinc skimmings

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
TRUCK (100,0 MILES)	TON ML	100,0000	0,002400	0,24
			SUBTOTAL	0,24
* TOTAL PROCESS ENERGY				0,24
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				0,24

TABLE 61. - Zinc: Preparing auto die-cast scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
TRUCK (100,0 MILES)	TON ML	100,0000	0,002400	0,24
			SUBTOTAL	0,24
(2) SWEATING AND HOLDING				
NATURAL GAS	CU, FT,	1820,0000	0,001000	1,82
ELECTRICAL ENERGY	KW HR	1,5000	0,010500	0,02
			SUBTOTAL	1,84
* TOTAL PROCESS ENERGY				2,08
AIR POLLUTION CONTROL				
NATURAL GAS	CU, FT,	1880,0000	0,001000	1,88
ELECTRICAL ENERGY	KW HR	4,0000	0,010500	0,04
			SUBTOTAL	1,92
* TOTAL POLLUTION CONTROL ENERGY				1,92
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				4,00

TABLE 62. - Zinc: Preparing mixed die-cast scrap

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PREPARED SCRAP	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PREPARED SCRAP
(1) COLLECTION				
TRUCK (100.0 MILES)	TON ML	100.0000	0.002400	0.24
			SUBTOTAL	0.24
(2) SWEATING AND HOLDING				
NATURAL GAS	CU. FT.	1800.0000	0.001000	1.80
ELECTRICAL ENERGY	KW HR	1.5000	0.010500	0.02
			SUBTOTAL	1.82
* TOTAL PROCESS ENERGY				2.06
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	4.0000	0.010500	0.04
			SUBTOTAL	0.04
* TOTAL POLLUTION CONTROL ENERGY				0.04
* TOTAL ENERGY PER NET TON OF PREPARED SCRAP				2.10

TABLE 63. - Zinc: Producing zinc dust from scrap in distillation retorts

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) RETORT DISTILLATION				
SCRAP - GALVANIZING DROSS	NET TON	0.9000	0.240000	0.22
SCRAP - AUTO DIE CAST	NET TON	0.2000	4.000000	0.80
SCRAP - MIXED DIE CAST	NET TON	0.0500	2.100000	0.11
NATURAL GAS	CU. FT.	22000.0000	0.001000	22.00
ELECTRICAL ENERGY	KW HR	15.0000	0.010500	0.16
SILICON CARBIDE	NET TON	0.0050	50.000000	0.25
			SUBTOTAL	23.54
(2) GRINDING AND SCREENING				
ELECTRICAL ENERGY	KW HR	5.0000	0.010500	0.05
			SUBTOTAL	0.05
* TOTAL PROCESS ENERGY				23.59
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	28.0000	0.010500	0.29
			SUBTOTAL	0.29
* TOTAL POLLUTION CONTROL ENERGY				0.29
SPACE HEATING				
NATURAL GAS	CU. FT.	130.0000	0.001000	0.13
			SUBTOTAL	0.13
* TOTAL SPACE HEATING ENERGY				0.13
* TOTAL ENERGY PER NET TON OF PRODUCT				24.01

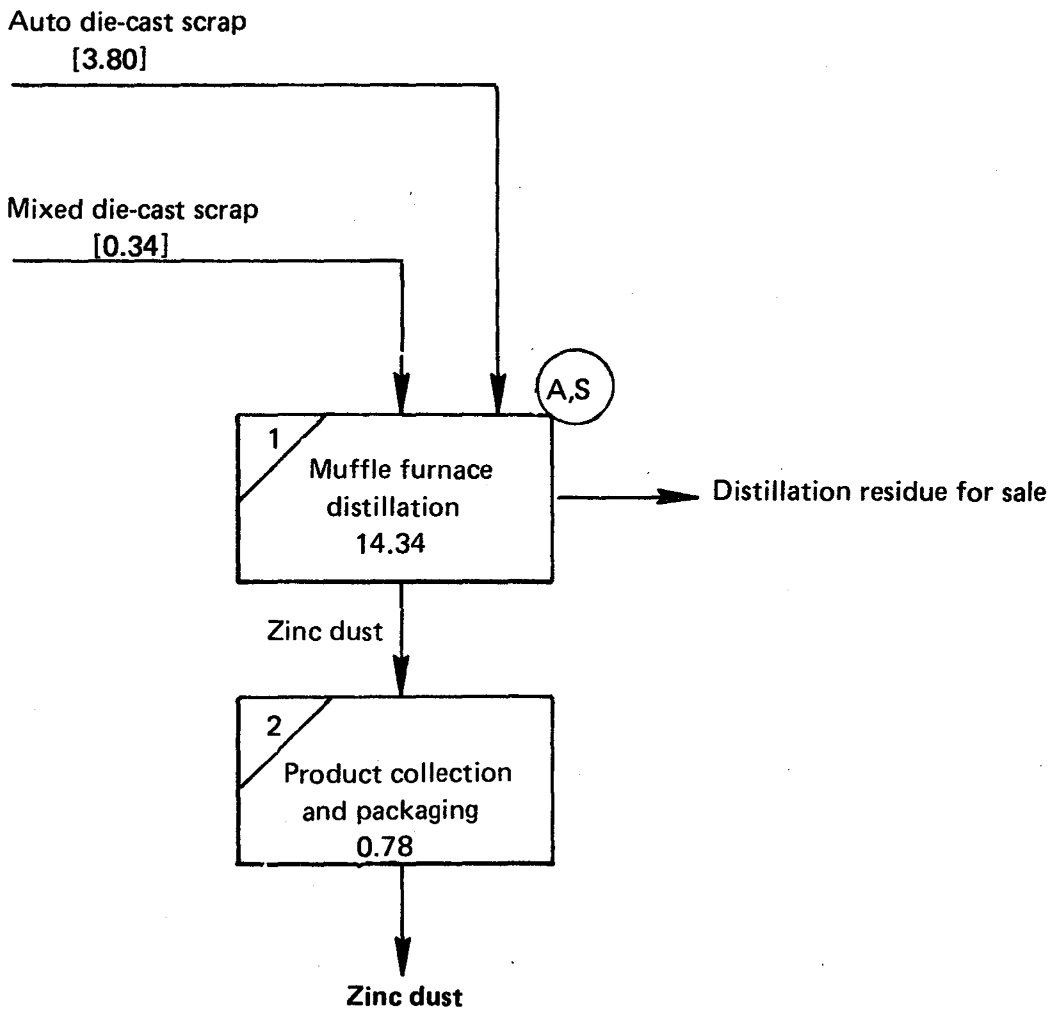
Producing Zinc Oxide by Muffle Furnace Distillation Process

A flowsheet and energy table for this process are presented in figure 63 and table 64. The breakdown of energy requirements for zinc dust production by the process is distillation fuel (72%), scrap preparation (21%), and pollution control (2%). The total energy required for the process is 19.71 million Btu per ton of zinc dust.

TABLE 64. - Zinc: Producing zinc dust from scrap in muffle furnace

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) MUFFLE FURNACE DISTILLATION				
SCRAP - AUTO DIE CAST	NET TON	0.9500	4.000000	3.80
SCRAP - MIXED DIE CAST	NET TON	0.1600	2.100000	0.34
NATURAL GAS	CU. FT.	14000.0000	0.001000	14.00
ELECTRICAL ENERGY	KW HR	25.0000	0.010500	0.26
SILICON CARBIDE	NET TON	0.0015	50.000000	0.08
			SUBTOTAL	18.48
(2) PRODUCT COLLECTION AND PACKAGING				
ELECTRICAL ENERGY	KW HR	74.0000	0.010500	0.78
			SUBTOTAL	0.78
* TOTAL PROCESS ENERGY				19.26
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	30.0000	0.010500	0.32
			SUBTOTAL	0.32
* TOTAL POLLUTION CONTROL ENERGY				0.32
SPACE HEATING				
NATURAL GAS	CU. FT.	130.0000	0.001000	0.13
			SUBTOTAL	0.13
* TOTAL SPACE HEATING ENERGY				0.13
* TOTAL ENERGY PER NET TON OF PRODUCT				19.71

In addition, the muffle furnace is also capable of producing ZnO or slab zinc instead of zinc dust. The energy required for ZnO production (per ton zinc content) is essentially the same as for zinc dust production. However, energy required to produce slab zinc would be lower than that required for zinc dust production because product collection and packaging steps are not required. Energy requirements for slab zinc production are about 18.93 million Btu per ton of slab zinc.



SUMMARY

	Million Btu per ton of product
Process energy	19.26
Pollution control energy	.32
Space heating	.13
Total energy	19.71

FIGURE 63. - Zinc: Producing zinc dust from scrap in muffle furnace.

Pot Melting Clean Die-Cast Scrap

A flowsheet and energy table for pot melting clean die-cast scrap are presented in table 65 and figure 61 which show that fuel used directly in the process comprises 77% of the total energy requirements. Energy required for transportation of scrap is 19% of the total. Field trips indicated no energy is consumed for pollution control. The energy required for the process is 2.58 million Btu per ton of remelted zinc die-cast metal.

TABLE 65. - Zinc: Recycling clean zinc die-cast scrap by pot melting

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) COLLECTION				
TRUCK	TON MI	210.0000	0.002400	0.50
			SUBTOTAL	0.50
(2) POT MELTING AND CASTING				
NATURAL GAS	CU. FT.	1950.0000	0.001000	1.95
ELECTRICAL ENERGY	KW HR	3.0000	0.010500	0.03
			SUBTOTAL	1.98
* TOTAL PROCESS ENERGY				2.48
POLLUTION CONTROL ENERGY				
ELECTRICAL ENERGY	KW HR	0.0000	0.010500	0.00
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.00
SPACE HEATING ENERGY				
NATURAL GAS	CU. FT.	100.0000	0.001000	0.10
			SUBTOTAL	0.10
* TOTAL SPACE HEATING ENERGY				0.10
* TOTAL ENERGY PER NET TON OF PRODUCT				2.58

Pot Melting Off-Specification Die-Cast Scrap

A flowsheet and energy table for the process are presented in table 66 and figure 62. Because of the necessity to flux, refine, and/or alloy the off-specification die-cast scrap and because of lower recoveries, the energy required per ton of product is higher than that required for pot melting clean die-cast scrap. However, of the 3.26 million Btu per ton of product required, fuel required for the process accounts for about 77% of the energy, and transportation, for about 18%. The balance of energy required is accounted for by fluxes, electrical energy, and space heating.

TABLE 66. - Zinc: Recycling off-specification zinc die-cast scrap by pot melting

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) TRANSPORTATION				
TRUCK	TON MI	250.0000	0.002400	0.60
			SUBTOTAL	0.60
(2) POT MELTING, REFINING, CASTING				
NATURAL GAS	CU. FT.	2475.0000	0.001000	2.48
ELECTRICAL ENERGY	KW HR	3.0000	0.010500	0.03
SODIUM CHLORIDE	NET TON	0.0010	0.490000	0.00
KCL	NET TON	0.0010	2.590000	0.00
ALUMINUM FLORIDE	NET TON	0.0010	51.400002	0.05
			SUBTOTAL	2.56
* TOTAL PROCESS ENERGY				3.16
POLLUTION CONTROL ENERGY				
ELECTRICAL ENERGY	KW HR	0.0000	0.010500	0.00
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.00
SPACE HEATING ENERGY				
NATURAL GAS	CU. FT.	100.0000	0.001000	0.10
			SUBTOTAL	0.10
* TOTAL SPACE HEATING ENERGY				0.10
* TOTAL ENERGY PER NET TON OF PRODUCT				3.26

Major Heat Losses

Major areas of heat loss in the various secondary zinc recovery schemes are outlined below.

Distillation Retorts

The distillation retort requires about 22 million Btu per ton of zinc vaporized. In fact, about 90% of fuel energy input to the retort is lost, primarily as sensible heat in combustion gases. Heat losses in furnace products and shell losses are relatively small by comparison.

Muffle Furnace

Though the muffle furnace utilizes fuel energy more efficiently than does the retort, there are substantial losses of energy, primarily as hot combustion gases which leave the furnace at about 2,000° F. By comparison, heat loss in the shell and furnace products is small. Overall, heat efficiency in the muffle furnace is about 15% to 20%.

Pot Furnace

Pot melting zinc scrap has a heat efficiency of only about 10% to 15%. Because of the indirect heating involved, most of the heat loss is in the form of combustion gases.

Research and Development

The potential areas of research and development in the secondary zinc industry are as follows:

1. Utilizing waste combustion gases from the distillation furnaces for heating sweating furnaces, holding kettles, or preheating combustion air to the distillation retort burners;

2. Devising a method to recover heat from the condensation of zinc vapors in making zinc dust or slab zinc by distillation processes;

3. Utilizing the heat liberated in zinc dust oxidation to make ZnO (presently this heat is not being recovered);

4. Developing a viable process scheme to treat zinc skimmings generated in the zinc industry; a large share of these skimmings were originally treated by the now obsolete horizontal retort furnace; and

5. Developing an economically viable process scheme to recover zinc in the low-zinc-content flue dusts generated in the steel industry.

Reference

1. Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4--Energy Data and Flowsheets, High-Priority Commodities). BuMines Open File Rept. 80-75, 1975, 192 pp.; available for consultation at Bureau of Mines facilities in Albany, Oreg., Avondale, Md., Reno and Boulder City, Nev., Rolla, Mo., Salt Lake City, Utah, Tuscaloosa, Ala., and Twin Cities, Minn.; and at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 245 759.

MUNICIPAL SOLID WASTE

Background

Process Technology

The traditional approach for disposal of municipal solid waste (MSW) has focused on landfill or incineration. In general, these traditional techniques do not in themselves involve resource recovery. However, either landfill or incineration may include source segregation, and incineration may include energy recovery.

Source segregation can be considered the forerunner of resource recovery. In its simplest form, it consists of selective handpicking of the more valuable scrap metals from MSW (for example, copper, lead batteries, and aluminum cans) for sale to scrap dealers. This was followed, on a larger scale, by placing containers at locations like homes and landfills, for the separate collection of specific MSW components, such as bottles, paper, aluminum cans, and tin cans. Although revenues were received from the sale of these components, the segregation was often done primarily to reduce landfill volume. Recently, high-value waste material has been collected successfully by paying for the material brought in to collection centers. Aluminum cans are a good example of this type of source segregation.

With the growing desire to conserve natural resources and reduce pollution, combined with an increasing scarcity of landfill space, traditional methods of MSW disposal (landfill or incineration with minimal source segregation) are becoming less acceptable. Source segregation is best applied only to the high-value MSW components like aluminum. Its major disadvantage is that it requires a high degree of cooperation and self-discipline from the general population.

Many approaches have been suggested to recover the energy and mineral-based materials in MSW. Current technology in resource recovery includes the following: Low-temperature dry systems for recovery of metals, glass, and a solid refuse-derived fuel (RDF); high-temperature pyrolysis systems to produce a fuel oil or gas with recovery of metals and glass; wet systems that recover metals, glass, and paper fiber; and recovery of metals and glass from municipal incinerator residues.

Technology for the recovery of materials from incinerator residue has advanced significantly in the past few years as a result of work done by the Bureau of Mines and others. Currently operating commercial units recover only magnetic scrap. In addition, several pyrolysis systems have been developed by private companies and operated on a demonstration plant basis. A wet system, for recovering paper fiber, has also been demonstrated by a private company, but neither of these technologies has yet been installed on a commercial basis.

Much of the current research effort is focused on treating raw MSW for resource recovery and RDF production. Within the United States there are several installations operating commercially and several more are under construction or in the startup mode. These plants plan to recover and recycle magnetic metals, nonmagnetic metals (basically nonferrous), glass, and a combustible RDF (for example, paper, plastic, and rubber). This analysis concentrates on the energy requirements of such RDF-producing plants.

The technology for MSW resource recovery and incinerator residue recovery is still developing, and neither system is currently in widespread commercial use in the United States. In 1976, approximately 140,000 tons (ferrous content) of magnetic scrap was recovered from MSW. This was derived from eight incinerator residue recovery units recovering about 70,000 tons of magnetic scrap materials (approximately 35,000 tons ferrous content) and 22 other units[19] recovering about 105,000 tons of magnetic scrap (essentially 100% ferrous) from MSW. This 140,000 tons of ferrous scrap from MSW represents about 0.8% of a total of about 18,515,000 tons of obsolete iron and steel scrap which was recycled in the United States in 1976. More than 10 new MSW-based commercial plants are scheduled to commence operations in 1977 to 1978. The rate at which resource recovery is implemented in the United States will be influenced by the success of these plants.

Products

The reusable components of MSW include newsprint, corrugated board, plastics, rubber, miscellaneous paper, glass, magnetic metals, and nonmagnetic metals (mainly aluminum). Uses for these components, including direct recycle and dissipative uses, are outlined in table 67. Potential end-use markets for the recovered components are discussed later. Some of the impurity limitations imposed by the various industries are also presented, but these are only indicative, not definitive. The American Society for Testing and Materials (ASTM) is currently developing specifications for the material recovered from MSW, and the Department of Commerce is also preparing guidelines for specifications under the Resource Conservation and Recovery Act of 1976. With the exception of scrap used in copper cementation, none of these end-use markets has used MSW-derived metallic scrap on a long-term or continuous commercial basis. However, tests have been run indicating such use is feasible.

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[19]Only two of these units were commercial-scale resource recovery systems. The other 20 were pilot plants, demonstration plants, or shredfills (shredding MSW prior to landfill) with magnetic separation units.

TABLE 67. - Potential uses for components of municipal solid waste (MSW)

MSW component	Direct reuse	Direct reuse market	General specifications	Particular specifications	Dissipative use	Dissipative end-use market	General specifications
Newsprint....	Recycle.	Newsprint.......	Low contamination	-	Incinerate	Power generation	Low moisture, low alkali metals, low chlorine, low ash, and high-Btu value.
Corrugated board.	...do...	Corrugated board	.....do.......	-			
Plastics.....	Unproven	-	-	-			
Rubber.......	...do...	-	-	-			
Miscellaneous paper.	-	-	-	-			
Glass cullet.	Recycle.	Remelt glass....	Low nonglass contamination (ceramics).	-	Fill......	Aggregate for brick or paving material.	-
Magnetic metals (ferrous).	Detin...	Steel producers.	Low organics..	Low aluminum, no heat over 450° C.	Dissolve..	Copper precipitation	Low organics, no surface coatings.
Do.........	Recycle.	Integrated steel producers.	.....do.......	Low tin, low copper.	-	-	-
Do.........	...do...	Nonintegrated steel producers	.....do.......	-	-	-	-
Do.........	...do...	Export..........	.....do.......	-	-	-	-
Nonmagnetic metals (aluminum).	...do...	Wrought alloys..	High purity...	Only aluminum cans.	Remelt....	Deoxidation of iron and steel.	Low organics.
Do........	...do...	Casting alloys..	.....do.......	-	-	-	-
Residue ash and dirt.	-	-	-	-	Landfill..	-	-

Fractions

Magnetic Fraction

Detinning

As discussed in the chapter dealing with tin, detinners use a wet alkaline chemical process to remove the tin from cans. Based on the economics of the process, detinners require a minimum of about 0.15% Sn content in the scrap they purchase. To minimize loss of the caustic leaching solution, the scrap is typically required to contain less than 4% Al and less than 3% combustibles. Heating of the cans above ~450° C (859° F) must be avoided during or before recovery, because this will cause the tin to alloy with the steel, making tin recovery economically impractical. To effect good recoveries, the scrap should not be baled or balled, and bulk density should be less than 25 pounds per cubic foot.

Steel Producers

The steel industry uses scrap as a source of iron units; however, tramp elements can cause problems. Lead is undesirable because it can attack furnace refractories, and tin and copper create problems when steel is flat-rolled. Integrated mills producing sheet products can tolerate only minor amounts of these impurities. Generally, the mills prefer scrap containing less than 0.1% Cu and 0.15% Pb. Tin specifications vary with producer and product but are quite restrictive. Organic contamination can occasionally overload pollution control systems and, in most cases, a level of 10% or less is desired. On the other hand, many nonintegrated mills, producing non-flat-rolled products, can tolerate higher amounts of selected impurities in the scrap charge.

Export

The export market primarily serves the overseas steel industry. Requirements for export scrap are similar to those for the nonintegrated domestic market.

Copper Precipitation

Copper producers use magnetic scrap (for its iron content) to precipitate (cement) copper from copper-bearing leach solutions. The ferrous content of such scrap should be at least 96%. Since maximum surface area is desired, the scrap should not be balled or crushed. Furthermore, it also must be clean of surface coatings such as paint, varnish, etc. (less than 2% combustibles is desired). If surface coatings are present, they are usually removed by burning under controlled conditions. This use has historically been one of the largest markets for tin can scrap, even though limited to the copper-producing Western States.

Nonmagnetic Fraction

Aluminum Wrought Alloys

Wrought alloys, used by the aluminum industry to produce cans, have very restrictive metallic impurity limits (for example, less than 2.0% Mg, less than 1.5% Mn, less than 4% Cu, less than 0.04% Sn, and less than 0.04% Pb). Other contamination should be minimal--less than 1% dirt and less than 2% organics. Generally, only scrap aluminum cans can be recycled to wrought alloys.

Aluminum Cast Alloys

The casting alloys used by the aluminum industry generally have less severe impurity limits than wrought alloys (for example, less than 0.5% Sn and less than 0.3% Pb). Within these specifications, the scrap can contain both aluminum cans and cast aluminum scrap.

Deoxidizer

The steel industry uses aluminum scrap to deoxidize molten steel. The metallic impurity requirements for this dissipative use are not stringent, but low organic contamination is desired.

Other Nonferrous

Only minor amounts (for example, 0.3% MSW) of other nonferrous metals (for example, Pb, Zn, and Cu) are recovered from MSW. Although such metals may be sold to scrap processors, they appear to be recovered by handpicking during the collection process. Estimates on the amounts of such metals entering a resource recovery plant and their potential end-use markets remain speculative.

Refuse-Derived Fuel (RDF) Fraction

The RDF can be incinerated in a suspension burner or a stoker-type boiler. Little information is available on specifications, which will probably vary with location. In general, particle size will probably have to be less than 1 inch and residual ash will have to be low (probably less than 15%). The National Center for Resource Recovery (2) estimates that chlorides should be under 1.0% to minimize corrosion; sulfur should generally be [illegible] (under ~0.3%) to minimize pollution and meet emission standards; and to make RDF competitive as a fuel, its heating value has to be at least 5,000 Btu per pound with no more than 30% moisture.

Glass Fraction

The glass industry remelts glass cullet for use in the manufacture of glass containers. The cullet must meet tight impurity specifications. Aluminum and other metals form oxides that interfere with furnace operation and/or can affect the coloring of the glass. Ceramics or other materials which do not melt can form seeds, spots, or other defects in the finished product. Current practice requires that magnetics must be under 0.25 inch in size and be less than 0.05%; organics must be less than 0.2%; and nonmetallics (like ceramics) must be less than 0.1% and under 0.25 inch in size. Refractories are further restricted to 22 particles per pound, only 2 of which can be in the minus 20- to plus 40-mesh size range, while the other 20 particles are restricted to minus 40 to plus 60 mesh.

Process Description[20] and Energy Analysis

Since very few commercial MSW resource recovery facilities were in operation in 1976, no processing scheme can be considered typical in this relatively new technology sector. Recognizing that good energy data are generally lacking for the large number of processes being proposed, only one system was chosen for analysis. It was recognized that this would indicate only an order of magnitude of energy use, since a more definitive energy study would have to await commercial implementation of the technologies involved on a wider scale.

For the purposes of this study, the Bureau of Mines resource recovery flowsheet has been used. Although no commercial installations utilized the process in 1976, many processes have included portions of the technology and several installations in the planning stage or under construction intend to use a large portion of the process.[21] The energy estimates presented in this analysis are not meant to be representative of current industrial practice. They represent an estimate of the energy that would be consumed by an installation based on the Bureau of Mines flowsheet.

Subsystems

The incoming MSW is separated into four streams in the concentrate preparation section: Magnetic metal concentrate; nonmagnetic metal concentrate; glass concentrate; and combustible fraction.

The combustibles are used as RDF; the three concentrate streams undergo further processing in their respective subsystems to produce magnetic scrap, aluminum scrap, and glass cullet. As stated earlier, it is expected that the heavy nonferrous metals will have been handpicked before entering the MSW facility. The main processing units are described below.

Preparing Concentrates

Incoming MSW is dumped directly into a receiving pit where it is stored for processing. Front-end loaders transfer it to apron conveyors which feed the primary shredder (a double-opposed flail mill). This type of shredding liberates the various materials to be recovered by breaking open bags and boxes; cans are only dented or sliced, but not balled.

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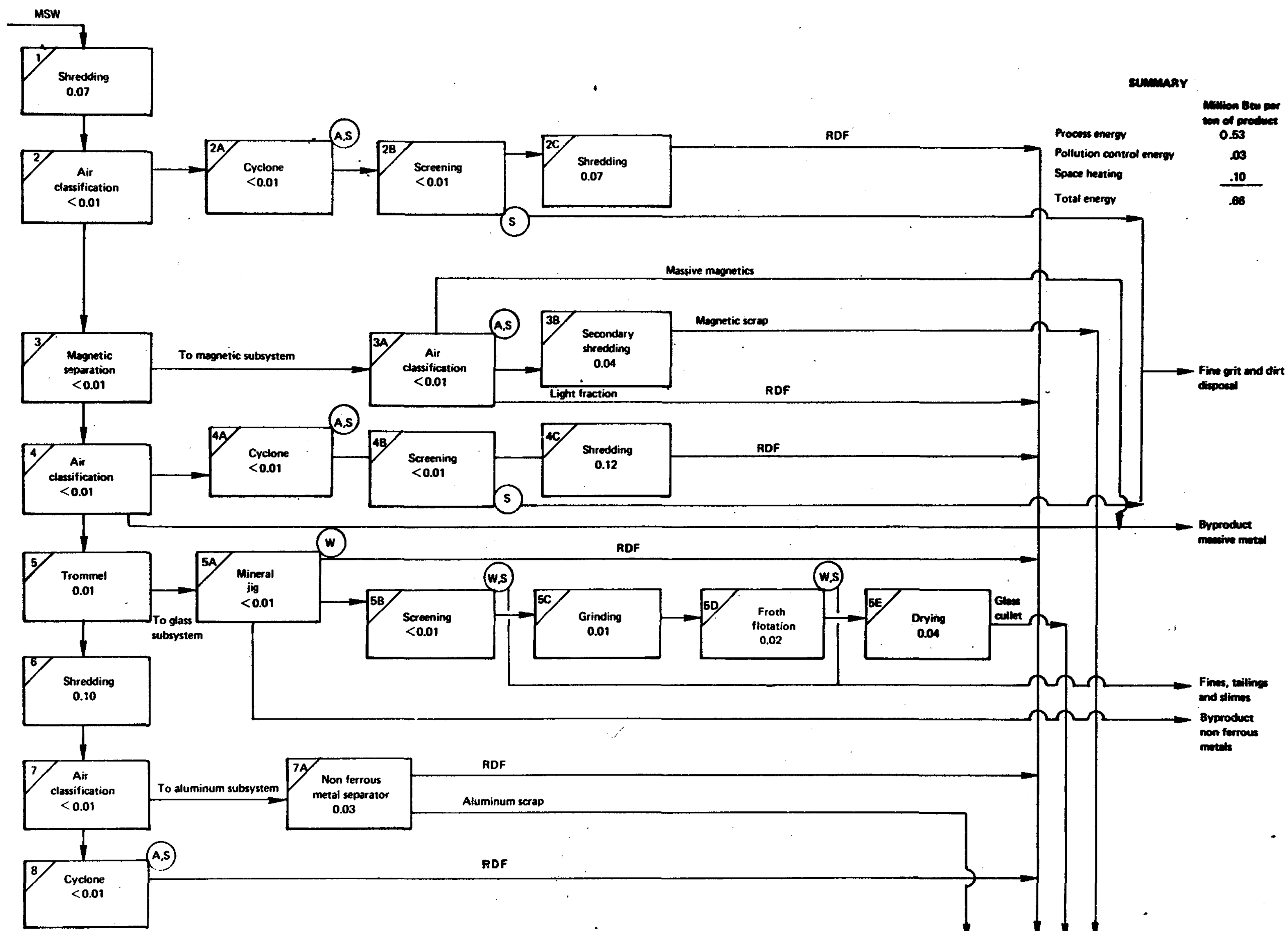
[20] This process description is based on the flowsheet presented in BuMines IC 8732. Portions of the description have been altered to conform with the methodology used in other sections of this report.

[21] A commercial-scale process much like the one described is under construction in Rochester, N.Y. Design capacity is 2,000 tons of MSW per day.



*Based on production of 2,000 pounds RDF, 205 pounds of magnetic scrap, 187 pounds of glass cullet, 11 pounds of aluminum scrap.

FIGURE 64. - Municipal solid waste (MSW): Preparing refuse-derived fuel (RDF) product and concentrates.

Air flowing through the hood, covering the shredder discharge, removes light refuse (primarily combustibles) from the stream and controls dusting. Light combustibles are collected in a cyclone; dust is caught in a baghouse. After shredding, the bulk of the iron is removed from the main refuse stream by a suspended magnetic separator. (This represents the first step in the magnetic subsystem and is discussed further in that section of this chapter.)

The discharge conveyor feeds the remaining nonmagnetic material into a horizontal air classifier which produces three streams. The massive materials fall straight through the air classifier and are treated in a magnetic separator, which separates the heavy magnetics from the heavy nonmagnetic scrap. The light material passes through the classifier and is collected in a cyclone; dust is collected in a baghouse. The third stream, which contains most of the glass, ceramics, nonferrous metals, and wastes, is conveyed from the classifer discharge to a trommel. The glass, ceramics, wastes, and dirt pass through the trommel and constitute the glass concentrate, which is conveyed to the glass recovery section.

The other stream from the trommel, containing most of the aluminum, is shredded and fed into a three-stage aspirator. The light combustible material, entrained in the airstream passing through the aspirator, is collected in a cyclone. The remaining material that passes through the aspirator constitutes the aluminum concentrate and is transferred to the aluminum recovery section.

The combustible material collected in the three cyclones is screened to remove fines and then shredded to a size suitable for use as an RDF. The RDF currently being produced by MSW resource-recovery facilities (pilot plants, demonstration plants, and commercial plants) generally meets the market requirements (2). The heating value is typically from 6,000 to 8,000 Btu per pound, with a moisture content of 15% to 25%, and 10% to 25% ash (the Bureau of Mines process is expected to produce 7% to 10% ash). Sulfur content usually ranges from 0.1% to 0.2% and chlorides are under 1.0%. (Based on past experience, it is estimated that 30% of the chlorine is present as organic chlorides.)

The energy analysis for this portion of the processing is presented in figure 64 and table 68. Shredding of the MSW (steps 1, 5, 9, 12) requires the largest amount of energy in this section (87.3% of the total energy required).

The amount of energy required for shredding is directly dependent upon the final product size of the RDF (for example, reported requirements range from about 10 kwhr per ton for a 12-inch product to 40 kwhr per ton for a 1-inch product) as discussed in reference 4. Pollution control energy is solely for the baghouses.

TABLE 68. - Municipal solid waste (MSW): Preparing refuse-derived fuel (RDF) product and concentrates

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(1) SHREDDING				
ELECTRICAL ENERGY	KW HR	6,7000	0,010500	0,07
			SUBTOTAL	0,07
(2) AIR CLASSIFICATION				
ELECTRICAL ENERGY	KW HR	0,2600	0,010500	0,00
			SUBTOTAL	0,00
(2A) CYCLONE				
ELECTRICAL ENERGY	KW HR	0,1300	0,010500	0,00
			SUBTOTAL	0,00
(2B) VIBRATING SCREEN				
ELECTRICAL ENERGY	KW HR	0,0100	0,010500	0,00
			SUBTOTAL	0,00
(2C) SECONDARY SHREDDING				
ELECTRICAL ENERGY	KW HR	6,2800	0,010500	0,07
			SUBTOTAL	0,07
(3) MAGNETIC SEPARATION				
ELECTRICAL ENERGY	KW HR	0,1670	0,010500	0,00
			SUBTOTAL	0,00
(3A) AIR CLASSIFICATION				
ELECTRICAL ENERGY	KW HR	0,1000	0,010500	0,00
			SUBTOTAL	0,00
(3B) SECONDARY SHREDDING				
ELECTRICAL ENERGY	KW HR	3,3800	0,010500	0,04
			SUBTOTAL	0,04
(4) AIR CLASSIFICATION				
ELECTRICAL ENERGY	KW HR	0,4300	0,010500	0,00
			SUBTOTAL	0,00
(4A) CYCLONE				
ELECTRICAL ENERGY	KW HR	0,2200	0,010500	0,00
			SUBTOTAL	0,00
(4B) SCREENING				
ELECTRICAL ENERGY	KW HR	0,0100	0,010500	0,00
			SUBTOTAL	0,00

TABLE 68. - Municipal solid waste (MSW): Preparing refuse-derived fuel (RDF) product and concentrates--Continued

(STEP NUMBER) PROCESS	UNIT	UNITS PER NET TON OF PRODUCT	ENERGY REQUIRED PER UNIT (MILLION BTU)	MILLION BTU PER NET TON OF PRODUCT
(6) SECONDARY SHREDDING				
ELECTRICAL ENERGY	KW HR	9.5400	0.010500	0.10
			SUBTOTAL	0.10
(7) AIR CLASSIFICATION				
ELECTRICAL ENERGY	KW HR	0.2900	0.010500	0.00
			SUBTOTAL	0.00
(7A) NON-FERROUS METAL SEPARATOR				
ELECTRICAL ENERGY	KW HR	2.9500	0.010500	0.03
			SUBTOTAL	0.03
(8) CYCLONE				
ELECTRICAL ENERGY	KW HR	0.1500	0.010500	0.00
			SUBTOTAL	0.00
IN PLANT TRANSPORTATION				
ELECTRICAL ENERGY	KW HR	2.2950	0.010500	0.02
			SUBTOTAL	0.02
* TOTAL PROCESS ENERGY				0.53
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	1.1330	0.010500	0.01
			SUBTOTAL	0.01
WATER POLLUTION CONTROL				
ELECTRICAL ENERGY	KW HR	1.5500	0.010500	0.02
			SUBTOTAL	0.02
SOLID WASTE DISPOSAL				
TRUCK	TON MI	1.3300	0.002400	0.00
			SUBTOTAL	0.00
* TOTAL POLLUTION CONTROL ENERGY				0.03
SPACE HEATING				
DISTILLATE FUEL OIL	GAL	0.7250	0.139000	0.10
			SUBTOTAL	0.10
* TOTAL SPACE HEATING ENERGY				0.10
* TOTAL ENERGY PER NET TON OF PRODUCT				0.66

Aluminum Subsystem

The aluminum concentrate from the three-stage aspirator is fed to a nonferrous metal separator (eddy current separator or a linear induction motor (LIM)). This unit produces two streams: A 95% metal product, which is sold as aluminum scrap, and a heavy combustible fraction. This nonmetallic product is pulverized before being combined with the RDF.

For this analysis, LIM was used. The LIM is the sole consumer of energy in the subsystem. Wide variations in separator energy requirements exist, depending on the specific design of the magnet (efficiencies range from 40% to 80%), the number of units required for the separation (some systems utilize several units in series), and whether an electromagnetic or permanent magnet unit is used. Based on field visits, a permanent magnet unit is estimated to have an energy requirement of 0.003 million Btu per ton of aluminum scrap.

The scrap aluminum product from this type of subsystem is expected to be suitable for reuse as can stock. Based on discussions with industry contacts, the product from an LIM will generally contain about 95% Al, 2% to 4% organics, and 1% to 3% other metals. However, the product will vary with the feed composition and the type of LIM.

Magnetic Subsystem

Magnetic metals are removed from the MSW stream by the magnetic separator located between the primary shredder and second air classifier. This metal fraction is then fed to a three-product air classifier to remove light combustibles and massive metals. The remaining material (mostly tin cans) is fed to a secondary shredder yielding the magnetic product. According to Bureau of Mines personnel, this product will not require further processing before being used for detinning.

For similar systems the magnetic product has been estimated typically to contain (1, 3) 90% to 95% Fe, 2% to 4% combustibles, 2% to 4% Al, 0.2% to 0.4% Sn, and 0.2% to 0.4% Pb. As in the concentrate preparation, shredding accounts for the largest fraction of the energy required in the magnetic subsystem.

Glass Subsystem

The glass concentrate (minus 0.75-inch material from trommel) is conveyed via a surge bin to a mineral jig which produces four fractions. Fine glass ceramics and sand pass through the screen and are collected as a hutch product. Small, heavy nonferrous metal, glass, and ceramics build up on the screen, with the metal forming a separate layer directly on the screen. The metal is periodically removed, while the nonmetallics are continuously discharged as a cup product. The jig overflow, containing organics, is dewatered and blended with RDF.

Cup and hutch products are dewatered on a screen. The material is ground and, after slurrying, fed to a magnetic separator to remove contaminating magnetic particles. A spiral classifier separates the nonmagnetic material into two streams; the slimes and water are sent to water recovery, while the remainder goes into a flotation cell. The cullet produced from the flotation cell is filtered, dried, and conveyed to a collection bin for storage and sale. Cullet produced by these types of systems is still being tested by container manufacturers.

The largest energy requirements in this subsystem are found in drying the glass cullet, followed by energy required in the separation step (magnetic separation, froth flotation, and classification) and water pollution control which involves clarifying, filtering, and landfilling the sludges.

Further Processing

In general, the products produced by MSW facilities may require some further offsite processing before they can go to an end-use market, although the Bureau of Mines indicates no such processing is necessary with their process. For example, further processing that may be required by other systems includes the following:

1. The magnetic fraction may undergo washing or further air classification to remove the residual organics, or detinners may treat the scrap to remove the aluminum or organics;

2. Copper producers may require that surface coatings be removed from the magnetic fraction before using for cementation; and

3. The nonmagnetic (aluminum) fraction may undergo further purification, air classifying, or incineration to remove remaining organics.

The type and amount of offsite processing required will depend on the MSW process used, the end-use market for which the material is intended, and the final user of the material.

Research Needs

During the course of this study, three areas which could benefit from further research were identified: One area is directly related to energy use; the other two relate indirectly and stem from the general lack of knowledge about the field. All three are included here to indicate the wide range of research which is needed.

1. Energy Data.--There is a general lack of data on energy required by the various types of equipment used in processing MSW (shredders, air classifiers, etc.). Data to facilitate analysis are needed. Such data should explain how energy consumption varies with equipment type (vertical shaft hammer mill, horizontal shaft hammer mill, flail mill, etc.); as well as data relating to feed rates and condition of feed (moisture content, particle size, etc.).

2. Volume of Material.--Recovery of values from MSW could eventually involve significant quantities of material being recycled to the economy. A better definition of the effects this material will have on existing markets, processors, prices, etc., is needed, as well as information on whether existing end-use markets can absorb the volume of material generated.

3. Impurity Levels.--Partially as a result of the potential volume of recyclable materials found in the field visits, there is growing concern over long-term implications of recycling material from MSW. For example, recycling steel scrap from MSW with higher-than-normal tramp element levels (such as copper or tin), relative to conventional steel scrap, may result in an increase in the long-term levels of these metals in iron and steel products, especially when some industry contacts indicate that impurities in scrap purchased often exceed maximum specifications. Research to better define this problem and its implications in all three product categories (magnetic metals, aluminum, and glass) is needed. This, in turn, could serve to better define research requirements for more efficient removal of tramp elements from the MSW product streams.

References

1. American Iron and Steel Institute, Committee of Tin Mill Products Producers. Ferrous Metal From Municipal Wastes as Charge Material for Cast Iron. May 1974.

2. National Center for Resource Recovery, Inc. Specifications for Materials Recovered From Municipal Refuse. EPA 670/2-75-034, Cincinnati, Ohio, May 1975.

3. Ostrowski, E. J. Recycling of Tin-Free Steel Cans and Scrap From Municipal Incinerator Residue. Pres. at 79th General Meeting, AISI, New York, May 26, 1971.

4. Preston, G. T. Resource Recovery and Flash Pyrolysis of Municipal Refuse. Pres. to Inst. of Gas Technol. Symp. on Clean Fuels from Biomass, Sewage, Urban Refuse and Agricultural Wastes, Orlando, Fla., Jan. 27, 1976.

SUMMARY

Energy requirements for recycling of the nine major commodities are summarized in table 69 with quantities of new (prompt industrial) and obsolete (old) scrap recycled in 1976 tabulated in table 70. Estimated energy requirements shown in table 69 are based on scrap having a zero energy value at the first collection point. Energy requirements include--

1. Energy directly consumed in recycling, as estimated from data gathered in field visits, supplemented by engineering judgment and calculations;

2. Energy needed to produce major materials used in the recycling process;

3. Energy used for pollution control; and

4. Energy for space heating.

Wherever possible, the methodology used and products found on the flowsheets are similar to those used in a previous study done for the Bureau of Mines in 1975 on the production of primary metals (1).

The results of this analysis should be used with care. For example, if an automobile is used to transport 10 pounds of aluminum cans a distance of 10 miles round trip to a collection center, it would add something like 12.5 million Btu per ton of product recycled (this assumes that an automobile obtains 20 miles per gallon of gasoline with a heating value of 125,000 Btu per gallon). Clearly, the magnitude of such energy consumption up to the collection center can be large and could significantly increase the amount of energy used as shown in table 69 for any one of the commodities. Similarly, the authors have not taken into account or assigned an energy value to labor, either in terms of direct energy requirements attributed to labor or indirect energy requirements, such as gasoline consumed by automobiles or buses used in commuting.

Data obtained from field visits generally showed material and energy requirements for both the whole plant and the most important energy-consuming processing steps, such as for the blast furnaces, reverb furnaces, and shredders. Overall, the authors believe that the energy requirements shown for the various processes considered here are accurate within 10% to 15%, recognizing that the variation can be considerably larger for individual, less energy-intensive process steps.

TABLE 69. - Summary of energy requirements by commodity and process in secondary metal recycling

Commodity/process	Product	Million Btu per ton of product
Aluminum:		
Reverb melting aluminum scrap	Ingots (casting alloys)	15.06
Do	Hot metal (casting alloys).	19.60
Reverb melting aluminum cans	Hot metal (can stock)	8.72
Copper:		
Reverb melting No. 1 copper scrap	Wirebar	3.81
Anode furnace/electrolytic refining No. 2 copper scrap.	do	17.27
Cupola/converter/electrolytic refining low-grade copper scrap.	do	42.42
Reverb melting brass/bronze scrap	Brass or bronze ingots.	7.09
Iron and steel:		
Electric arc furnace	Continuously cast blooms/billets.	8.33
Cupola	Castings	[1] 31.67
Lead:		
Pot melting	Ingots	.61
Blast furnace alone (hard lead)	do	9.65
Blast furnace/reverb furnace combination:		
Hard lead from blast furnace	do	9.61
Soft lead from reverb furnace	do	8.05
Nickel alloys:		
Induction melting (double vacuum)	do	19.45
Air induction melting	do	11.08
Stainless steel: Argon-oxygen-decarburization (AOD).	Strand cast billets	9.69
Tin: Tin recovery from detinning leach solution by electrowinning.	Electrolytic tin	172.88
Titanium: Vacuum arc furnaces (double melting).	-	([2])
Zinc:		
Distillation retorts	Zinc dust	24.01
Muffle furnaces	Slab zinc	[3]18.93
Do	Zinc dust	19.71
Do	Zinc oxide	19.71
Pot melting clean diecastings	Cast alloys	2.58
Pot melting off-specification diecastings.	do	3.26

[1]4.17 million Btu is accounted for by 0.18 ton of pig iron per ton of castings.
[2]See figure 54.
[3]See text on muffle furnace energy analysis in zinc section.

TABLE 70. - Amount of scrap recycled in 1976,[1] thousand tons

	New[2]	Old[3]	Total
Aluminum	1,030.0	416	1,446.0
Copper	940.0	485.0	1,425.0
Iron and steel[4]	22,629.0	18,515.0	41,144.0
Lead	100.0	570.0	670.0
Nickel and nickel alloys	34.5	23.0	57.5
Stainless steel	208.0	171.0	379.0
Tin	7.7	10.5	18.2
Titanium	8.4	.4	8.8
Zinc	128.0	52.0	180.0

[1]Figures are for scrap consumption unless otherwise indicated.
[2]Or prompt industrial.
[3]Or obsolete.
[4]Amount of scrap received.

Sources: Bureau of Mines and Arthur D. Little, Inc., estimates.

Reference

1. Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4--Energy Data and Flowsheets, High-Priority Commodities). BuMines Open File Rept. 80-75, 1975, 192 pp.; available for consultation at Bureau of Mines facilities in Albany, Oreg., Avondale, Md., Reno and Boulder City, Nev., Rolla, Mo., Salt Lake City, Utah, Tuscaloosa, Ala., and Twin Cities, Minn.; and at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 245 759.

APPENDIX

Table A-1 shows energy values used in this study for fuels, other energy sources, and commodities. Energy consumed by various modes of transport are shown on a ton-mile basis. All this energy information was prepared from an earlier report (1). In addition, 18 million Btu per ton iron are charged to a process when scrap iron or steel is used dissipatively, such as a lead blast furnace where iron is oxidized and forms part of the slag.

TABLE A-1. - Energy values for fuels, other energy sources, and commodities

Commodities	Unit	Million Btu per unit
Metallurgical coke	Net ton	31.500000
Tar and pitch	Gallon	.160000
Gasoline	.....do......	.125000
Distillate fuel oil	.....do......	.139000
Natural gas	Cubic foot	.001000
Electrical energy	Kilowatt-hour	.010500
Steam	Pound	.001400
Aluminum fluoride	Net ton	51.400000
Bentonite	.....do......	1.200000
Borax	.....do......	8.600000
Caustic soda	.....do......	29.900000
Gaseous chlorine	.....do......	18.000000
Cryolite	.....do......	155.000000
Carbon electrode	.....do......	82.000000
Graphite electrode	.....do......	160.000000
Hydrofluoric acid	.....do......	14.350000
Pig iron	.....do......	23.180000
Limestone	.....do......	.104000
Nitric acid	.....do......	14.200000
Gaseous nitrogen	.....do......	2.900000
Potassium chloride by flotation	.....do......	2.590000
Refractory	.....do......	26.600000
Sand (silica sand)	.....do......	.042000
Sodium chloride	.....do......	.490000
Steam	.....do......	2.800000
Tin ingot	.....do......	190.000000
Zinc (or zinc dust)	.....do......	65.000000
Mold wash	.....do......	3.000000
Charcoal	.....do......	25.000000
Truck	Ton mile	.002400
Rail	.....do......	.000670
Sodium nitrate (niter)	Net ton	42.250000
Propane	Pound	.021500
Foundry coke	Net ton	33.000000
Silicon carbide	.....do......	50.00000
Argon	Cubic foot	.000210
Oxygen	.....do......	.000150
Acetylene	.....do......	.002400
2110 welding rod	Net ton	30.000000
Ingot molds and stools	.....do......	24.500000
Trichloroethylene	Gallon	.100000
Mill scale (iron oxide)	Net ton	.710000
Nonmetallic abrasives	Pound	.040000
Metallic abrasives	.....do......	.017500
Scrap iron	Net ton	18.000000
Fluorspar	.....do......	1.590000
Tar	Gallon	.160000

Reference

1. Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4--Energy Data and Flowsheets, High-Priority Commodities). BuMines Open File Rept. 80-75, 1975, 192 pp.; available for consultation at Bureau of Mines facilities in Albany, Oreg., Avondale, Md., Reno and Boulder City, Nev., Rolla, Mo., Salt Lake City, Utah, Tuscaloosa, Ala., and Twin Cities, Minn.; and at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 245 759.

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