U.S. Department of the Interior
U.S. Geological Survey

Aluminum Recycling in the United States in 2000

By Patricia A. Plunkert

U.S. GEOLOGICAL SURVEY CIRCULAR 1196–W

FLOW STUDIES FOR RECYCLING METAL COMMODITIES IN THE UNITED STATES

FOREWORD

As world population increases and the world economy expands, so does the demand for natural resources. An accurate assessment of the Nation's mineral resources must include not only the resources available in the ground but also those that become available through recycling. Supplying this information to decisionmakers is an essential part of the USGS commitment to providing the science that society needs to meet natural resource and environmental challenges.

The U.S. Geological Survey is authorized by Congress to collect, analyze, and disseminate data on the domestic and international supply of and demand for minerals essential to the U.S. economy and national security. This information on mineral occurrence, production, use, and recycling helps policymakers manage resources wisely.

USGS Circular 1196, "Flow Studies for Recycling Metal Commodities in the United States," presents the results of flow studies for recycling 26 metal commodities, from aluminum to zinc. These metals are a key component of the U.S. economy. Overall, recycling accounts for more than half of the U.S. metal supply by weight and roughly 40 percent by value.

Charles G. Groat
Director

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CONVERSION FACTORS

Multiply	By	To obtain
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t, 1,000 kg)	1.102	ton, short (2,000 lb)

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ABSTRACT

As one of a series of reports on metals recycling, this report discusses the flow of aluminum from production through its uses with particular emphasis on the recycling of industrial scrap (new scrap) and used products (old scrap) in 2000. This materials flow study includes a description of aluminum supply and demand factors for the United States to illustrate the extent of aluminum recycling and to identify recycling trends. Understanding the system of materials flow from source to ultimate disposition can assist in improving the management of natural resources in a manner that is compatible with sound environmental practices. In 2000, the old scrap recycling efficiency for aluminum was estimated to be 42 percent. Almost 60 percent of the aluminum that was recycled in 2000 came from new scrap, and the recycling rate was estimated to be 36 percent. The principal source of old scrap was recycled aluminum beverage cans.

INTRODUCTION

This materials flow study of aluminum, as shown in figure 1, is intended to provide a snapshot of the flow of materials through the U.S. aluminum industry in 2000. It identifies sources and distribution of U.S. aluminum supply with particular emphasis on the flow of aluminum scrap. In 2000, approximately 36 percent of the aluminum supply in the United States came from recycled aluminum.

GLOBAL GEOLOGIC OCCURRENCE OF ALUMINUM

Aluminum is the third most abundant element in the Earth's crust, surpassed in abundance only by oxygen and silicon. Although it comprises about 8 percent of the Earth's crust, it is not found free in nature, but always in combination with other elements. Bauxite, which is a rock that consists of one or more aluminum hydroxide minerals, is the principal raw material used by the aluminum industry for the production of aluminum metal. The types of bauxite used are trihydrate, which consists chiefly of gibbsite, $Al_2O_3 \bullet 3H_2O$; monohydrate, which consists mainly of boehmite, $Al_2O_3 \bullet H_2O$; and mixed bauxite, which consists of gibbsite and boehmite. Bauxite deposits have formed chiefly by the weathering of aluminous rock; some have been transported to their present locations, but most are residual accumulations from which most constituents of the parent rock, other than alumina (Al_2O_3), have been leached. Conditions favorable for the formation of bauxite are warm tropical climate, abundant rainfall, aluminous parent rocks that have high permeability and good subsurface drainage, and long periods of tectonic stability that permit deep weathering and preservation of land surfaces (Patterson and Dyni, 1973).

Bauxite occurs in rocks that range in age from Precambrian to Holocene, and many deposits in the tropics are probably still forming. Most deposits of gibbsitic bauxite are located in the tropics. A few occur in the temperate belts, but the climate was probably tropical or subtropical at the time they were formed. Nearly all gibbsite type deposits are of Cenozoic age. Deposits of boehmitic bauxite occur chiefly in southern Europe, the Commonwealth of Independent States (CIS), Turkey, and China. Most boehmite deposits are associated with carbonate rocks of Jurassic and Cretaceous age but a few are of Paleozoic age. Though most of these deposits are north of the tropics, they could have formed under tropical conditions. Mixed bauxites containing gibbsite and boehmite tend to be more abundant in Paleozoic and Mesozoic deposits than in younger rocks (Patterson and others, 1986, p. B1).

In 2000, 22 countries reported bauxite mine production. Australia, Brazil, Guinea, and Jamaica accounted for about 70 percent of the total bauxite mined that year. The aluminum industry consumes nearly 90 percent of the bauxite mined; the remainder is used in many different types of abrasives, chemicals, refractories, and miscellaneous products. This study addresses only the flow of metallurgical-grade bauxite, which is bauxite that ultimately is converted to aluminum metal.

The proportion of trihydrate and monohydrate ores in this type of bauxite differs from deposit to deposit as do the type and amount of impurities like clay, iron oxide, silica, and titania. Most commercial bauxites have a minimum Al_2O_3 content of 50 to 55 percent with a texture that ranges from powdery clay to hard indurated masses. There is often greater tolerance for variations in impurity levels in bauxites used for metal production than those used for other applications, such as abrasives and refractories (Russell, 1999, p. 19-20).

PRODUCTION TECHNOLOGY

The extraction of aluminum from its ore and subsequent processing into finished products takes place in a series of suc-

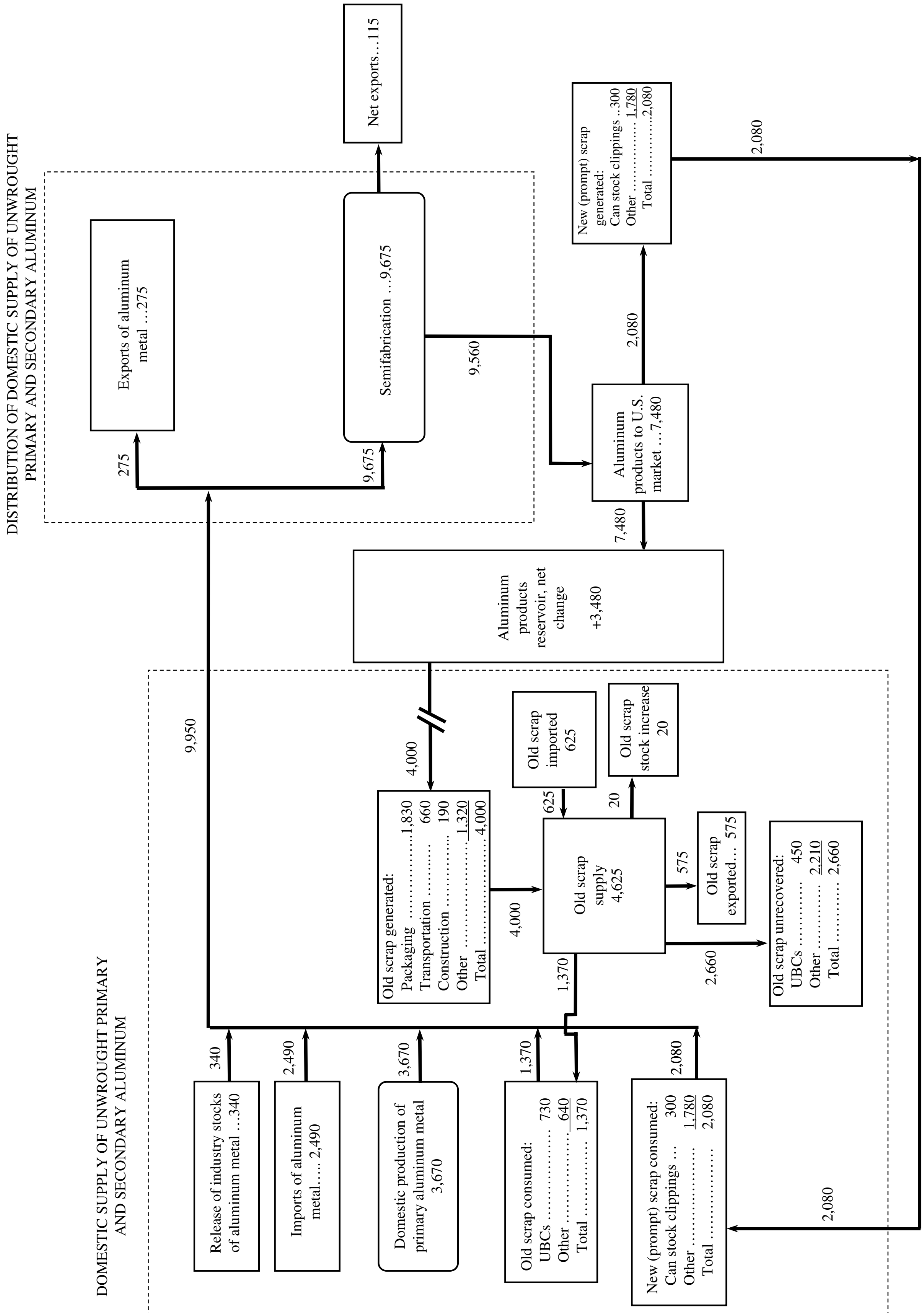

Figure 1. U.S. aluminum materials flow in 2000. Values are in thousand metric tons of contained metal. UBCs refers to used beverage cans.

cessive operations, each of which is largely independent of the other and generally located at different plant sites. After the bauxite is mined, it is sent to a refinery for conversion to alumina and finally to a smelter to extract the metal. The metal, which is either molten or cast into ingots and billets, is sent to fabrication plants where it is rolled, extruded, or cast into plates, sheets, bars, and other shapes. These semifabricated products are manufactured into consumer products.

Most bauxite ores are mined by open pit methods, and treatment at the mine site is usually confined to crushing, washing, and drying operations. Ore that is transported appreciable distances is often dried before shipment, which can result in savings in shipping costs that will more than offset the drying costs. The degree to which a specific bauxite is dried depends in part on its handling and dusting characteristics.

The starting material for electrolytic smelting of aluminum is pure anhydrous aluminum oxide (Al_2O_3) called alumina. Virtually all alumina commercially produced from bauxite is obtained by a process patented by Karl Josef Bayer (Austria) in 1888. The Bayer process involves a caustic leach of the bauxite at elevated temperature and pressure followed by separation of the resulting sodium aluminate solution and selective precipitation of the aluminum as the hydrated aluminum oxide ($Al_2O_3 \bullet 3H_2O$). The filtered and washed alumina trihydrate is then calcined for use in making metal.

Throughout the world, primary aluminum is produced by the electrolysis of alumina in molten fluoride salt. This is, in essence, the process that Charles Martin Hall (United States) and Paul Louis Toussaint Héroult (France) independently invented in 1886, which is named after them, though its efficiency has been significantly improved over the years. In the Hall-Héroult process, alumina is dissolved in an electrolyte of molten cryolite (Na_3AlF_6). For each metric ton of aluminum produced, the smelting process consumes, in addition to large amounts of electrical energy, about 1.95 metric tons of alumina. As the electric current flows through the electrolyte, it reduces the dissolved alumina into its component elements as metallic aluminum and oxygen gas. When the oxygen reacts with the carbon anodes, bubbles of carbon monoxide and carbon dioxide gas are formed. Liquid aluminum settles on the bottom of the cell and periodically is siphoned off by vacuum into crucibles. The metal, in either molten or cast form, is then transferred to plants that produce plate, sheet, bar, forgings, cast parts, and other semifabricated products before being sent to fabricators that produce finished products for the consumer (Altenpohl, 1998, p. 7-25).

USES

Aluminum is used in virtually all segments of the economy. Its physical properties enhance its versatility. The metal is lightweight, ductile, malleable, and corrosion resistant and is a good conductor of heat and electricity. Unalloyed aluminum is soft and has limited strength. The addition of small quantities of alloying elements, such as copper, magnesium, manganese, nickel, silicon, and zinc, can increase the hardness, strength, and other properties of aluminum. Adding to aluminum's adaptability is the fact that it can be fabricated into desired forms and shapes by every major metalworking technique—cast, rolled, forged, extruded, drawn, or machined.

Aluminum in alloyed and unalloyed forms is suitable for use in a wide variety of products for the consumer and capital goods markets. The largest markets are transportation, packaging, construction, electrical, consumer durables, and machinery and equipment (fig. 2).

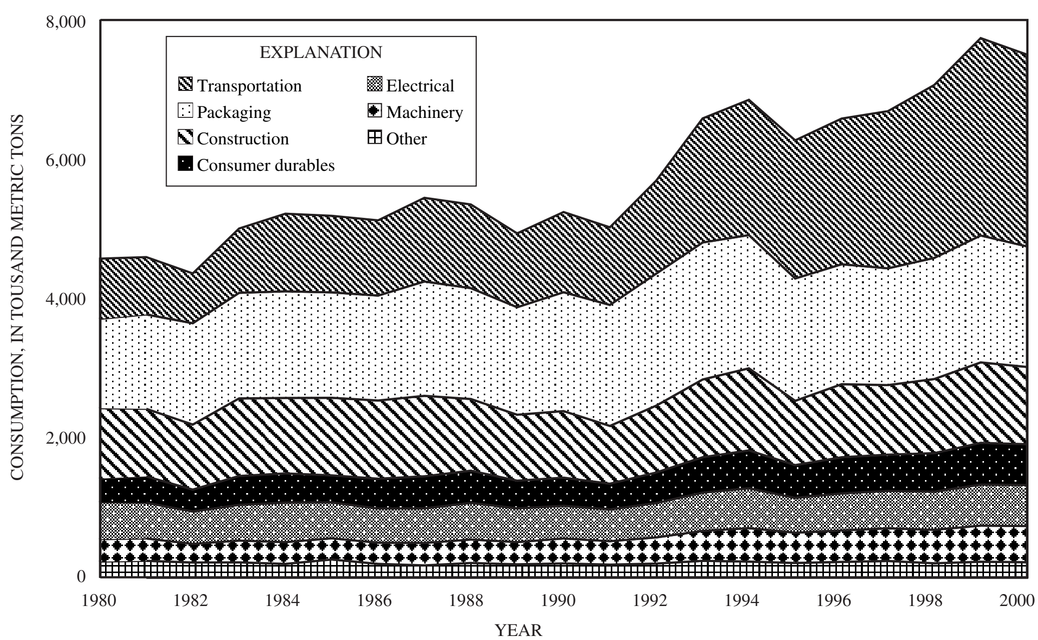

Figure 2. U.S. aluminum consumption, by end-use sector, from 1980 through 2000.

The transportation sector, which is the largest single market for aluminum worldwide, includes the manufacture of automobiles, buses, trailers, ships, railroad and subway cars, as well as aerospace applications and mobile homes. In recent years, aluminum has made significant inroads into the automotive industry. Its light weight and recyclability have provided the impetus for the increased use of aluminum to help meet new and more stringent corporate average fuel efficiency (CAFE) standards. The use of aluminum for truck and automobile engine blocks and cylinder heads, heat exchangers, transmission housings, engine parts, and wheels has increased steadily during the past decade. Aluminum use in some body sheet applications has increased as well. In 2000, automotive and light truck applications represented approximately 20 percent of U.S. aluminum shipments, which was equivalent to an average aluminum content of 117 kilograms (kg) (257 pounds) per vehicle (Aluminum Association Inc., undated b).

The International Aluminium Institute (undated b) has estimated that 90 percent of truck trailers have aluminium bodies as do long-distance buses and cargo containers. Aluminum components reduce the weight of tractor-trailers, which allows them to reduce fuel costs and to carry a bigger load without exceeding highway weight limits.

The success of the modern commercial aviation industry has depended upon aluminum. The metal's combination of lightness, strength, and workability, as well as its abundance and low cost, makes it an ideal material for mass-produced commercial aircraft. Aluminum, which is the primary aircraft material, comprises about 80 percent of an aircraft's unladen weight. The standard Boeing 747 jumbo jet contains approximately 75,000 kg of aluminum (International Aluminium Institute, undated a).

In the United States, aluminum used by the packaging and container industry in such products as beverage cans, food containers, and household and institutional foil ranked second to transportation in total shipments. The largest single segment of this market is aluminum beverage cans. As reported by the Can Manufacturers Institute (2001, p. 16), aluminum beverage can shipments in the United States were approximately 100 billion cans in 2000. Beverage cans in the United States are made almost exclusively of aluminum. Because of consumer preference, however, aluminum faces stiffer competition from steel cans and glass and plastic containers in other areas of the world and, therefore, accounts for a smaller percentage of total beverage container demand in those countries.

In addition to competition from other materials, the evolution of manufacturing technology has also affected aluminum demand in the container industry. The first use of aluminum in beverage containers was the easy-open ring-pull aluminum ends on tinplate cans. The first all aluminum can was introduced in the late 1960s. Over time, the thickness of aluminum can body stock has been significantly reduced, which has led to an increased yield of cans per pound of aluminum. The average yield of cans per pound of aluminum has increased by 50 percent to more than 33 cans in 2000 from just under 22 cans in 1972 (Aluminum Association Inc., 2001). This increased yield, which lowered the aluminum can's average unit cost and weight, has contributed to its overall growth and dominance over steel in the beverage container industry.

Aluminum foil is used in containers and packaging for food, cosmetics, and pharmaceuticals. Foil is light, strong, flexible, and durable and provides a barrier against light, odor, moisture, and bacteria.

The third largest domestic market for aluminum and the largest market in most other areas of the world is the building and construction industry. An estimated 20 percent of the world's aluminum production goes into the building and construction sector principally in the form of sheet and extrusions. In Europe alone, consumption of aluminum for construction has risen to more than 1.5 million metric tons per year (Mt/yr) in 2000 from more than 100,000 metric tons per year (t/yr) in 1960. Exterior building applications include curtain walling, window frames, siding and roofing, greenhouses and conservatories, scaffolding and ladders, and, more recently, the supporting frames for solar panels. Interior uses include partitions, cast door handles, staircases, and heating and air conditioning systems. Aluminum's high strength-to-weight ratio allows architects to meet desired performance specifications while minimizing the load on a building's support structure. Other advantages are long service life, low maintenance, and design flexibility (Metal Bulletin Monthly, 2001).

The foregoing are the three dominant markets for aluminum. Its physical and chemical characteristics, however, make aluminum suitable for a myriad of other applications, such as transmission wiring, consumer durables, signage, sporting equipment, and cookware.

PRICES

The monthly average U.S. market price of primary aluminum metal fluctuated throughout 2000. The average began the year at 80.1 cents per pound and by December had fallen to 74.3 cents per pound. The average price for the year, however, increased to 74.6 cents per pound in 2000 from 65.7 cents per pound in 1999. The London Metal Exchange (LME) cash price for high-grade primary aluminum ingot followed the same general trend as the U.S. market price. The 2000 average annual LME cash price was 70.3 cents per pound (Platts Metals Week, 2001).

Purchase prices for aluminum scrap, which closely track those for primary metal, also fluctuated during the year and closed at lower levels than those at the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 47.5 to 48.5 cents per pound; clean dry aluminum turnings, 40 to 41 cents per pound; and old sheet and cast aluminum, 38.5 to 39.5 cents per pound. Aluminum producers' buying price range for processed and delivered aluminum used beverage cans (UBCs) also closed lower at yearend. The price range began the year at 57 to 59 cents per pound and closed the year at 53 to 54 cents per pound (American Metal Market, 2001a). The monthly average transaction price for aluminum UBCs also decreased during 2000. The monthly average began the year at 62.9 cents per pound and had fallen to 53.9 cents per pound by December. Similar to the trend of the U.S. market price of primary aluminum ingot, however, the annual average transaction price of 57.7 cents per pound for aluminum UBCs in 2000 was higher than the 1999 annual average of 50.6 cents per pound (Container Recycling Report, 2001).

The yearend indicator prices for selected secondary aluminum alloy ingots also decreased significantly compared with those of 1999. The closing prices for 2000 were as follows: alloy 380 (1 percent zinc content), 68.7 cents per pound; alloy 360 (0.6 percent copper content), 74.1 cents per pound; alloy 413 (0.6 percent copper content), 73.8 cents per pound; and alloy 319, 72.7 cents per pound (American Metal Market, 2001b). The annual average U.S. market price for A-380 alloy (3 percent zinc content) in 2000 was 65.6 cents per pound, and the average annual LME cash price for a similar 380 alloy was 55.2 cents per pound (Platts Metals Week, 2001).

From the late 1970s and throughout the 1980s, aluminum prices, for the most part, reflected the law of supply and demand (fig. 3). During the early 1980s, the aluminum industry suffered from a period of oversupply, high inventories, excess capacity, and weak demand, which caused aluminum prices to tumble. By 1986, excess capacity had been permanently closed, inventories were low, and the worldwide demand for aluminum made a dramatic surge upward. This extremely tight supply and demand situation, which continued throughout 1987 and 1988, brought about a dramatic increase in aluminum prices.

During the 1990s, the speculative effect of the futures market began to exert its presence on aluminum prices. Prices were not only reacting to the laws of supply and demand, but also to the perceived direction of the market as reflected on the futures exchanges.

In the early 1990s, the major influence on aluminum prices was the dissolution of the Soviet Union. To generate hard currency, large quantities of Russian aluminum ingot entered the world market. Unfortunately, the aluminum market had just entered an economic downturn and was unable to absorb the Russian material. This period of oversupply, decreasing demand, and increasing inventories depressed world aluminum prices.

By the mid-1990s, production cutbacks, increased demand, declining inventories, and the perceived improvement in the world market led to a dramatic rebound in aluminum prices. Prices began to cycle downward again during the late 1990s as the economic crisis in the Asian market exerted pressure on the prices of several commodities, which included aluminum. Once again, the aluminum market was entering a period of oversupply. The perceived downward influences of the Asian crisis, however, may have hastened the decline in prices before the actual oversupply condition in the marketplace (Plunkert, 1999).

SOURCES OF ALUMINUM SCRAP

The secondary aluminum industry started shortly before World War I at a time when the United States had only one primary aluminum producer. A secondary industry was not

Figure 3. Annual average U.S. primary aluminum metal prices from 1980 through 2000. Source: Platts Metals Week.

needed prior to that time because the supply of aluminum scrap was limited. Although the secondary industry did grow during World War I and thereafter, that growth was modest until World War II. Secondary smelters emerged from the war years with the technology needed to process huge quantities of aircraft scrap and aluminum product manufacturing (new) scrap (Plunkert, 1990).

Aluminum recovery from scrap has become an important component of the supply and demand relationship in the United States. Increased costs for energy and growing concerns over waste management have provided the impetus for increased recycling rates, but it is the economics of recycling that has sustained the growth of the market for recycled aluminum. Only about 5 to 8 percent of the energy required to produce primary aluminum ingot is needed to produce recycled aluminum ingot. In addition, to achieve a given output of ingot, recycled aluminum requires only about 10 percent of the capital equipment compared with primary aluminum. The economics of recycled aluminum are even more attractive in light of the fact that a large part of the raw materials currently used for virgin aluminum production in the United States is imported. Because the value of recycling is universally recognized, the market for recycled aluminum is robust. In this competitive market, recyclers take an active role in attracting aluminum for recycling, thus minimizing the amount of aluminum disposed into the solid waste stream (Aluminum Association Inc., 1998, p. 4).

Aluminum recovered from scrap has shown a fifteenfold increase since 1950. In addition to improvements in recycling technologies, some of the increase in aluminum scrap recovery can be attributed to a changing and growing end-use consumption pattern. Aluminum products developed for the construction, transportation, and electrical industries tend to have a fairly long life cycle and are slow to enter the scrap supply stream. The emergence of the aluminum beverage can in the mid-1960s with a life cycle of as little as 60 days added dramatically to the potential aluminum scrap supply.

Initially, the public treated aluminum cans as a discardable product. It was not until the early 1970s that can recycling began to accelerate as the public and the industry recognized the economic and ecological advantages of recycling. In the 1980s, Materials Recovery Facilities (MRFs) gave new prominence to the job of collecting, sorting, and processing waste materials. Millions of households participate in curbside recycling programs, which provide the materials for MRFs, and chief among the recovered materials are aluminum cans. Although aluminum cans may be small in comparative tonnage to other materials in the waste stream, it is their monetary value that is often essential to the economic survival of these facilities. During the past 20 years, industry recycling centers and MRFs have facilitated the collection of aluminum UBCs.

In 2000, the U.S. Geological Survey (USGS) estimated that almost 3.5 million metric tons (Mt) of metal was recovered from purchased aluminum scrap. Of this total, approximately 40 percent was recovered from old scrap. Of the old scrap processed, approximately one-half was recovered from aluminum UBCs.

Table 1 is the basis for the data shown in figure 1. Definitions of the terms used in the table are detailed in the Appendix. Statistical data for the various types of old and new scrap consumed by the domestic recycling industries are reported to the USGS on a monthly and annual basis and are published in the USGS Mineral Industry Surveys and Minerals Yearbook series. Data on trade were obtained from monthly reports published by the U.S. Census Bureau.

Table 1. Salient statistics for U.S. aluminum scrap in 2000.

[Values in thousand metric tons, metal content, unless otherwise specified]

Old scrap:	
Generated[1]	4,000
Consumed[2]	1,370
Consumption value	$1.9 billion
Recycling efficiency[3]	42 percent
Supply[4]	4,625
Unrecovered[5]	2,660
New scrap consumed[6]	2,080
New-to-old-scrap ratio[7]	60:40
Recycling rate[8]	36 percent
U.S. net imports of scrap[9]	50
Value of U.S. net imports of scrap	$96 million

[1]Aluminum content of products theoretically becoming obsolete in the United States in 2000. It excludes dissipative uses and net U.S. imports of finished products containing aluminum in the year of consumption.

[2]Aluminum content of aluminum products that were recycled in 2000.

[3](Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imports minus old scrap stock increase).

[4]Old scrap generated plus old scrap imports.

[5](Old scrap generated plus old scrap imports) minus old scrap stock increase minus old scrap consumed minus old scrap exports.

[6]Metal content of prompt industrial aluminum scrap (excluding home scrap).

[7]Ratio of quantities consumed, in percent.

[8]This is the fraction of supply that is scrap on an annual basis. It is defined as old plus new scrap consumed divided by apparent supply (primary plus secondary production (old plus new scrap) plus imports minus exports plus adjustment for Government and industry stock changes), in percent.

[9]Trade in scrap is assumed to be old scrap.

OLD SCRAP GENERATED

Old scrap is a product of obsolescence and becomes available to the secondary industry when durable and nondurable consumer products are discarded. To determine the quantity of old scrap available to be recycled for a specific period of time, estimates of the lifetimes for various aluminum-containing products are combined with historical end-use data to determine a theoretical availability of old scrap for a given period of time. The end-use data are based on shipment data published by Aluminum Association Inc. in their Annual Statistical Review and factored into the calculated apparent consumption for a specific period. For example, the average life of the transportation component of consumption was estimated to be 25 years. Because the aluminum consumed in transportation applications was estimated to be 663,000 t in 1975 (Aluminum Association percentage distribution times apparent consumption), which is 25 years prior to the study period of 2000, this is the quantity of material that is included in the "old scrap generated" figure for the transportation sector for 2000. The same type of estimation procedure with varying product lifetimes was used for the other end-use categories; namely, packaging, building and construction, consumer durables, electrical, machinery and equipment, and other. Although the life cycle for an aluminum beverage can has been estimated to be as little as 60 days, a life cycle estimate of 1 year was used for the packaging component of the calculation. This should not introduce much distortion because shipments to that sector are relatively stable.

NEW SCRAP

New scrap is aluminum metal that never reached a consumer. Also referred to as "prompt" or "new industrial," the scrap is generated from aluminum wrought and cast products as they are processed by fabricators into consumer or industrial products. Home scrap, which is new scrap that is recycled within the company that generated the scrap and consequently seldom enters the commercial secondary market, is not included in this study. Prompt industrial scrap, however, is new scrap from a fabricator that does not choose to or is not equipped to recycle the scrap. This scrap then enters the secondary market. New scrap may include aluminum solids, clippings, stampings, and cuttings; borings and turnings that are generated during machining operations; melt residues, such as skimmings, drosses, spillings, and sweepings; and obsolete and surplus metal products that do not enter the market owing to quality control or other product specifications (Aluminum Association Inc., 1998, p. 4).

DISPOSITION OF ALUMINUM SCRAP

Scrap has its greatest value when it is returned directly to the same product from which it was manufactured. New scrap, such as sheet side trim, turnings, and ingot butts, is essentially the same metal quality as the fabricated or semifabricated product from which it was generated and hence is higher valued. Class scrap from the can manufacturing process is a good example of a well-defined new scrap. The composition of class scrap will fall into a very narrow range independent of the initial manufacturer. Because the processor must have a good idea of the scrap chemistry to effectively blend the material to make the final alloy, processors are usually willing to pay for the assurance of a known chemistry. If the chemistry of the scrap is less well defined, then the processor cannot predict the exact chemistry after melting. In the case of a secondary smelter that produces specification ingot, the lack of knowledge can mean additional processing time at the end of a melt cycle owing to compositional adjustments. This additional processing cost is often reflected in a lower valuation of the scrap input. The more a scrap processor knows about the scrap chemistry, the more effectively the processor can use it (Peterson, 2003).

OLD SCRAP RECYCLING EFFICIENCY

Recycling efficiency shows the relation between what is theoretically available for recycling and what is and is not recovered. By definition, this relation is the amount of old scrap consumed plus old scrap exports divided by the sum of old scrap generated plus old scrap imports plus or minus old scrap stock changes. Each component used to determine the relation is considered in terms of recoverable metal content. The recycling efficiency for old scrap was calculated to be 42 percent for 2000 (table 1). If aluminum recovery from new scrap is included in the calculation, then the recycling efficiency for aluminum increases to 60 percent. Factors that would lead to underestimating old scrap recycling efficiency could be underestimates of the amount of scrap consumed or exported and overestimates of old scrap supply if the average product lives by market segment were too short. The opposites of these factors could lead to an overestimation of recycling efficiency. All scrap imports and exports were assumed to be old scrap. Also, no attempt has been made to estimate the aluminum consumed in dissipative uses or the aluminum content of finished products that may have entered or exited the domestic flow of material through international traded goods. An economic model was developed by Bruggink (2000) of Alcoa Inc. that can be used to forecast aluminum scrap supply by source and to examine the impact of changes in old scrap recovery rates on the U.S. supply system.

INFRASTRUCTURE

The aluminum recycling industry is characterized by companies that fit one of the following profiles: large integrated aluminum producers, independent manufacturers of wrought products (shaped for end product use), producers of secondary-specification alloy ingot, and toll processors that reclaim metal for producers without taking title to the recoverable scrap or dross. Industrial aluminum recyclers range from single small plants to multiplant operations. Production of individual companies can range from 5,000 t/yr to 1 Mt/yr of recycled metal.

An aluminum recycler may perform at least one of the following activities:

- UBC Processing—Aluminum is recovered from UBCs and new scrap generated by the canmaking process. This forms a closed-loop scrap source that recycles used cans back into new can sheet.
- Secondary Specification Aluminum Alloys Production—Aluminum is recovered from scrap of various sources to produce a specific alloy ingot for a customer. The end product is commonly called specification aluminum alloy and includes 18 different alloys, each of which has a specific chemical composition. The specific alloy is dependent on the customer's intended end product, such as an automobile part or other consumer product.
- Remelt Secondary Ingot (RSI) Production—Aluminum scrap is recycled into an intermediate product without a specific chemical composition, which can then be sold into the market. The customer will then remelt the ingot (hence the name) and add alloys to meet the unique chemical specifications of the intended end product.
- Deoxidation Ingot Production—Aluminum is recovered for steel deoxidizer products, which are important in the steelmaking process. The end product may take the form of various aluminum shapes—shot, cones, stars, or pyramid shapes.
- Dross Processing—Aluminum is recovered from dross, which is a byproduct that forms in furnaces during normal melt processing. Dross contains aluminum that ranges from 10 to 80 percent entrained with other metal oxide impurities formed during the melting process, which include chloride, fluoride, and aluminum oxides. In this process, the aluminum is recovered from the dross either mechanically or by adding salts during the melting process. The recovered aluminum may be returned to a customer through a tolling relationship as molten metal or RSI.

Excluding fabricating mills with remelt facilities, the U.S. secondary aluminum industry comprises approximately 50 companies or plants that produce foundry ingot and/or scrap ingot billet (Aluminum Association Inc., undated a).

TRADE

Aluminum scrap is traded in the international marketplace. Price and shipping costs are usually the determining factors in choosing whether to sell scrap in the domestic market or the international market. U.S. trade in aluminum scrap has grown dramatically during the past 40 years. Most of the scrap shipped into the United States comes from Canada. In 2000, the United States received almost one-half of its scrap imports from Canada. Canada has also become the major recipient of scrap exports from the United States. In 2000, almost 40 percent of the United States exports of aluminum scrap were shipped to Canada.

PROCESSING OF ALUMINUM SCRAP

Scrap dealers and brokers play a key role in the efficient collection and processing of aluminum scrap. The scrap dealer serves as a collection point for scrap aluminum by buying old aluminum products and cans from the public. A strength of scrap dealers is the built-in collection and transportation systems connected to their operations. This includes trailer drop-off or roll-off containers to collect scrap at the point of generation. This helps ensure a captive source and quality-assured supply. Scrap dealers vary in size and in degree of processing sophistication. A scrap dealer may have shredding and compacting machinery for the initial processing of scrap. Smaller dealers and yards with little or no processing capabilities tend to sell their scrap to larger dealers either directly or through a scrap broker.

Another important source of aluminum scrap is the scrap broker who, like the dealer, often trades in several different kinds of metal. The broker adds liquidity to the market by acting as a go-between for the dealer and consumer. Brokers can also act as an inventory point for just-in-time manufacturing.

The secondary aluminum recycling industry uses relatively simple processes. Two general types of scrap are available—furnace-ready scrap and scrap requiring some preprocessing. The preprocessing steps that involve crushing and/or shredding and drying can be done by either the scrap consumer or the scrap dealer. The shredders and crushers are used for size reduction and for iron removal; several sets of magnets often are placed at the exit end of the crusher to remove any iron-containing scrap that was included in the aluminum scrap. The typical dryer resembles a rotary kiln with an afterburner and baghouse for pollution control. The dryer's function is to remove contaminants, such as cutting oils, plastic, and other organics. The removal of contaminants helps to minimize air pollution from the melting furnaces and to minimize the amount of oxidation while melting (Viland, 1990).

A number of methods are used to melt aluminum scrap. Most have evolved from conventional aluminum melting technologies or are simple adaptations of preexisting technologies. The major methods are discussed below (Peterson, 2003).

REVERBERATORY (REVERB) DRY HEARTH MELTER

This is conventional technology for melting T-bar, RSI, and mill scrap. This furnace is basically a refractory-lined box with burners. The furnaces can be either stationary or tilting with the latter style producing better quality metal. Large pieces of scrap placed in the empty furnace hearth melt by direct flame contact or through heat transfer by radiation to form a pool of molten metal, which is then drawn off for later use. Care must be taken when charging lighter gauge materials to place them at the bottom of the solid load so that excessive oxidation does not occur. Melt loss for lighter gauge materials with this style of furnace can be high. No flux is used with these furnaces.

SIDE-BAY HEARTH MELTER

This furnace is an adaptation of the conventional reverb furnace. The furnace maintains a significant metal heel at all times; a metal heel is metal that remains in the furnace after the removal of the major portion of the contents. Scrap is charged to an external side bay and is not exposed to the burner environment. The burners inside the hearth supply heat to the metal, which is then circulated by a molten metal pump to the side bay where melting of the scrap charge can take place. Lighter gauge scrap can be melted in this furnace with higher recovery because of the lack of flame exposure. The side bay is often charged with a chloride salt flux to protect the molten metal and to remove the oxide films and particles from the scrap. The byproduct from the side bay is called black dross and is a mixture of salt components, oxides (films and particles), and metal droplets. Because of the flux usage, the molten metal is generally quite clean and free of oxide impurities.

STACK MELTER

The stack melter is another variant of a conventional reverb hearth melter. Heavier scrap pieces and ingots are charged into a special holding area. The furnace flue gases exit the furnace through this holding area and are used to preheat the scrap. Scrap moves down to the hearth until it reaches a ledge where the scrap finally melts and enters the metal pool. These furnaces have much higher energy efficiency than conventional reverb furnaces. Metal quality is reported to be high because oxide films usually stay on the hearth ledge. The furnace is restricted to heavier scrap and small ingots that fit into its material handling system. Turnings and light gauge scrap cannot be used.

ROTARY FURNACE

The rotary furnace is the “all-purpose” furnace of the aluminum industry. Because of its excellent mixing properties as a result of the barrel rotation, the rotary barrel has good thermal efficiency and can handle many different types of materials, which include extremely dirty scrap and drosses. As in the case of the side-bay furnace, a chloride flux is used to trap and hold the oxide impurities. Although oxides can be generated during the melting process, the flux captures and holds them, thus resulting in a relatively clean metal.

INDUCTION FURNACE

The induction furnace is the only commercial furnace that melts the scrap without the use of a combustion system. The induction coils couple with the electrically conductive aluminum and cause the scrap to heat and melt. Without direct flame impingement on the aluminum scrap, the metal temperature can stay lower and the oxidation process can be impeded. The coupling also induces a strong mixing action on the molten metal. Because of this mixing, oxide films and particles that are generated can get pulled into the metal pool.

OUTLOOK

Recycling of aluminum scrap is significant in economic, energy, and aluminum resource savings, as well as in environmental protection. The aluminum recycling industry has saved and will continue to save billions of dollars in energy and material costs compared with primary aluminum production costs. Recycling aluminum requires less than 6 percent of the energy to extract aluminum metal from bauxite ore and has helped contribute to significant amounts of commercial energy savings (U.S. Department of Energy, 2003). Recycling provides a continuous source of aluminum, and no matter how many times it is melted and recast, recycling does not change aluminum’s basic properties.

The packaging, transportation, building and construction, consumer durables, electrical, and machinery industries anticipate increasing their use of aluminum, which will increase the eventual supply of aluminum scrap available for recycling. Since its inception, the aluminum beverage can has been the most visible and significant source of aluminum scrap. As the transportation industry, particularly the automotive industry, increases its use of aluminum materials, these products, too, will play a significant role in the future availability of aluminum scrap. The industry, however, will need to continue to develop new technologies to recover and to identify the more complex types of scrap that will be found in today’s and future automobiles. Automobiles contain a mixture of recyclable parts in close contact. Separation technology will play a large role in segregating and preserving the value of each of these parts.

For these reasons, the aluminum recycling industry should continue to grow. The increased use of aluminum in the automotive industry with its longer life cycle has delayed the return of increasingly large tonnages of automotive aluminum scrap to the market. This material, however, will eventually become part of the scrap flow stream and thereby increase the recycling rate and improve the recycling efficiency as well.

Aluminum recycling has been around for nearly 100 years. The continued use of aluminum assures the industry of a continuous supply of feed material and a growing market for recycled aluminum.

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APPENDIX—DEFINITIONS

apparent consumption. Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply. Apparent consumption plus secondary production (new scrap).

calcinations. The heating of ores, concentrates, precipitates, or residues to decompose carbonates, hydrates, or other compounds.

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizer, making it exceptionally difficult and costly to recycle or recover the metal.

home scrap. Scrap generated as process scrap and consumed in the same plant where it is generated.

new scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption, including all defective finished or semifinished articles that must be reworked. Examples of new scrap are borings, castings, clippings, drosses, skims, and turnings. New scrap includes scrap generated at facilities that consume old scrap. Included as new scrap is prompt industrial scrap—scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old-scrap ratio. New scrap consumption compared with old scrap consumption, measured in weight and expressed as a percentage of new plus old scrap consumed (for example, 40:60).

old scrap. Scrap including (but not limited to) metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, silver from photographic materials, metals from shredded cars and appliances, used aluminum beverage cans, spent catalysts, and tool bits. This is also referred to as postconsumer scrap and may originate from industry or the general public. Expended or obsolete materials used dissipatively, such as paints and fertilizers, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration, excluding dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as [consumption of old scrap (COS) plus exports of old scrap (OSE)] divided by [old scrap generated (OSG) plus imports of old scrap (OSI) plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks], measured in weight and expressed as a percentage:

$$\frac{\text{COS + OSE}}{\text{OSG + OSI + decrease in OSS or} - \text{increase in OSS}} \times 100$$

old scrap supply. Old scrap generated plus old scrap imported plus a decrease in old scrap stocks or minus an increase in old scrap stocks.

old scrap unrecovered. Old scrap supply minus old scrap consumed minus old scrap exported.

price. The total value of old scrap consumed was estimated by adding the value of used beverage can scrap consumed to the value of other old scrap. The value of used beverage can scrap was calculated using the average annual transaction price for used aluminum beverage can scrap. The value of other old scrap was based on the average annual price for old aluminum cast and sheet scrap. The total value of net imports of aluminum scrap was derived from trade statistics reported by the U.S. Census Bureau as follows: total value of aluminum scrap imports minus total value of aluminum scrap exports.

recycling. Reclamation of a metal in useable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying metals (or other base metals) in steel, recovery of antimony in battery lead, recovery of copper in copper sulfate, and even the recovery of a metal where it is not desired but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels only because the cost of removing it from tinplate scrap is too high and (or) tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the apparent metal supply that is scrap on an annual basis. It is defined as [consumption of old scrap (COS) plus consumption of new scrap (CNS)] divided by apparent supply (AS); measured in weight and expressed as a percentage:

$$\frac{\text{COS + CNS}}{\text{AS}} \times 100$$

scrap consumption. Scrap added to the production flow of a metal or metal product.