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ISASMELT™ for the Recycling of E-Scrap and Copper in the U.S. Case Study Example of a New Compact Recycling Plant

GERARDO R.F. ALVEAR FLORES,[1,4] STANKO NIKOLIC,[2] and PHILLIP J. MACKEY[3,5]

1.—Xstrata Technology, Vancouver, BC, Canada. 2.—Xstrata Technology, Brisbane, QLD, Australia. 3.—P.J. Mackey Technology Inc., Montreal, QC, Canada. 4.—e-mail: galvear@xt-t.com. 5.—e-mail: pjmackey@hotmail.com

As living standards around the world improve and metal consumption increases, extracting raw materials will likely become more challenging in the future. Although already part of the general metal supply stream, metal recycling has to increase if we are to build a more sustainable society. With the recent widespread adoption of a range of consumer and industrial electronics, the recycling of the so-called electronic scrap ("e-scrap") has also increased in importance. One of the leading technologies for the recycling of e-scrap and copper scrap is the ISASMELT™ Top Submerged Lance technology. This article describes new opportunities for the U.S. recycling industry to yield full value from collected, sorted, and separated waste metals, in particular, e-scrap and lower grade copper scrap by the use of ISASMELT™ technology. The article includes the description of a case study example of a regional, compact ISASMELT™ plant in the United States treating a blend of e-scrap and copper scrap, having a total feed capacity of 75000 t/year of feed. Plants of higher or lower capacity are also discussed.

INTRODUCTION

After the retirement of a given electrical or electronic product, full recycling to recover contained metals involves a large number of steps—from the initial collection stage and preliminary sorting, which generally involves some degree of physical upgrading and separation, through to the final processing stages to produce pure metals. Although all steps are important, it is the near-final processing step, producing a payable metal product, that is ultimately the key to successfully and sustainably recycling these materials. The implementation of the ISASMELT™ technology for the recycling of valuable metals at Umicore Precious Metals Refining Hoboken Plant in Belgium and Aurubis AG Lünen plant in Germany as part of the Kayser Recycling System are both good examples of how ISASMELT™ technology has been adapted to recycle not only electronic scrap ("e-scrap") and copper bearing materials but also several other nonferrous metals.

In the United States, there are now mechanisms and systems developing for the collection, initial sorting, and subsequent sorting of not only e-scrap but also a variety of copper products. However, large quantities of separated e-scrap are presently exported from the United States for treatment. In regard to copper scrap, some No. 1 copper, large quantities of No. 2 copper,* and lower grade copper scrap collected in the United States are also exported for treatment elsewhere. Historically, the bulk of this copper scrap was generally treated within the United States,[1–4] but, since about 2000, the tonnage of copper scrap exports has increased considerably. Figure 1, taken from the recent publication of the Copper Development Association, "The US Copper base Scrap Industry and its By-products-An Overview (13th Edition)",[1] illustrates the trends in the net exports and consumption of copper in scrap in the United States for the period 1981–2012. Through much of the 1980s, of the order of 200000 tons annually (181000 metric tonnes) was exported; this figure had jumped to more than 800000 tons annually (726000 metric tonnes) by

*No.1 copper and No. 2 copper are metal scrap with 96–98 wt.% and 94–96 wt.% copper content, respectively.

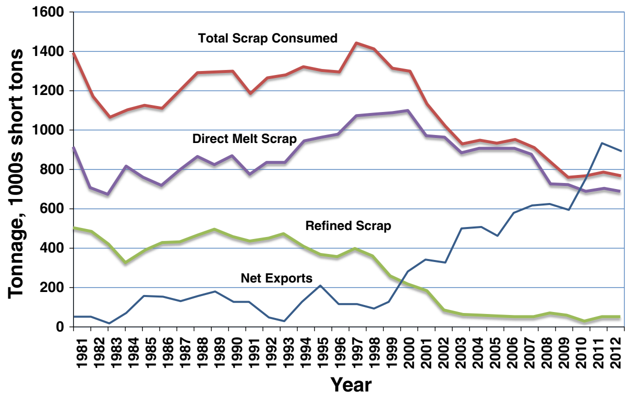

Fig. 1. Trends in U.S. net exports and consumption of copper in scrap, 1981–2012, in thousands of short tons.[1] Data source: U.S. Geological Survey.

2012, on account of a insufficient copper scrap treatment capacity available in the United States. As will be discussed in this article, it is evident that there is adequate material to supply new copper and e-scrap recycling plants in the United States.

E-SCRAP AND COPPER RECYCLING: SUPPLY AND TRENDS

Background to Copper Recycling

Since the earliest times, a certain proportion of metals has always been recycled after use, in part because of the relative ease of production from scrap metal, essentially requiring only melting and refining. The inherent value of the metal was no doubt also a factor favoring retreatment of scrap. Furthermore, unlike some nonmetallic substances, nonferrous metals do not lose their chemical or physical properties in the recycling and subsequent refining steps and hence can be recycled many times over. In the early part of the nineteenth century, when the main uses for copper were essentially in applications for locomotive firebox components and for ship's sheathing, copper recycling was common. Used copper from these applications was typically melted down in a coal-fired reverberatory furnace. This was followed by a fire-refining operation to produce high-grade copper ingots for subsequent reuse.

Today, copper is used in a myriad of industrial, commercial, and household products, and as such, copper destined for recycling occurs in a variety of forms and grades. The consumption of copper in the United States now approaches some 2 million tonnes per year.[5] Although much of the copper collected for recycling may be present in a form that is relatively pure, such as factory scrap or copper that is in a clean, metallic state (No. 1 copper scrap or No. 2 copper scrap), large amounts are present as a lower grade material, which means that they are associated with other metals, ceramics, or plastics.

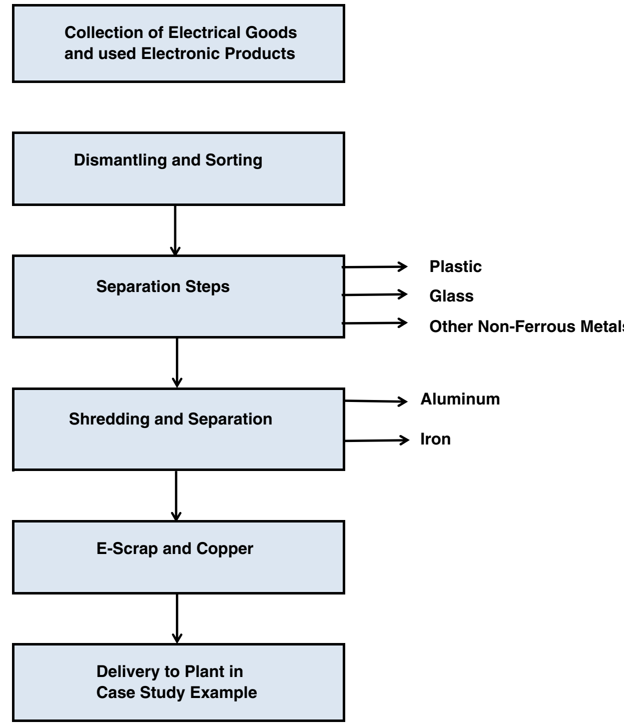

Fig. 2. Example of collection and processing chain for used household electrical goods and appliances and electronic products.[6]

Importance of Collection

In today's world, almost all electrical and electronic components incorporate several valuable precious metals such as gold, platinum, or silver along with copper. Therefore, when a product's useful life is over, such metals are made available for recycling together with the copper. A typical processing chain for used household and consumer goods is illustrated in Fig. 2.[6] Collection is the first critical step in this process. In fact, Reck and Graedel[7] recently identified collection as one of the main challenges facing the efficient recycling of such materials.

Nevertheless, important progress toward improved collection is being made by several interested parties including both computer companies and recyclers. Examples are operations by HP,[8] Dell,[9] or Best Buy,[10] where a variety of recycle options are now available for consumers to dispose of their used products. Services such as those provided by Sims[11] and Z-loop[12] are evidence of the increasing value and importance of the metals recycling industry in the United States.

Electrical and E-Scrap

Electrical and e-scrap, or more generally what is known now in many countries as waste electrical and electronic equipment (WEEE), covers a wide range of materials and products from used electrical products, including household appliances and the like, to used electronic products such as computers, cell phones, and so on. The term "WEEE" is applicable to the complete range of such collected waste products.

In practice, once collected, these materials are generally processed through the route shown in Fig. 2 to yield different subproducts for subsequent processing such as:

- Plastics and glass
- Ferrous metal components
- Nonferrous metals such as aluminum
- Subproducts containing copper and important levels of precious metals such as gold and silver, often invariably associated with copper (smelter grade e-scrap is typically this category of separated material)

The rapid rise in consumer usage of a wide variety of electronic and electrical products (some with a fairly short life—several months to perhaps a few years—leading to early obsolescence) has generated large quantities of waste materials. This situation has in some cases prompted government regulations affecting disposal, exports, and the like. The sheer number of computers, monitors, television sets, and other electronic items that become obsolete each year is indeed large. In 2009, for example, it was estimated that the United States annually discarded some 30 million computers and some 100 million cell phones.[6] The trend in the quantity of U.S. collected and recycled electronics in recent years is illustrated in Fig. 3, based on data developed by the Institute of Scrap Recycling Industries, Inc.[13] This indicates that in 2010 some 3.1 million tonnes were collected/recycled, which corresponds to about 10 kg/capita.

It is also known that some proportion of electronic waste material still ends up in a landfill; hence, the amounts of material available for recycle would be higher than indicated here. As shown in Fig. 2, recycled electronic and electrical products are first dismantled, then sorted, and finally separated into several different materials (Al, Fe, Cu, and precious metals, glass, plastics, etc.). Much of the copper and precious metals-containing subproduct so obtained in the United States is exported to countries such as Canada, Europe, China, and elsewhere for processing.

The Commodities Research Unit of the United Kingdom estimates that the total European Union (EU) generation (2008 data) of WEEE is some 10 million tonnes per year, of which 70%, or 7 million tonnes per year, are collected for treatment, with about 96% of the material being treated within the EU.[6] Boliden has reported[14] that in 2011, out of a batch of 2.7 million tonnes of WEEE material collected within the European countries of the EU (estimated by the writers to represent some 30% of the total collected in the EU per year), that upon sorting and separation, some 120000 tonnes of what is known as e-scrap or "smelter grade e-scrap" was obtained (essentially representing the "e-scrap and copper" box in Fig. 2). The reported quantities of copper, gold, and silver in this amount of e-scrap material are summarized in Table I.[14]

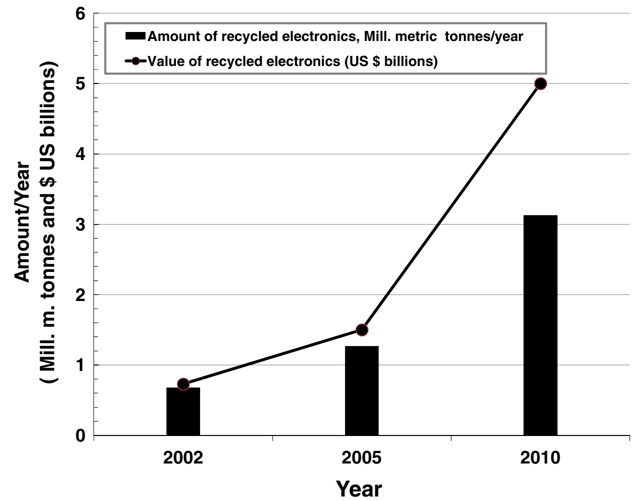

Fig. 3. The amount (in millions of metric tonnes/year) and value (in US$ billions/year) of U.S. recycled electronics for the years 2002, 2005, and 2010.[13]

It is noted that on this basis and for current conditions, the United States with a population greater than 309 million could potentially collect more than 5 million tonnes per year of waste electronics plus electrical components, and this is estimated to provide more than 0.25 million tonnes of smelter grade e-scrap per year.

The complexity of e-scrap, together with the high unit value per tonne, requires the correct technology choice for effective treatment of the material. It is here that the ISASMELT^{TM} technology is ideally suited to this duty as it enables complex e-scrap component materials to be processed in the United States as an environmentally and energy efficient operation.

Copper Scrap: U.S. Trends

As discussed, Fig. 1 illustrates the trends in the net exports and consumption of copper in scrap in the United States for the period 1981–2102. Data on copper flows within the United States are discussed here. Table II presents data for copper flows in the United States for the period 2003–2011.[5] It is shown that the apparent consumption of refined copper in the United States for 2011 was 1.937 million tonnes. In addition, Fig. 4 presents the trend in copper scrap exports shown as tonnes of material according to four scrap types for the period 2003–2010. The copper flow in the United States consists of several streams including the following broad types:

i. Primary refined copper
ii. Copper imports
iii. Recycled copper within the United States for reuse
iv. Copper exports

Table I. Example (for the year 2011) of the resulting tonnage and analysis of e-scrap generated by sorting/separation from a given quantity (2.7 million tonnes in this example) of WEEE[14]

Item	Unit	Amount	Comments
Tonnage of WEEE collected	Million tonnes	2.7	The population represented by this amount of WEEE was not reported, but it is considered by the authors to be in the range of approximately 140–180 million based on typical Western Europe data. This corresponds to nearly 17 kg/capita.
Resulting tonnage of smelter grade e-scrap	Million tonnes	0.12	Corresponding to ~4.4% of WEEE
Metals contained in the above smelter grade e-scrap (tonnes)			
Copper	Tonnes	22000	1. Equivalent wt.% in e-scrap: 18.3% 2. Equivalent wt.% in original WEEE material: 0.81%
Silver	Tonnes	80	1. Equivalent wt.% in e-scrap: 0.067% 2. Equivalent wt.% in original WEEE material: 0.003%
Gold	Tonnes	7.5	1. Equivalent wt.% in e-scrap: 0.0063% 2. Equivalent wt.% in original WEEE material: 0.00028%
Balance	Tonnes	97000	1. Equivalent wt.% in e-scrap: 81.6%, typically mostly SiO_2, Al_2O_3, some Fe and Al metals and plastics
Estimated contained value (rounded) of above smelter grade e-scrap at typical current prices	USD/tonne	$4600	

It is noted that the term "WEEE" in the EU generally includes all waste electronic and electrical materials, whereas in the United States, the amounts of waste electronic and electrical materials are often counted separately but sometimes used interchangeably. Hence, U.S. and EU figures for tonnages of e-scrap given on a capita basis sometimes vary. Quite a few factors might cause the figures to vary; certainly the difference in terminology confounds a direct comparison. The value per tonne is based on the following metal prices (US $): Cu: $3.30/lb, Ag, $23/oz, and Au: $1400/oz.

Table II. Copper flows in the United States for the years 2003–2011 (in 1000s tonnes of contained copper)[5]

	Year								
Category[a]	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1. Primary refined copper	1250	1260	1210	1210	1268	1220	1113	1057	882
2. Cu scrap imports (as t of Cu)	77	86	97	100	113	90	61	81	93
3. Refined Cu imports	882	807	1000	1070	829	724	664	605	670
4. Cu produced from secondary Cu[b]	944	965	953	969	933	859	777	785	802
5. Copper exports as scrap (as t of Cu)[c]	482	500	461	562	635	636	590	723	868
6. Apparent total Cu supply[d,e]	2671	2618	2799	2787	2508	2257	2025	1805	1689
7. Apparent consumption of refined Cu	2524	2662	2506	2327	2356	2228	1817	1947	1937

Sources: U.S. Geological Survey, U.S. Department of Commerce, U.S. International Trade Commission, and Copper Development Association.[5]
[a]Copper imports and exports of scrap shown as tonnes of Cu content as estimated by authors from tonnes of material.
[b]Differences between rows 5 and 6 are due to stock changes and possible variations in Cu grade of scrap that was estimated by the authors; summed over the 9 years included here indicates a difference of less than 5%.
[c]Includes Cu from old and new scrap.
[d]From "CDA Annual Data 2012, Copper Supply and Consumption 1991–2011".
[e]Based on sum of rows 1 to 4 minus row 5.

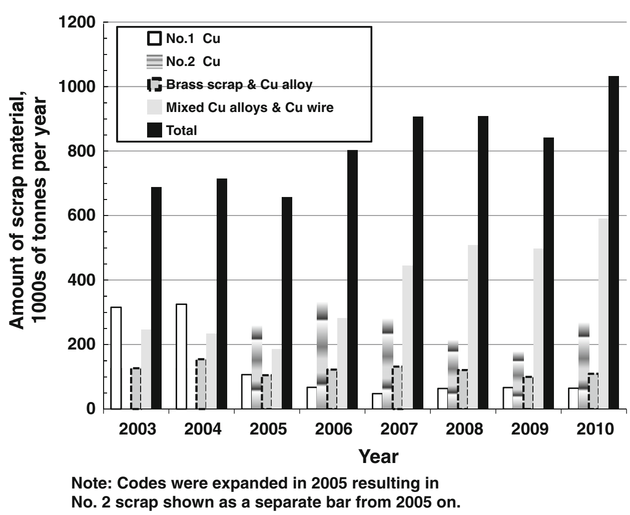

Fig. 4. Trend in the amounts of copper scrap material exported from the United States by year 2003–2010 and type of scrap. (Note: Data are given as tonnes of material, not as tonnes of contained copper). Source: U.S. Geological Survey.[5]

It is noted that this breakdown by type is only approximate for the purposes of illustration of recent trends; the U.S. Department of Commerce and the U.S. International Trade Commission break down copper scrap into a greater number of categories than shown in Fig. 4.

The information in Table II and Fig. 4 indicates that a considerable tonnage of higher grade copper scrap is currently recycled in the United States (Refer to row 4 in Table II). This material is essentially high-grade factory scrap, the so-called No. 1 scrap and other forms of clean copper scrap. The major U.S. copper and brass fabricating plants that handle such material are listed in Table III. As noted, in general, these plants process high-grade copper scrap. Interesting too from Table II and Figs. 1 and 3 is the fact that a considerable quantity of lower grade copper scrap is currently exported from the United States for treatment elsewhere. Thus, in 2010, the United States exported some 1033000 tonnes of copper scrap material (far right-hand bar in Fig. 4, containing an estimated 723000 tonnes of contained copper, Table II (authors' estimate)). Thus, it can be observed that there is plenty of material to supply new recycling plants located in the United States if they have cost-effective and environmental compliant technology to treat it.

Table III. Major U.S. copper fabricating plants

Plant	Location
Aurubis AG	Buffalo, NY, USA
Cambridge-Lee Reading tube	Reading, PA, USA
Cerro Tube	Mexico, MO, USA
CMC Howell Metal	New Market, CT, USA
Hussey Copper	Leetsdale, PA, USA
Mueller copper tube products	Wynne, AK, USA
Olin Brass	East Alton, IL, USA
Revere Copper Products	Rome, NY, USA
SDI La Farga Rod Plant	New Haven, IN, USA

POTENTIAL GROWTH OF COPPER AND E-SCRAP RECYCLING IN THE UNITED STATES

The combination of both a large increase in the use of consumer electronics and a heightened increase in recycling in general suggests that the tonnage of e-scrap available to the recycle market in the United States will grow significantly over the next decade.

Not only has the amount of metals available for recycling increased in recent times—and this trend is expected to continue—but also the complexity of the recycled products has changed. This degree of

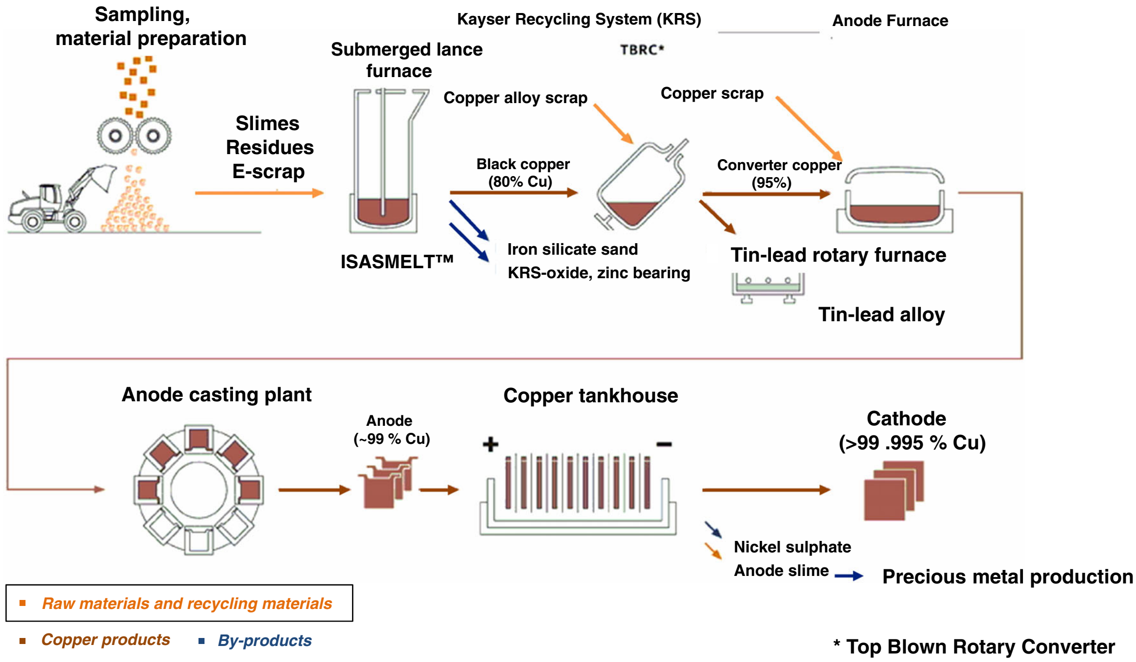

Fig. 5. Aurubis A.G. ISASMELT™ plant as part of the Kayser Recycling System.[15,17]

complexity has required the development of specialized equipment and technology not only to pretreat and sort the materials but also to further smelt and refine. In particular, the ISASMELT™ technology has been adapted to handle the recycling of a wide range of metals, including precious metals, copper, lead, nickel, zinc, and tin.[15–17]

Two successful examples of the application of the ISASMELT™ technology to the recycling of base and precious metals are as follows:[15–17]

- Aurubis A.G. ISASMELT™ plant, located in Lünen, Germany
- Umicore ISASMELT™ plant located in Hoboken, Belgium

Figures 5 and 6 show the schematic process flowsheets for the Aurubis and Umicore plants, respectively. The Aurubis A.G. ISASMELT™ plant (Fig. 5) is a key component of the Kayser Recycling System developed by Aurubis to recover copper, tin, zinc-bearing oxide, and precious metals. The Umicore ISASMELT™ plant (Fig. 6) is part of a pyro- and hydro-metallurgy circuit designed by Umicore, where copper and lead are used as base-metal collectors to recover precious metals, platinum group metals (PGMs), and other valuable elements.

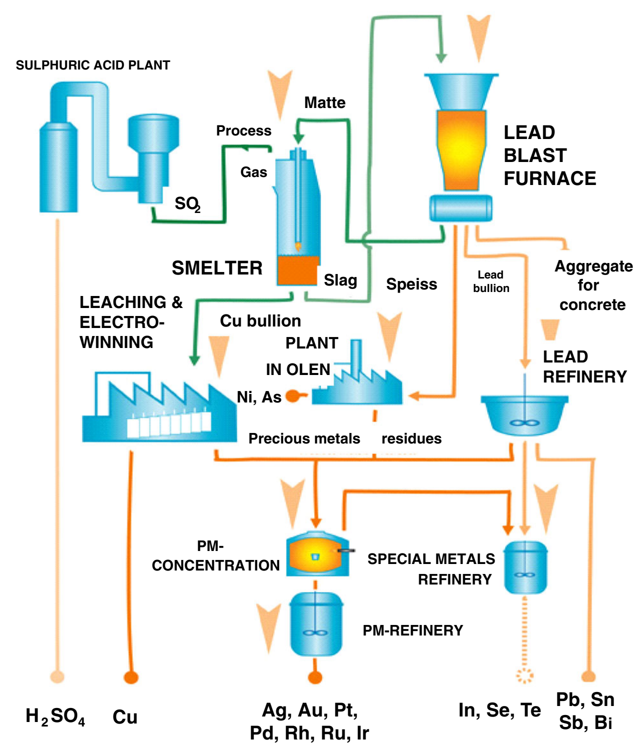

Fig. 6. Umicore ISASMELT™ plant as part of the Umicore Precious Metals Recycling System.[15,16]

TREATMENT OF E-SCRAP AND COPPER SCRAP BY THE ISASMELT™ PROCESS

Isasmelt™ Principle

ISASMELT™ technology[15,18–20] is based on the use of a stationary, vertical furnace design that employs a top-submerged lance injection system to provide highly efficient smelting of the feed, which in this example is a blend of e-scrap and copper scrap. The lance action causes effective mixing and reaction of these feed materials within the molten slag bath. The furnace itself is largely enclosed to minimize escape of any fugitive gases, whereas with

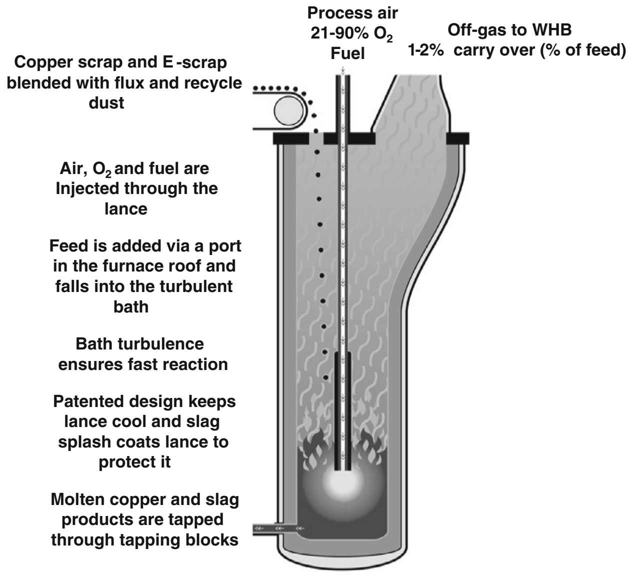

Fig. 7. The ISASMELT™ process concept for the processing of e-scrap and copper scrap.

the vertical furnace design, the furnace footprint is relatively small. The use of an advanced process control system results in the furnace operation being largely automated. The process concept is illustrated in Fig. 7.

The ISASMELT™ furnace treating the above material essentially represents a slag reaction process, wherein the fresh feed of e-scrap and copper scrap is introduced to the furnace and digested within the molten slag phase as shown in Fig. 7. It is in the slag phase where the main chemical reactions occur and oxidation of the feed materials takes place.

The oxygen transfer process in smelting is achieved through the controlled oxidation of iron in the slag (FeO) and subsequent formation of some magnetite (Fe_3O_4). Oxygen from the lance air (oxygen-enriched air) reacts with any metallic iron and aluminum contained in the feed, as well as with any added fuel, generating the reaction heat while forming metal oxides (slag), metallic copper, and an off-gas stream. The high temperature provides adequate reaction time in the well-stirred furnace melt, and the above-bath zone provides for complete combustion of the organic materials. Monitoring at the European ISASMELT™ plants (plants shown in Figs. 5 and 6) for example shows emissions of polychlorinated biphenyls (PCBs) to be extremely low.[21,22]

The metallic copper serves to completely absorb all the precious group metals present in the feed material. The following section describes the application of the ISASMELT™ process to the recycling of the feed material consisting of a blend of e-scrap and copper scrap.

Case Study Example

This case study example is presented to illustrate the ability of the ISASMELT™ process to treat a mixed or blended feed consisting of e-scrap and low-grade copper scrap, producing a copper metal product and a discardable slag. The ability of the ISASMELT™ technology to scale up or down[20] would enable smaller lower cost regional plants to be economically built initially, thereby simplifying the scrap collection and transportation systems. As the recycling market grows, these plants could be scaled up to suit the growing rate of scrap collected. It is noted that as a comparison, the lead recycling industry in the United States is typically made up of several regional plants. Although the present case study example considers a compact plant handling 75000 t/year of blended e-scrap plus low-grade copper scrap feed in the United States, larger plants can also be built. As an example of the flexibility of the process, the ISASMELT plant can increase its throughput with limited additional investment. For instance, the Aurubis ISASMELT plant was able to increase its throughput capacity by more than 45%. The same criteria could be applied to the proposed ISASMELT study case to expand the plant throughput in the future if market conditions allow for it.

A schematic flowsheet of the proposed 75000 t/year plant concept treating as feed a blend of copper scrap and e-scrap is given in Fig. 8. It is noted that based on the different ISASMELT™ plants discussed by Alvear and Nikolic,[15] the ISASMELT™ process has proven its ability to handle an extremely wide range of feed materials from the perspective of both physical and chemical characteristics, and a plant can be designed to handle higher or lower tonnages. The individual feed materials can therefore vary widely in composition, depending on their source, as shown in Table IV provided as a guideline. However, some degree of feed preparation and blending is recommended to ensure stable feed composition to the furnace.

The proposed plant has facilities to receive and handle a range of different feed types according to both physical properties and chemical composition. After receipt and sampling, the feed materials can be loaded into their respective bins by a mobile equipment operator. Separate bins would also be installed for the metering out of silica flux and coal specific to the feed blend being treated. Using weight vibrator feeders, the feed materials are metered from the day bins onto a collector conveyor. The mass flow rate of each material will be controlled by a distributed control system operated from the ISASMELT™ plant control room.

The feed mix will be brought to the ISASMELT™ building and furnace via belt conveyors. As discussed, the unique smelting action of the ISASMELT™ furnace enables the mixed feed to be readily absorbed by the melt, producing, in the present example, a black copper layer and a slag.

As discussed by Alvear and Nikolic,[15] the ISASMELT™ process has the flexibility to allow smelt-

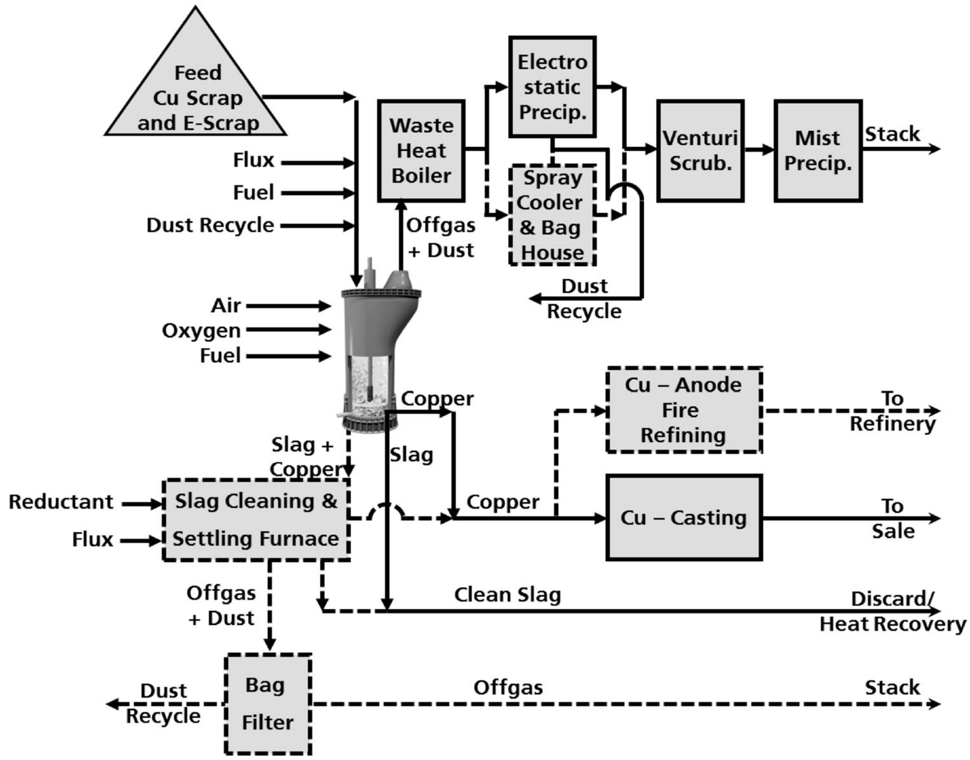

Fig. 8. Block-flow diagram of ISASMELT^{TM} plant for treating a blend of e-scrap and copper scrap. Note that the installation of the anode furnace unit is optional and that cast copper bars without refining may be shipped to a third-party refinery for treatment. It is also noted that the installation of the slag cleaning furnace is optional, depending on how the plant is designed.

Table IV. Typical composition range of feed materials

Element	Cu	Fe	Sn	Pb	Zn	Ni
Range (wt.%)	1–80	0–95	0–50	0–50	0–40	0–10

Note that the ISASMELT^{TM} can also handle a wide range of gangue oxide levels in the feed (SiO_2, CaO, MgO, and Al_2O_3), and a range of hydrocarbon contents and moisture levels.

ing to operate at any given condition chosen from a wide range of possible oxygen and sulfur partial pressures in the system. This is quite useful when the charge contains several metals so that a certain degree of selectivity can be adopted to oxidize as needed the metals in the feed. In the present situation, several operating conditions are therefore possible depending on the specific makeup of the feed.

For the case study example discussed here, the feed consisting of e-scrap and copper scrap can be batch smelted under so-called reductive smelting conditions[15] such that copper and base metals contained in the feed react to form an initial copper bath. This melt also serves to collect all the precious metals present in the feed. Depending on the feed composition and other conditions, as the bath builds up in the furnace, the copper melt—sometimes referred to as black copper—can assay between about 60% and 80% Cu content.

At the completion of feeding a batch to the furnace, the lance is raised. After a short settling period, the slag layer that has formed on top of the copper melt is then tapped out via the upper taphole. This slag can be granulated and may be sold as iron-silicate sand, or it can be appropriately stockpiled or shipped to a designated storage area. If conditions require it, a slag settling furnace can be installed to allow for additional settling of any copper prills that may be present in the slag (this furnace is shown by dotted lines in Fig. 8). Lance injection is then resumed so that in a short oxidizing step, the copper remaining in the furnace is converted to high-grade copper suitable for the subsequent refining step (Fig. 8). When the melt is ready, the lance is raised and the final high-grade copper charge is tapped out via the copper taphole located near the furnace hearth.

The small slag heel remaining in the furnace can conveniently be left in the furnace, where it would be reduced during the following reductive smelting step, or if required, the slag can be treated in a small electric furnace (Fig. 8). Alternatively, if the metal content of the slag warrants it, this slag can be transferred to a small rotary furnace for reduction to a Pb-Sn alloy that can be collected and then sold. The next reductive smelting step then commences and the cycle continues.

The high-grade copper is tapped for transfer to the anode or fire refining furnace, and the refined melt cast as anodes for shipment to an electrolytic refinery. Alternatively, the high-grade copper with minimum on-site refining can be cast into bars, which after sampling are shipped to a custom refiner for electrolytic copper refining along with gold and silver production.

Off-gases leaving the ISASMELT™ furnace will first enter into a compact waste heat boiler that serves to cool the gases and at the same time generates waste heat and steam for plant use. The cooled gases are then cleaned of dust in the hot electrostatic precipitator or in a bag house (with additional gas cooling). Cleaned gases exit the facility via the plant stack.

Water used on the site is treated in a dedicated water treatment plant and then recycled for use to the smelter. A minimum amount of freshwater makeup and demineralized water makeup is required for the plant and waste heat boiler, respectively. Overall plant liquid effluents and gaseous emissions are therefore extremely low.

Energy Consumption

It has been previously noted[23,24] that the energy requirement for the production of copper from recycled copper scrap is considerably lower than the energy required for producing copper from mined ore. As an example, the total estimated energy requirement for the plant concept presented here, plus the subsequent electrorefining step (for the production of cathode copper) and transportation of cathodes to market, is of the order of 760 kWh of electricity per tonne of cathode copper and 12400 MJ of fossil fuel per tonne of cathode copper.

By comparison, the total estimated energy consumption to produce cathode copper from ore analyzing 0.5% Cu ore (including mining, concentrating, smelting, electrorefining, and transporting cathodes to market) is of the order of 6800 kWh of electricity per tonne of cathode copper and 27300 MJ of fossil fuel per tonne of cathode copper.[25,26]**

The amount of CO_2 emissions per tonne of copper produced by the process described here would be about 10% of the CO_2 emissions for producing 1 tonne of copper from ore. The energy implications of metals recycling are further discussed by Rankin.[27]

Additionally, it is of interest to note that on average, it requires approximately 13 U.S. gallons of oil to ship 1 tonne of copper scrap material across the Pacific to China or Southeast Asia. Typically, even for the simple smelting of this same 1 tonne of metallic copper scrap in a fuel-fired reverberatory furnace (without the heat recovery and energy savings of the ISASMELT™ furnace), roughly the same amount of fossil fuel is required (melting only, no oxygen enrichment). Hence, there is an overall "energy" saving of approximately 13 U.S. gallons of oil per tonne of copper scrap if the copper scrap material were to be treated in a plant in the United States rather than exported across the Pacific. It is assumed that fuel required in the collection and transportation steps would be similar in the case of either treatment in the United States or export (typically this fuel would be of the order of 4 U.S. gallons per tonne handled for a 500-mile trip).

CONCLUDING COMMENTS

The collection and recycling of waste electronic materials in the United States is a large and growing business. After sorting of the collected waste electronic and electrical material, and separation into subfractions, much of the copper and precious metal-rich material produced are currently exported from the United States for treatment elsewhere. Large amounts of copper scrap are also exported from the United States. The present article describes an ISASMELT™ plant, which, based on successful designs in Europe, is ideally suited to handle these materials within the United States. This article describes new opportunities for the U.S. recycling industries to yield full value from the collected, sorted and separated e-scrap and lower grade copper scrap by the use of ISASMELT™ technology. A compact, regional 75000 metric tonnes per year ISASMELT™ plant is described in the article for the treatment of copper and e-scrap, processing this into copper ingots or anode quality copper for the market.

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**Note: The energy data given here for mining (0.5% Cu ore), milling and flotation, and electrorefining are based on the data of Marsden,[26] whereas the data for smelting the produced concentrates are based on the data of Coursol et al.[25] The energy data for the smelting of Cu scrap in the Isasmelt plant considered here was prorated from the Isasmelt data given by Coursol et al.[25] For reference, the electrical component for electrorefining (electricity for transport to market is assumed zero) is 442 kWh/tonne of cathode copper, and the corresponding fossil fuel component including transport to market is 4625 MJ/tonne of cathode copper.

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