Processing of Electronic Scrap with Ausmelt TSL Technology

F. Adam[1]*, J. Wood*[2]*, R. Andrews*[3]

[1]Process Engineer – PT Metso Outotec Indonesia, Sentral Senayan, 10270 Jakarta, Indonesia
[2]Technology Manager – Metso Australia Pty Ltd, Dandenong South, 3175 Victoria, Australia
[3]Process Design Manager – Metso Australia Pty Ltd, Dandenong South, 3175 Victoria, Australia

Abstract. Continued decreasing of the world's average copper ore grades, coupled with a meteoric rise in the generation of consumer waste streams, has led to the processing of electronic scrap (e-scrap) and other secondaries assuming increasing importance within the global copper industry. Treatment of these secondary feeds has traditionally been carried out in the Blast furnace, Peirce-Smith converter and/or anode furnace. More recently however, bath smelting processes such as the Ausmelt TSL and Outotec Kaldo technologies have emerged as the preferred option for processing these materials due to their superior environmental performance and flexibility to operate under a wide range of conditions. Furthermore, the ability of these processes to handle a wide range of feed inputs make them ideally placed for the processing of not only e-scrap but also other waste streams from the clean energy transition such as end of life e-mobility batteries and photovoltaic systems. This paper focuses on the processing of electronic scrap and other copper secondaries with Ausmelt TSL technology and discusses specific issues facing secondary copper smelters in relation to impurity management and process offgas handling/cleaning.

Keywords: e-scrap, copper secondaries, recycling, Ausmelt TSL

1 Introduction

Copper is used across a range of applications including electricity transmission, electronics, information and communication technologies, construction and transportation. During the past 20 years, copper consumption has increased by roughly 2.5% each year, with similar growth expected in coming years (Figure 1), driven in large-part by the clean energy transition.

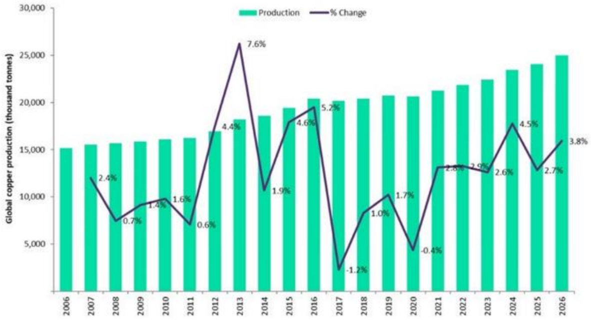


Fig. 1. Global copper production (thousand tonnes), 2006–2026 [1]

Mined copper ore typically contains around 0.5 – 1.5% Cu (open-pit) and 2% (underground) [2], with primary smelting the dominant processing route for transforming sulphide concentrates to produce metallic copper. The processes of ore processing, pyrometallurgy, and electrorefining account for around 80% of primary copper production [3], with the balance comprising of hydrometallurgical processes (leaching and SX-EW) and scrap recycling.

The past 30 years has seen a steady and continued decline in copper ore grades (Figure 2). Consequently, concentrates have shown a corresponding decrease in copper content due to more complex mineralogy affecting the separation of sulphide minerals from the unwanted gangue.

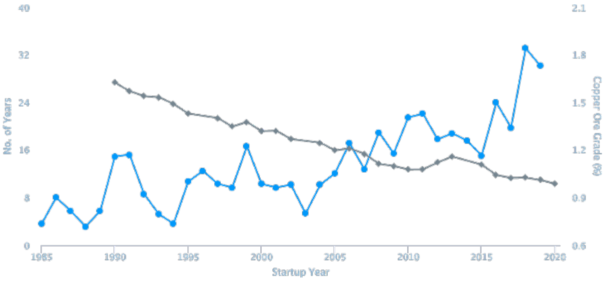


Fig. 2. Declining trend of copper grade in ore [4]

More recently, the copper industry has witnessed significant growth in the recovery of copper and other metal values from secondary materials [5], including:

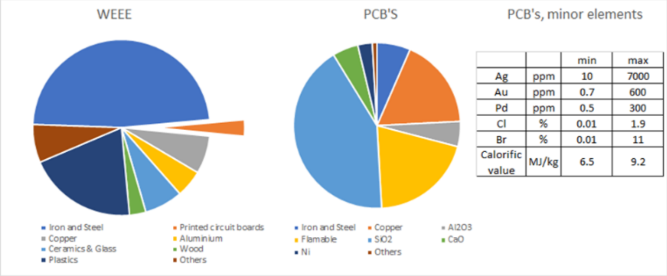
- Electrical and electronic wastes (domestic electrical, audio-visual, computer and telecommunication appliances)
- Metallurgical wastes (low grade slags, residues, anode slimes, oxide residues etc.)
- Industrial wastes (copper sheeting, bars, pipes, wire, ship screws, etc.)
- Consumer wastes (brass and bronze)

Copper production from secondary feedstocks has increased significantly in the past 20 years, with refined secondary copper production in 2021 (c.a. 4.2 million metric tonnes), representing a more than 8% increase compared with 2020 and 100% increase compared with 2004 [6].

Since most copper smelters are constrained by feed input capacity, low copper content in concentrate means smelters produce less copper and increased quantities of slag, negatively impacting smelter revenues and increasing operating costs. As a result of these cost pressures, the processing of secondary copper feedstocks, particularly end of life Waste Electrical and Electronic Equipment (WEEE), has become increasingly attractive. The presence of not only copper but also precious metals such as gold, silver and palladium providing added incentives for the treatment of these secondary materials. The terms “E-Waste”, or “E-Scrap” are also commonly used to describe such materials. In 2019, a total of 53.6 Mt e-scrap was generated globally, equating to an average of 7.3 kg per capita. Surprisingly, only around 17 per cent of generated e-scrap was recycled. E-scrap generation is projected to grow to 74.7 Mt by 2030 and up to 110 Mt in 2050 [7].

The practice of mixing e-scrap with primary copper concentrates has been successfully implemented at a number of smelters. The Ausmelt furnace operated by Daye Nonferrous Metals in China processes more than 1.5 million dry tonnes per year of copper concentrates along with up to 50 tph of e-scrap, making it as the largest TSL copper smelter in the world. Generation of dioxins, furans and various halide species can present challenges, effectively limiting the quantities of e-scrap able to be processed at primary copper smelting facilities.

The main challenge of e-scrap processing is variability in feed composition and presence of problematic impurities including plastics/organics, halides, aluminum and silica (Figure 3). Variability in the physical characteristics and composition of e-scrap present difficulties in achieving tight operational and metallurgical control of the smelting process. To overcome these challenges, dismantling, shredding, sorting, drying, blending and/or agglomeration stages are often required to transform ‘raw’ feed into a form amenable to smelting. Despite implementation of such pre-treatment and blending practices prior to smelting however, achieving a homogeneous feed blend is still difficult. As a result, the smelting process must be inherently flexible and versatile to adapt its operating conditions.



		min	max
Ag	ppm	10	7000
Au	ppm	0.7	600
Pd	ppm	0.5	300
Cl	%	0.01	1.9
Br	%	0.01	11
Calorific value	MJ/kg	6.5	9.2

Fig. 3. Typical E-Scrap and PCB composition [8]

2 Metso Technologies to Process Copper Secondaries

Selecting the right technology is key to the successful and efficient recycling of secondary copper feedstocks such as e-scrap. Metso, as the frontrunner in sustainable technologies, has a comprehensive technology portfolio for the treatment of e-scrap and other copper secondaries, consisting of proven smelting, refining, hydrometallurgy and gas-cleaning technologies, all contributing to the safe and profitable processing of these materials:

- Ausmelt TSL process
- Outotec® Kaldo TBRC process
- Outotec® Gas Cleaning Plant
- Outotec® Electric Slag Cleaning Furnace
- Outotec® Peirce Smith Converting process
- Outotec® Fire Refining process
- Outotec® Anode Casting Shop
- Electrorefining
- Electrowinning
- Precious Metals Plant
- Process Water Recycling Plant

2.1 Metso Ausmelt TSL

Metso Ausmelt Top-Submerged-Lance (TSL) technology utilizes a vertically arranged, cylindrical vessel equipped with a centrally-located lance submerged in the bath to deliver fuel, air and oxygen (Figure 4). Feed is charged via a port in the furnace roof together with fluxes and reductant (if required). The Ausmelt TSL process can operate in a batch-wise or continuous fashion, depending on the nature of the feed materials being treated and product quality requirements.

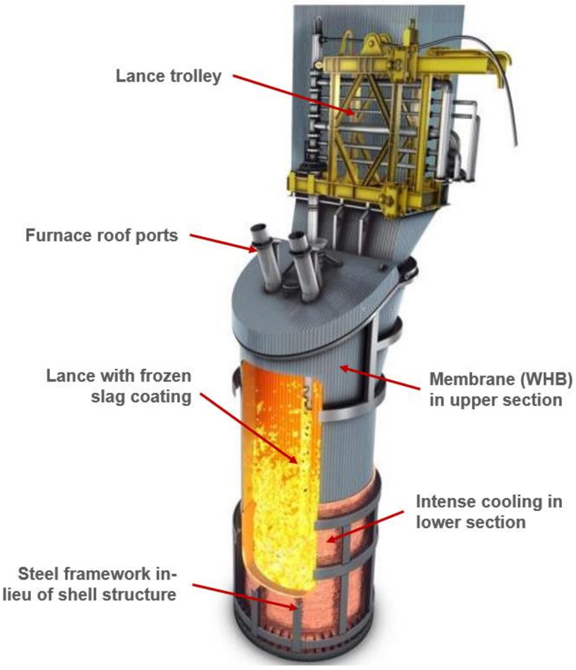


Fig. 4. Schematic of Metso Ausmelt TSL Furnace

2.2 Metso’s Outotec Kaldo TBRC

The Outotec Kaldo Top-Blown-Rotary-Converter (TBRC) is a batch smelting process using a top blowing lance positioned in a rotating and tiltable furnace (Figure 5). The combination of furnace rotation and top-blowing results in significant bath mixing and agitation to achieve high rates of reaction. The Kaldo furnace is equipped with advanced charging and offgas systems, for a compact plant layout and high levels of operational flexibility.

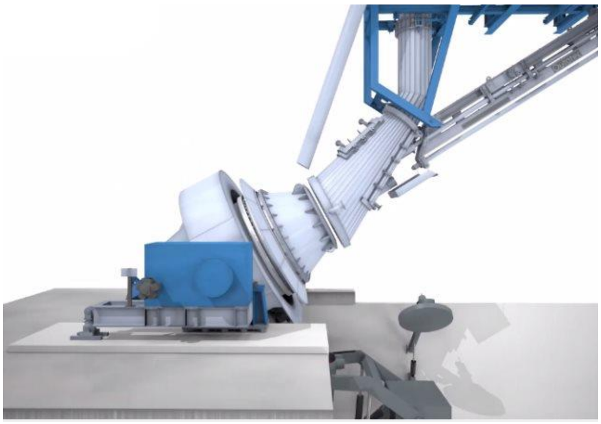


Fig. 5. Schematic of Metso’s Outotec Kaldo TBRC Furnace

Table 1 provides details of selected operating references for both Ausmelt TSL and Outotec Kaldo TBRC technologies.

Table 1. Metso’s secondary copper processing technologies

Technology	Location	Feed Materials	Feed Input Capacity
Ausmelt TSL	Dowa Mining (Japan)	E-scrap Residues	150,000 tpa
Ausmelt TSL	GRM (Korea)	E-scrap Residues	110,000 tpa
Outotec Kaldo	Boliden Rönnskår (Sweden)	E-scrap	120,000 tpa

Kosaka Smelting & Refining Co., Ltd., a subsidiary of Dowa Holdings Co., Ltd. (Dowa) located in Kosaka, Japan, stopped their Flash Smelting operation in 2008 and commenced operation of an Ausmelt TSL furnace to process a wide range of copper secondaries. The smelting process comprises of multi-stage, batch operation to produce a high-grade, raw copper product. Slag generated in the process is discarded, whilst the metal is sent to downstream hydrometallurgical and refining unit operations to recover copper, gold, silver, lead and other valuable metals.

GRM Co. Ltd. was established in 2008 to develop a new secondary smelter plant in Danyang, Korea (Figure 6). GRM employs a continuous smelting operation in a single an Ausmelt TSL furnace to produce a ‘black copper’ product (>75% Cu) which is sent for further upgrading in downstream operations. The process plant also produces ferrosilica and gypsum as byproduct.

Fig. 6. Ausmelt TSL Plant operated by GRM

In 1990, the Boliden Rönnskår smelter introduced Kaldo furnace technology to treat both lead concentrates and electronic scrap. The e-scrap recycling operation has expanded over the years and in 2012, Boliden Rönnskår smelter installed a new Kaldo plant, giving the total input capacity of 120,000 tpa.

3 Secondary Copper Smelting with Ausmelt TSL Furnace

One of the key challenges in the processing of secondary copper feedstocks is variability in feeds composition. For example, WEEE materials can vary widely, from large household appliances such as refrigerators and washing machines to small items such as LED lights and mobile phones. One point in common is that these are complex manufactured items, made from a wide range of materials with low homogeneity. Establishing a long-term, continuous supply of homogeneous material is thus extremely difficult. This is made even more challenging by the continued evolution of technology.

The TSL furnace is ideally suited to the processing of secondary copper materials given that physical characteristics of the feed are not overly critical to its operation. Feed materials able to be treated in the TSL process include:

- Heavy, bulky items and/or lumpy materials (e.g. fittings and crushed metallurgical wastes);
- fine, ‘fluffy’ and/or dusty materials (e.g. shredded materials and metallurgical dusts);
- complex waste electrical and electronic equipment (WEEE);
- irregular sized materials (e.g. scrap off-cuts and fittings);
- high moisture content materials (e.g. residues).

Flexibility to operate under a wide range of conditions combined with high levels of automation make the Ausmelt TSL process well suited to the processing of copper secondaries. The complex and variable composition of these materials are easily handled through precise control of the process chemistry, temperature and bath oxygen potential (pO_2).

E-scrap is typically characterized by a high plastics/organics content. This results in significant energy liberation during the treatment of these materials.

Consequently, this minimizes the auxiliary fuel requirement for the process. Regulation of the bath temperature is achieved by adjusting the lance oxygen enrichment and/or fuel rate, with continuous measurement of the bath temperature achieved with an optical pyrometer installed in the lance.

Conditions above the bath are controlled independently through the addition of post-combustion air, enabling recovery of heat generated by the process. Additionally, injecting a portion of the e-scrap via the Ausmelt lance may be used to achieve the desired bath temperature and oxygen potential.

The precise levels of process control achieved with Ausmelt TSL technology enables the efficient recovery of metal values to targeted product phases from which they can be economically recovered, whilst impurities and gangue components are directed to a discard slag or by-products from which can be safely treated.

The TSL plant operation is controlled using a plant-wide, integrated Process Control System (PCS) designed to provide high levels of automation, precise control of the metallurgical process and minimal operator interaction. The Ausmelt PCS is complemented by Safety Instrument System (SIS) designed to detect and mitigate unsafe plant operation which might impact personnel or plant equipment. Sensors and artificial intelligence incorporated within the Ausmelt plant design also provide for:

- Automated positioning of the Ausmelt lance to ensure optimum submergence for precise control of the metallurgical process
- Detection of process disturbances via monitoring of the Ausmelt lance movement, alerting operations personnel in advance of any potential process and/or equipment issues
- Online guidance to operations personnel by Metso's Smelting Advisor

Typically, secondary copper materials can be processed in the Ausmelt TSL furnace using one of two basic flowsheets. In Flowsheet 1 (Figure 7), a continuous 'reductive smelt' stage is used to generate an intermediate black copper product and low copper content discard slag. Treatment of this black copper to produce a raw copper product may subsequently be achieved via an oxidative converting stage in the same Ausmelt TSL Furnace (two-stage batch process) or converting in a separate unit (e.g. Kaldo TBRC or Peirce-Smith converter).

This flowsheet provides benefits in instances where an Ausmelt TSL Furnace is used to replace an existing smelting furnace, given that downstream converting and refining operations may already exist. This flowsheet may also be favoured when treating lower grade materials. The generation of a discard slag in the smelting stage eliminates the need for downstream processing (copper recovery) of this material.

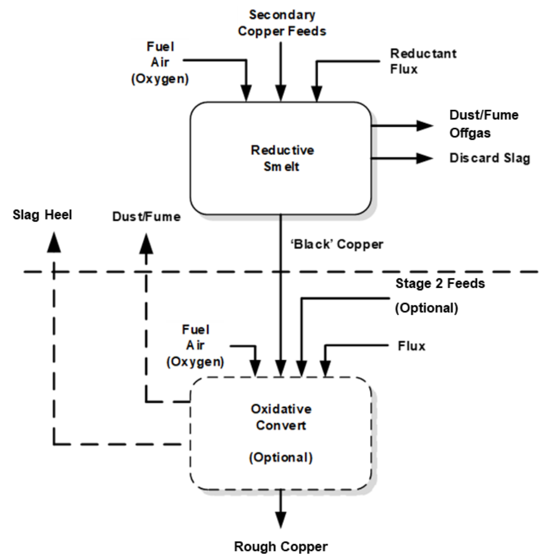


Fig. 7. Flowsheet 1 – Reductive smelting

Conversely, in instances where feed materials are characterised by large variations in copper, precious metal and/or impurity levels, it is often beneficial for smelting to be carried out using a multi-stage, batch process (Figure 8). Selective introduction of customised feed blends in each stage and precise control of furnace operating conditions (particularly pO_2) in this flowsheet provides for the maximum recovery of valuable metals and elimination of impurities with the slag.

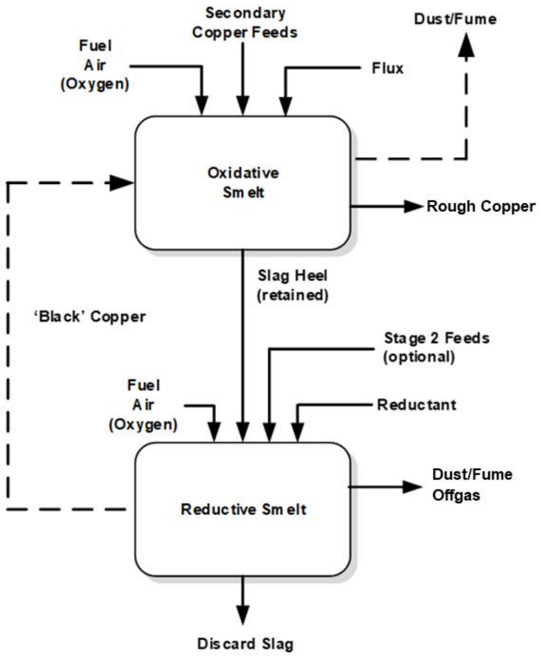


Fig. 8. Flowsheet 2 – Multi-stage smelting

In the first oxidative smelting stage, the high-grade copper product generated acts as a collector for valuable minor elements (precious metals, cobalt etc.) which are recovered using sophisticated downstream refining operations. Flux is added to achieve the desired slag fluidity and chemistry (Figure 9).

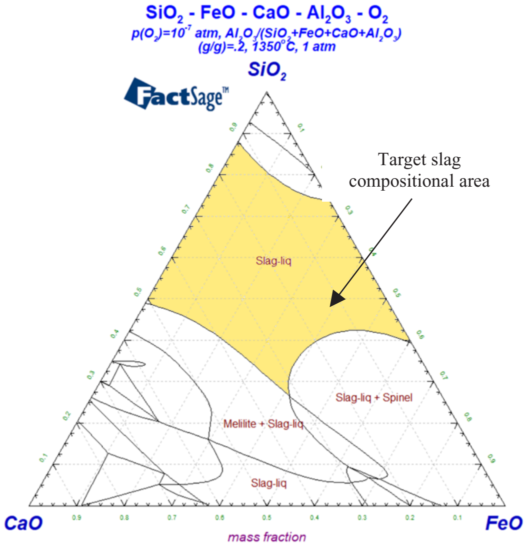


Fig. 9. Smelting stage ternary phase diagram

Slag from this stage is subsequently processed under reducing conditions in Stage 2 to provide for the recovery of desired metal values to a 'dirty' black copper product that is retained in the furnace for next smelting cycle. Impurities and gangue components of the feed are distributed to the discard slag. Additional benefits of this flowsheet include:

- Desired metal values may be recovered in separate product streams;
- an ability for the thermal duty in each stages to be optimised;
- slag chemistry adjustment in each stage, reducing the overall process flux requirement.

Ultimately, flowsheet selection is based on the grade of secondaries being treated, the type and concentration of impurities in the feed, the nature and capacity of existing processing/refining infrastructure and client's preferred product stream/s. Furthermore, the inherent versatility and flexibility of Ausmelt TSL Technology allows for the addition and/or removal of extra stages, even if not included within the original design.

In addition to control of the furnace bath conditions (temperature, pO_2, slag composition, etc.), handling and cleaning of process offgas is also considered as part of the overall Ausmelt TSL Plant. Secondary copper materials are commonly associated with various types of plastics and ceramics, many of which contain elements which produce toxic/hazardous substances if processed under certain conditions.

As a result, gas collection and abatement systems typically located downstream of the Ausmelt TSL Furnace incorporates capabilities to handle:

- Nitrogen oxides (NO_x)
- Carbon monoxide (CO)
- Sulphur dioxide (SO_2)
- volatile species (Pb, Zn, Hg, Cd etc.)
- halides (Cl, F, Br etc.);
- Polychlorinated dibenzoparadioxins (PCDD)
- Polychlorinated dibenzofurans (PCDF)

These hazardous substances may limit the portion of e-scrap able to be treated as part of the overall feed blend. Tight control of both the furnace operation and offgas system is required to mitigate the formation of these harmful compounds. Metso's Outotec wet gas cleaning technologies, which have been commercially proven for the removal of halides, trace amounts of SO_2 and minimize the formation of dioxins and furans, are also included as part of the Ausmelt TSL plant engineering design and equipment supply scope.

4 Conclusion

Generation of copper secondaries, particularly electronic scrap, will continue to grow in the coming years and may present a global problem if not handled properly. Recycling of secondary copper materials to recover copper and other precious metals is an effective means of addressing this problem. Inconsistency in the composition and physical characteristics of e-scrap and other copper secondaries is one of the main challenges to overcome in the processing of these materials. This necessitates the use of versatile and flexible technologies to effectively handle these feeds and economically recover valuable metals. Metso Ausmelt TSL technology is one of the most flexible and versatile technologies that has been commercially applied for the processing of secondary copper materials. The technology can be adapted to handle a wide range of feed materials. Furthermore, its capability to maintain precise control of the metallurgical process enables the recovery of copper and other valuable metals. The technology is complemented by Metso's range of offgas cleaning solutions, required to manage harmful and hazardous substances generated from the treatment of e-scrap in particular and to ensure the gas emissions to atmosphere are in accordance with the strictest environmental policies.

References

1. Mining Technology, 2022 [online]. Available from <https://www.mining-technology.com/comment/global-copper-output-grow/> [Accessed 29 August 2023].
2. M. E. Schlesinger, K. C. Sole, W. G. Davenport, G. R.F. Alvear Flores, *Extractive Metallurgy of Copper*, **Sixth Edition,** 22 (2021)
3. M. E. Schlesinger, K. C. Sole, W. G. Davenport, G. R.F. Alvear Flores, *Extractive Metallurgy of Copper*, **Sixth Edition,** 361 (2021)
4. Winton, 2017. Copper-Bottomed Booms and Busts [online].<https://www.winton.com/longer-view/copper-bottomed-booms-and-busts> [Accessed 28 August 2023].
5. M. Reuter and A. Van Schaik. *Thermodynamic Metrics for measuring the "Sustainability" of Design for Recycling,* Journal of Metals, Vol. 60(8): 39-46. (2008)

6. Statita Research Development, 2022. Production volume of refined secondary copper worldwide from 2005 to 2021 [online]. Available from <https://www.statista.com/statistics/281022/global-production-of-refined-secondary-copper/> [Accessed 31 August 2023]
7. Waste Management World, 2022. Global e-waste flows monitor 2022 [online]. Available from <https://waste-management-world.com/materials/global-e-waste-flows-monitor/> [Accessed 28 August 2023].
8. S. Hughes, M. Jåfs , H. Johto, J. Stål and J. Karone. *Outotec Solutions for E-Scrap Processing*. (2019)