50 Years of Recycling Copper and Precious Metals in Canadian Copper Smelters

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Introduction

The history of copper recycling is almost as old as the history of copper itself. Since the Bronze Age, humans have known that copper can be easily melted and re-cast into new objects. It was quickly recognized that recycling copper was a much simpler process than producing copper from raw materials, which were difficult to obtain and in short supply. In the 21st century, recycling takes place not only in primary smelters but also in brass mills, foundries and refineries. While these participants in the copper value chain recycle a significant proportion of the total copper recycled, they tend to recycle the higher grade scrap, such as No.1 and No.2 copper. This chapter will focus on recycling at the primary smelting stage of the copper production process, where recycling of the more complex recyclable feeds is executed. It should be recognized there is also considerable metal recycling conducted by the lead, nickel, zinc and aluminum smelters in Canada. While some of these recycling initiatives do also recover some copper, they will be discussed separately in other chapters of this book.

Recycling makes up 13-19% of the global copper supply every year, therefore, it represents an important source of copper units to sustain global consumption. Due to price pressure, copper has been substituted in its more traditional and homogeneous applications, such as plumbing and roofing, by alternative materials. Copper is, however, increasingly being consumed in greater quantities to make more complex products, such as circuit boards and insulated wire. These more heterogeneous applications make recycling at the end of their useful lives more complex, as the constituent materials are not easily separated from one another.

However, as copper applications have increased in complexity over the past 50 years, so has our ability to recycle more complex secondary materials in primary copper smelters.

Fifty Years of Development

Up until the early 1970s, the configuration of most primary copper smelters in Canada and the rest of the world was based on smelting concentrates in reverberatory furnaces, followed by matte conversion in Peirce-Smith converters.

Very little energy is generated by the smelting process itself in a reverberatory furnace and therefore these furnaces require a significant external source of energy to fuel the process. The stability and metal recovery efficiency of the process is also sensitive to feed quality, therefore, there was limited reason to try and feed non concentrate materials (such as recycle feeds) to the vessel, as these were likely to have highly variable physical and chemical compositions and could cause potential process upsets.

However, the introduction of flash smelting technologies by Outokumpu and Inco in the late 1940s and early 1950s started a revolution in the way copper concentrates were smelted. By feeding concentrate and pure oxygen or oxygen-enriched air to the vessel through a burner arrangement, they were able to partially combust the sulphide minerals in the concentrate. It was then possible to harness the energy released through this exothermic reaction to fuel the smelting process, thereby eliminating the need for an external fuel source. The heat generated could in fact exceed the heat required for concentrate smelting. This provided an opportunity to employ any excess energy to smelt non-concentrate materials.

Not only were these new methods of smelting more energy efficient, but they were also more environmentally friendly as they produced relatively small volumes of gasses with high SO_2 content that could be readily captured as sulphuric acid and other by-products. This trend to cleaner, more energy efficient methods of smelting concentrate also led to a number of other new technologies, including bath smelting and continuous smelting.

Following the development of the Inco flash furnace at Copper Cliff, the Canadian copper smelting industry saw several new smelting technologies implemented throughout the 1970s and 1980s. In 1973, the Noranda Reactor, a bath smelting technology, was installed at the Horne smelter. In 1982, the Mitsubishi continuous smelting process was installed at Kidd Creek.

Because of the positive heat balance of these flash and bath smelting processes, the ability to smelt non-concentrates economically became more feasible; however, each process still has its own limitations. For instance, the burner technology in flash smelters typically requires fine, dry, relatively consistent feed, which therefore limits the types of non-concentrate materials that can be fed to them without some extensive preparation, blending or alternative feed system. Bath smelting technologies on the other hand may be slightly less energy efficient but are much more flexible with regards to feed quality. As a result, bath type smelters have learned to leverage the flexibility in their processes to handle progressively more complex secondaries. For example, Xstrata's Horne copper smelter can treat materials with moistures as high as 60% and that contain some surface oil (such as turnings), ceramics and plastics (such as electronics).

One of the factors influencing today's choice of smelting technology seems to be what the expected feed material will be. Smelters interested in processing high volumes of a fairly homogeneous blend of copper concentrates may tend to choose a flash-type furnace, while those interested in having the flexibility to blend a wide range of feeds may tend to select a Reactor or a submerged lance technology, such as the IsaSmelt.

Along with advances made to technology, the smelting industry has undergone a geographic and structural transformation over the past 50 years. Historically, smelters were built close to large mines to form integrated mining, milling, smelting and refining operations. These smelters were largely captive smelters, treating only their own concentrates. However, over the past 40 years, there has been a shift towards custom smelting, with most new smelters being built close to the large end-user markets of copper such as Japan, China and India, rather than close to the mines.

As can be seen in Figures 1 and 2, the proportion of copper generated by pure integrated copper smelters has dropped from 60% to just one third of total annual production over the past 30 years. Over this same timeframe, total copper production has increased from 4.7 Mt to 14.3 Mt, therefore, this proportional increase actually reflects a 280% increase in custom smelting production versus just a 70% increase in integrated production over the same 30 year time period.

Similarly, global smelting capacity has shifted away from developed countries such as Japan, the USA, Canada and Germany to developing countries, where the operating cost environment is lower and where demand for copper is highest as infrastructure is being built. Figures 3 and 4 highlight the shift that has occurred with respect to where total global copper smelting capacity was, and is now located. In 1973, Canada and the USA accounted for 36% of total copper smelter capacity, while today they represent just 6% of global capacity.

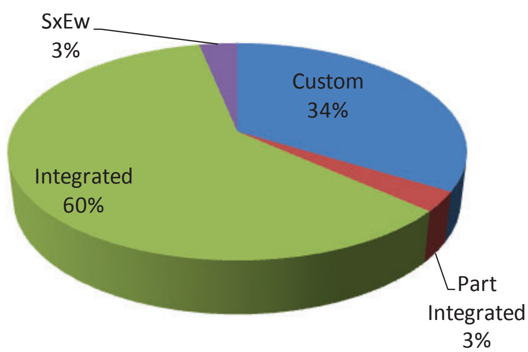

Figure 1. Global copper concentrate smelting & refining production breakdown, 1980 (total 4.7 Mt Cu)
Source: Brook Hunt, (2010b)

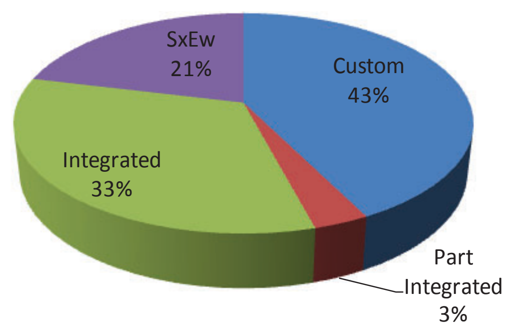

Figure 2. Global copper concentrate smelting & refining production breakdown, 2010 (total 14.3 Mt Cu)
Source: Brook Hunt, (2010b)

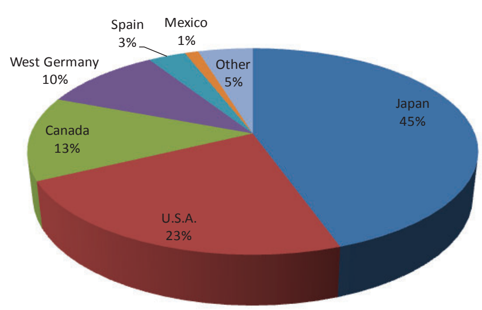

Figure 3. Global copper smelting capacity by country, 1973 (total 1.7 Mt) (Source: CRU Copper Studies, 1974)

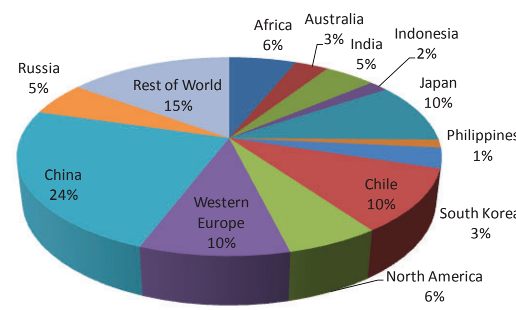

Figure 4. Global copper smelting capacity by country, 2010 (total 17.6 Mt) (Source: Brook Hunt, (2010c)

While there were five copper smelters in Canada in the 1970s, in 2011 just one remains: Xstrata's Horne smelter. A similar picture has emerged in the USA. In the 1970s, there were 17 primary American copper smelting operations, while today, only three smelters remain operational: Freeport-McMoRan's Miami smelter, Rio Tinto's Kennecott Utah Copper Garfield smelter and Grupo Mexico's Asarco Hayden smelter.

The Horne smelter was constructed in 1927 as part of a large integrated mining, milling and smelting operation in the town now known as Rouyn-Noranda, Quebec. The original smelter (Figure 5) had a roaster, reverberatory furnace, Peirce-Smith converter configuration. One of the three reverberatory furnaces was replaced in the 1970s with Noranda's own engineered Noranda Reactor. The Noranda Reactor capacity was steadily increased through increased oxygen enrichment and it eventually replaced all of the reverberatory furnaces by the late 1980s. In 1997, the Noranda Continuous Converter was added and replaced most of the conventional Peirce-Smith converter operations. When the last of the Horne operation's mines closed in 1976, the Horne became a fully custom smelter. Initially, much of the feeds to the then-custom smelter were locally sourced concentrates, however, as the region's mine feed supply declined in the late 1970s and 1980s, the Horne began expanding into non-traditional feed sources.

Figure 5. Xstrata's Horne smelter under construction in 1926

Records exist that show the Horne started processing recyclable feeds in the 1940s, but it wasn't until the early 1980s that recyclables became an important element in the business strategy of the operation and a significant proportion of the smelter feedstock. This coincides with the shift from reverberatory furnaces to the Noranda Reactor that enabled more efficient recycling of non-concentrate materials. Since the 1990s, the Horne has been able to feed well above 100,000 tonnes per year of secondaries to the smelter and this represents approximately 15% of the total smelter feed.

Over the same period, the Horne has learned how to feed increasingly complex recyclables to the Noranda Process Reactor and, more recently, to the Noranda Continuous Converter. By fully exploiting the flexibility of both the Reactor and the Noranda Converter (Figure 6), Horne personnel are able to feed materials in a continuous fashion that are very moist or very dry, along with materials that are fine or as large as 4" (10 cm) in diameter. Improvements made over the years to the gas handling and treatment systems have also enabled the Horne to safely treat materials containing plastics and other organics and a wide range of impurities. There have also been a number of developments at the CCR Refinery that allow the group to manage high levels of impurities in anode that could impact copper quality. Figure 7 shows a view of the Horne smelter in 2011.

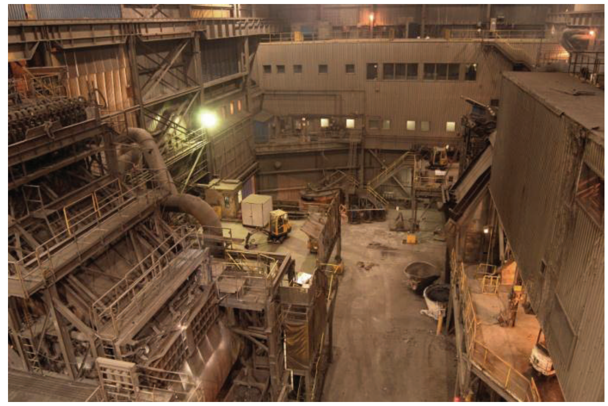

Figure 6. The Horne smelter with the Noranda Reactor on the left and the Noranda Converter on the right

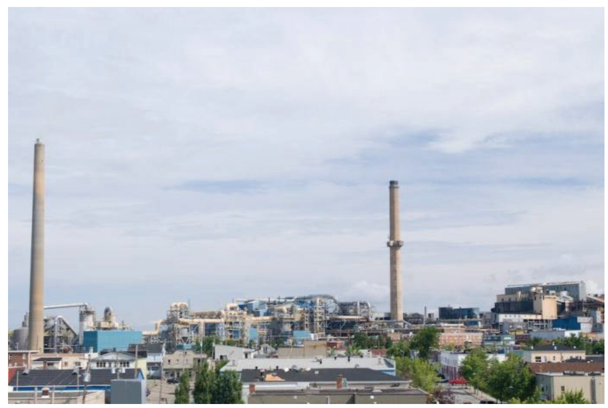

Figure 7. Xstrata's Horne Smelter in 2011

Hudson Bay Mining and Smelting (now HudBay Minerals) operated a reverberatory furnace in Flin Flon, Manitoba, from 1931 until 2010. Due to the energy intensive nature of reverberatory furnaces, HudBay focused primarily on smelting concentrate. They did experiment with taking small amounts of secondaries over the years, including circuit boards in the 1990s, but secondaries never became an integral part of the smelter's feedstock.

Noranda's Gaspé smelter also operated a reverberatory furnace from 1955 until 2002. However, the installation of a new converter in 1998 enabled the smelter to take considerable amounts of scrap and secondary materials for recycling. Gaspé focused largely on recycling #2 copper scrap as well as by-products from brass mills, such as slag and skimmings. In the late 1990s, Gaspé processed almost 40,000 tonnes of secondaries annually.

The Kidd Creek smelter was commissioned in 1982 by the Canada Development Corporation, shortly after it acquired the Kidd Creek Metallurgical Complex from

Texasgulf. It eventually became part of the Xstrata Copper group, who operated the smelter until its closure in 2010. The Kidd smelter was the first licensee installation of the Mitsubishi continuous smelting operation. As the Mitsubishi smelting furnace is fed through a series of lances, the types of secondaries that Kidd could process were somewhat limited by shape and size, therefore they tended to take finer secondary materials with physical properties similar to concentrates, such as residues and catalysts. As the Kidd complex had the benefit of both the copper smelter and a zinc plant, over the years they took a number of spent Cu-Zn and Zn-based catalysts, originating from petrochemical and oil refining operations. The total annual volume of secondaries received and processed by Kidd ranged between 5,000 and 10,000 tonnes per year.

While Inco (now Vale) has typically focused on Ni- and Co-containing recyclables, approximately 5,000 tonnes of high grade scrap (#2 Cu and off-spec anodes) was recycled annually in the anode furnaces until the closure of the copper refinery in 2005.

Evolution of Secondaries

As previously noted, until relatively recently, the primary technology for copper smelting was the reverberatory furnace, making low grade Cu matte for conversion in Peirce-Smith converters. It was recognized that both the slag and copper blow stages of the converter cycle required inert materials to control the heat generated during the cycle. Normally, clean-up materials from the converter aisle were used, but it was also recognized that additional conversion energy was available to smelt other materials. At this point, the Horne smelter started experimenting with scrap copper as a means of generating revenue and additional copper units for the refinery.

In 1946, the Horne smelter made its first trials with brass shell cases. While the trials highlighted the challenges related to unloading, sampling and preparation, most importantly, the brass presented significant process challenges to the converter aisle operations. Initially, the brass was added during the copper blow stage, but the contained zinc quickly fumed and created problems in the electrostatic precipitators. This was overcome by adding the brasses during the early matte blows. Ultimately, a capacity of 15,000 to 20,000 tonnes per year of secondary feeds was developed.

In the post-World War II period, the recycling of copper was principally concerned with clean, high grade materials that could bear the relatively high cost of transportation to the Horne smelter from sources that were 600 to 800 km away. During this time, scrap yards did not employ the sophisticated technologies of today that could upgrade lower grade materials into materials of interest to the Horne. Therefore, the only practically available copper materials were yellow (cartridge brass), red (plumbing brass), and #1 and #2 copper scrap (see Figure 8).

Figure 8. Bales of #2 copper, an example of a traditional type of copper scrap

The Horne's recycling activities remained limited to these categories from the mid-1940s until the late-1970s. Once the Horne changed its principal smelting furnace from a reverberatory to the Noranda Process Reactor, an entirely new recycling capability was opened up. The Noranda Reactor produces high grade (72%) copper matte and requires much smaller-sized feeds than Peirce-Smith converters, but can handle larger-sized feeds than flash type vessels. While the traditional brass and copper scrap materials were still appropriate for the Peirce-Smith converters, they were not suitable for the Reactor. The Reactor was, however, very suitable for many low grade, wet and complex feeds that were not easily recycled.

As the usages of copper evolved towards more electrical and electronics applications, potential new sources of recyclable copper became available. At the same time, more stringent environmental regulations requiring industrial processes to meet increasingly lower metal releases created a whole new category of copper-bearing water treatment sludges that were potential candidates for recycling. These changes to the usages of copper, and the subsequent materials in need of recycling, required a new approach to address the challenges of receiving, sampling, feeding and smelting materials that were lower copper content, wet and, in many cases, plastic-containing. The new materials were also physically very different from those traditionally received. Additionally, many of these new materials also contained precious metals that could be recovered efficiently in the Reactor process.

When compared to concentrates smelted in the Noranda Reactor, the new recyclable materials were physically and chemically different. These materials typically were very heterogeneous and arrived at the smelter with dimensions that were larger than the Horne's 4" (10 cm) limitation for continuous feeding operation (see Figure 9). They also needed to be screened to ensure they didn't contain potential environmental, hygiene and operational hazards such as contaminants, radioactivity, or reactivity.

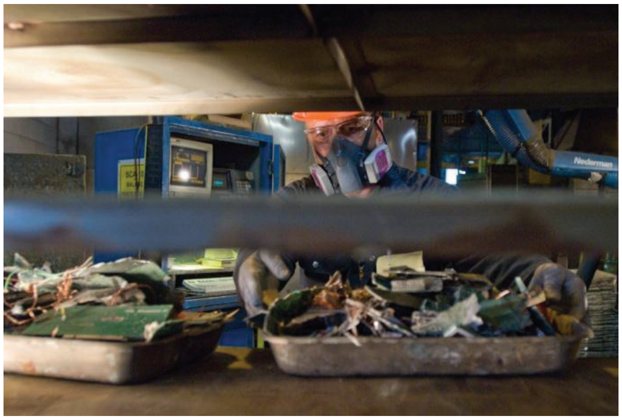

Figure 9. The sampling and sample preparation of heterogeneous recyclables present unique challenges

Starting in the early 1980s, the Horne made a series of investments to address these challenges. It began with a new recyclable materials unloading and shredding line, plus a sample preparation plant to matte the heterogeneous samples and form homogeneous materials appropriate for assaying. This was followed by additional shredding capacity for electronic materials in the early 1990s. These investments provided a means of accurately determining the metal content for payment purposes and preparing the materials for efficient smelting. Equipment, procedures and training were also implemented to identify and remove the potential hazards associated with these more complex materials.

It is also important to note that with rising copper and precious metal prices, the range of materials that could be economically recycled also increased. No longer were high grade copper scraps the sole target of the recycling industry, but rather all grades of scrap, and especially those that also contained precious metals became viable recyclables. Metal prices were effectively a catalyst for the development of new materials that the Horne would smelt.

Aside from the process and operational changes within the Horne's operation, there were also changes required to the permitting of the facility. Government regulations required that the Horne sought new operating permits in order to treat the wider range of recyclable materials. The Basel Convention of 1987 also changed the regulatory framework to enable legal importation of materials that were considered wastes under the Basel Convention. Combined, these regulatory changes required that the Horne develop, in conjunction with the process, a competence to manage the new legal process.

Environmental Impact of Recycling

A significant focus of the Horne smelter is now the processing of electronic scrap containing copper, but more significantly, precious metals (see Figure 10). These scrap materials also contain plastics that must be smelted in a manner that does not create negative environmental impacts. It is well documented that the conditions of combustion must be properly controlled to ensure plastics such as those used in electronic materials do not generate dioxins and furans. It has been repeatedly demonstrated through sampling campaigns that the Noranda Reactor process deals with this issue effectively by using a high temperature smelting process with a surplus of oxygen, a relatively long gas retention time in the vessel, followed by a rapid quenching of the gasses. These test programs have demonstrated that the Horne meets international standards for organic emission even with a high proportion of electronics in the mix of materials smelted.

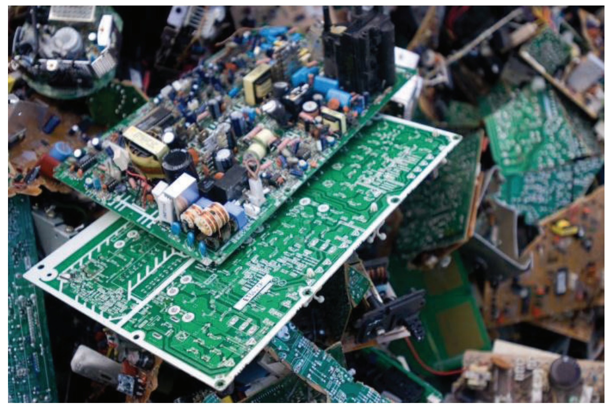

Figure 10. End-of-life electronics, an example of the more complex secondaries recycled today

The plastics in the Horne material mix have effectively eliminated the requirement to use supplemental metallurgical coke to control slag metallurgy. In the year 2000, the Horne consumed almost 12,000 tonnes of metallurgical coke. Today, the Horne has almost completely eliminated the use of metallurgical coke by effectively harnessing the carbon contained in electronic scrap.

With global average mine copper head grade being only 1.14% in 2010, to make 1 tonne of copper, one would need to mine more than 87 tonnes of ore. On average, 80% of the energy required to produce copper from mined sources is related to the mining and milling processes, due to the need for energy intensive steps like ore hauling, crushing and grinding.

Only 20% of the total energy expended to produce copper cathode from ore relates to the smelting and refining processes. Since recycled copper avoids the energy-intensive early stages of the copper production process and generally has a much higher copper content than ore, there are clear carbon footprint advantages to the recycling of copper from all sources.

However, responsible management is critical to ensure the recovery of the valuable metals is performed in a way that protects the health and safety of workers, communities and the environment. Recyclable materials may contain heavy metals (Pb, Cd), beryllium, halogens, be radioactive, reactive, dusty or contain unacceptable components such as flammable batteries. All of these potential risks must be managed through stringent pre-acceptance evaluation, and post-reception verifications to ensure all health and safety criteria are met and any unacceptable materials are prevented from entering the recycling process. Working closely with its significant recycling partners, the Horne has paid particular attention to these aspects over the past years, requiring significant management commitment and financial expenditures.

Conclusion

Over the past 50 years, copper smelting technology has evolved and transformed from a process that was once energy intensive and bore a significant environmental footprint, to one that is much more sustainable. Over the same timeframe, the business of copper smelting has also transformed, from a regional service offering into a global business.

As the copper smelting industry has evolved into a global industry, copper smelting in Canada and the USA have undergone many transformations as well. Today, the North American copper smelting business is smaller and more focused. As the only remaining Canadian smelter whose primary aim is to recover copper, the Horne has found a niche in proficiently handling complex concentrates and complicated recyclables.

Statistics show that recyclables are likely to grow as a percentage of the global copper feed supply in coming years. Additionally, forecasts predict that demand for copper will outstrip supply over the next few years, until new mines are brought on-stream. As a result of this supply-demand imbalance, commodity prices will likely remain strong and, combined with improving technologies, is expected to make once uneconomic secondary materials available and able to be recycled over the medium term.

Even once new mine capacity is brought on-line, the average ore grade of copper mines is expected to continue the declining trend that has existed for the past several years. The average head grade in 1980 was 1.57% Cu and in 2010, was only 1.14% (Figure 11). As this trend is expected to continue, the cost of mining and extracting copper from ore is only going to increase, making secondary sources of copper increasingly important.

The picture is similar for Au, whereby the average Au head grade in 2008 was 1.4 g/t, down from 1.7 g/t in 2004. Electronics, meanwhile, contain an average of approximately 78 g/t Au and 20% Cu. Therefore, recycling just one tonne of electronics replaces the need to mine more than 85 tonnes of Au ore and 17 tonnes of Cu ore.

The increasing focus on sustainability and recycling will also likely drive non-traditional, metal-bearing wastes to be recycled. It is expected that we will also see greater numbers of government-mandated waste diversion initiatives, such as the various electronic take-back programs that exist in Europe and North America today. These, together with improvements in the technological capabilities to recycle complex secondaries, will drive new and increasingly advanced recycling solutions for copper and precious metals in the future.

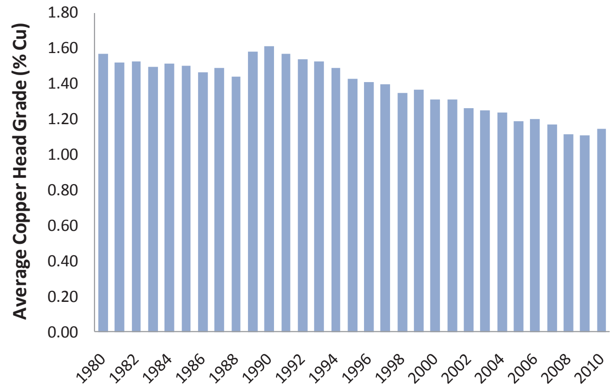

Figure 11. Average copper head grade from 1980 to 2010 (Brook Hunt, 2010a)

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