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The future of recycling

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Abstract

Recycling in general and metal recycling in particular, many believe, enjoy a very bright future. As resource depletion, environmental concerns, and other factors drive primary production costs up, the relative importance of recycling in supplying the material needs of society will grow. This optimistic view, however, may paint an overly rosy and misleading picture.

A large portion of secondary metal production is based on the recycling of new scrap, which is constrained far more by the available supply of new scrap than by metal prices or recycling costs. Secondary production from old scrap is more sensitive to costs and prices, and so would benefit from a rise in metal prices. History, however, indicates that the cost-reducing effects of new technology have over the past century more than offset the cost-increasing effects of depletion, causing real metal prices to fall. In recent decades, this decline in prices has continued despite government policies that are increasingly forcing firms to cover their environmental costs.

While this favorable trend may not continue forever, it does suggest that secondary producers will have to pursue aggressively new technologies and other innovations that reduce their costs as fast or faster than primary producers if they hope to expand their future share of total metal production. © 1999 Elsevier Science Ltd. All rights reserved.

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Many environmentalists, scientists, and other well-informed and thoughtful individuals foresee a very bright future for metal recycling. After all, recycled or secondary metals compete with primary production, which depends on the exploitation of non-renewable resources. As mining companies are forced to resort to lower grade, more remote, and more difficult to process deposits, their costs will rise. Moreover, rising energy costs and government policies forcing mining companies and metallurgical plants to pay the full environmental costs of their operations will accentuate this trend. This, in turn, will make recycling more competitive, and over time the relative importance of secondary metal production in supplying the needs of society will grow.

The following excerpt from Ayres (1997, p. 5) is a particularly articulate illustration of this optimistic view of the future of recycling:

> We are in a period of economic transition. The “cowboy economy” of the past is obsolescent, if not obsolete. Environmental services are no longer free goods, and this fact is driving major changes. Recycling is the wave of the (immediate) future. The potential savings in terms of energy and capital have long been obvious. The savings in terms of reduced environmental impact are less obvious but increasingly important…. Increasing energy and other resource costs, together with increasing costs of waste disposal, will favor this shift in any case.

Let me stress at the outset that I am not pessimistic about the future of recycling. We will continue to recycle metals, and secondary production will contribute an important part of our future metal supplies. Secondary processors will certainly continue to exist, and many presumably will prosper.

Recycling does, however, have to compete with mining and primary metal production. The issue is whether

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recycling will account for a growing share of total metal production. This for me is an open question. The answer will depend in part on how active and how successful secondary producers are in introducing new technologies and other cost-reducing innovations compared to primary metal producers. The answer will depend as well on other factors largely beyond the control of secondary producers.

The determinants of recycling vary from metal to metal. They also differ for secondary metal produced from new scrap (the scrap that arises in the course of producing new goods) and for secondary metal produced from old scrap (the scrap that arises when products come to the end of their useful life). The comments that follow discuss metals in a general way, despite the risks of ignoring their important differences and idiosyncrasies. They do, however, distinguish between secondary metal produced from new and old scrap, as this distinction is critical.

Recycling new scrap

Since the generation of new scrap and its subsequent recycling are simply part of the normal production cycle, secondary metal produced from new scrap is often not treated as part of total metal supply or taken into account when calculating apparent metal consumption. To do so results in double counting and an overestimation of the total supply of available metal.[2] Nevertheless, it would be inappropriate to ignore new scrap here, as it accounts for a sizable portion of total secondary production — some 55% for iron and steel, 55% for aluminum, 66% for copper, 4% for lead, and 72% for zinc in recent years for the United States (US Geological Survey 1996, 1997).

Since new scrap is easy to collect, easy to identify, and normally of high quality, its recycling costs are low, and almost all new scrap is recycled. While the price for new scrap goes up and down with the market price of metal, these fluctuations have little or no effect on the amount of new scrap recycled. For this reason, economists say the supply of secondary metal produced from new scrap is inelastic. This simply means its supply is unresponsive to changes in the market price of the metal.

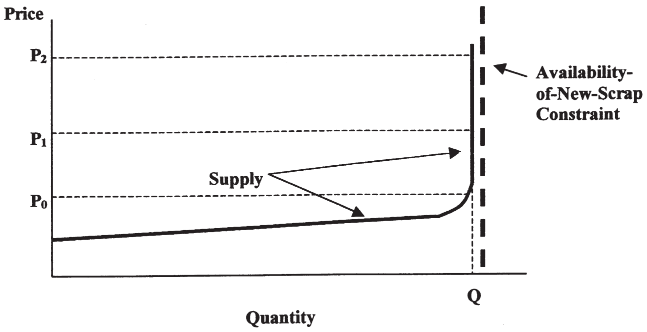

Fig. 1. Supply curve for secondary metal from new scrap. Source: U.S. Geological Survey.

Fig. 1 illustrates a hypothetical supply curve for secondary metal produced from new scrap that reflects these characteristics. A supply curve shows how much of a product — here, secondary metal produced from new scrap — will be offered to the market over a year or some other time period, at various prices. Because the costs of recycling new scrap are low, firms have an incentive to recycle all, or nearly all, of the available new scrap at a metal price at or above P_0. If the market price typically varies between P_1 and P_2, price fluctuations have little effect on supply.

Changes in the amount of secondary metal supplied from new scrap do occur, but they come about because of changes in the availability of new scrap — that is, from shifts in the availability-of-new-scrap constraint shown in Fig. 1 — rather than changes in the metal market price. From one year to the next, the availability of new scrap varies primarily with the overall level of metal consumption, which in turn more or less follows the business cycle. In the longer run, two other factors are also important: first, changes in the allocation of metal among its end uses (as some products generate more new scrap per ton of metal used than others); and second, changes in technology that alter the amount of new scrap generated in the production of specific metal-using goods.

These two factors determine whether secondary metal from new scrap accounts for a rising or falling share of total metal consumption over time. Changes in the allocation of a metal among its end uses depend among other things on consumer tastes and preferences, and are difficult to predict. Manufacturers and other metal users, on the other hand, do have a strong economic incentive to develop new processing technologies that reduce the amount of new scrap they generate. Thus, this second factor may help explain why the share of total metal consumption accounted for by secondary metal from new scrap has fallen for some metals, such as copper, lead, and iron and steel (Jolly, 1997, p. 12; Heenan, 1997, p. 131; US Geological Survey, 1997, p. 5).

This downward trend, however, does not apply to all metals. Fig. 2 illustrates the amount of total aluminum, copper, lead, and zinc consumption coming from the recycling of new scrap for the United States over the period 1970–98. For aluminum and zinc, the share of secondary from new scrap is growing.

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[2] The US Geological Survey, for example, in calculating apparent metal consumption for the United States, adds domestic primary production, domestic secondary production for old scrap, and imports, and then subtracts exports. Domestic secondary production from new scrap is not considered in this calculation.

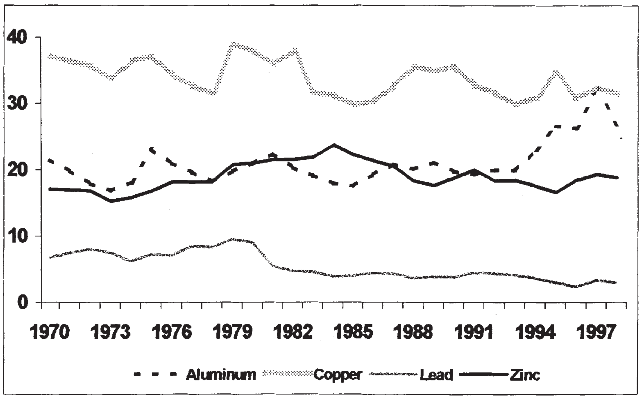

Fig. 2. Secondary production from new scrap as a percentage of apparent consumption for aluminum, copper, lead, and zinc for the United States, 1970–98. Source: U.S. Geological Survey.

Recycling old scrap

Fig. 3, which provides the same information for old scrap, shows the importance of old scrap recycling in metal consumption, declining for copper but increasing for aluminum and lead. In the case of aluminum, the explanation lies largely with the rapid growth in the use (and recycling) of aluminum beverage containers over this period. In the case of lead, the reason is similar. Motor vehicle batteries, which are extensively recycled, have consumed a growing share of total lead production, as the use of lead as an additive in gasoline and in other end uses has fallen.

The costs of recycling old scrap vary greatly. Some old scrap is easy to collect, easy to identify, and of high quality. Its recycling costs are low, and like new scrap it is largely recycled regardless of the price of metal. Alternatively, some old scrap is prohibitively expensive to recycle because it is widely dispersed and collection costs are very high, or because it is of such poor quality. Little of this scrap is recycled. In between these two extremes, one finds large quantities of old scrap that are economical to recycle at prices within the normal range of metal prices.

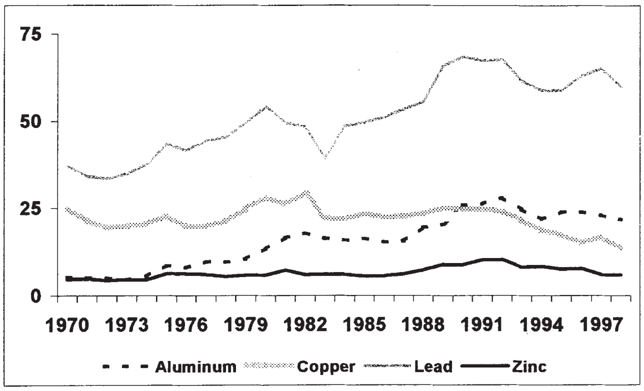

Fig. 3. Secondary production from old scrap as a percentage of apparent consumption for aluminum, copper, lead, and zinc for the United States, 1970–98.

As a result, as the price of metal rises, firms find it profitable to collect and process more and more old scrap, making the supply of secondary metal produced from old scrap more responsive, or elastic, to changes in price than secondary from new scrap. Ultimately, of course, the supply of secondary metal from old scrap is constrained by the amount of old scrap available for recycling, but this constraint is not binding over the normal range of metal prices.

Fig. 4 illustrates a hypothetical supply curve for secondary production from old scrap that reflects these typical characteristics. As the market price for the metal varies between P_1 and P_2, the amount of secondary production from old scrap rises and falls as well. There are, of course, other factors that affect the recycling of old scrap.[3] We have already noted that the introduction of the aluminum beverage container, an end product with a short useful life that is widely recycled, has in recent years increased the importance of old scrap recycling for that metal. The growing use of lead in batteries has similarly increased the amount of lead consumption contributed by old scrap recycling. Radetzki and Van Duyne (1985) suggest that the growth rate of the economy as a whole may also affect the share of total metal supply coming from the recycling of old scrap.

So a number of factors influence the recycling of old scrap other than metal prices. Nevertheless, a sharp rise in metal prices, due to mineral depletion or more strin-

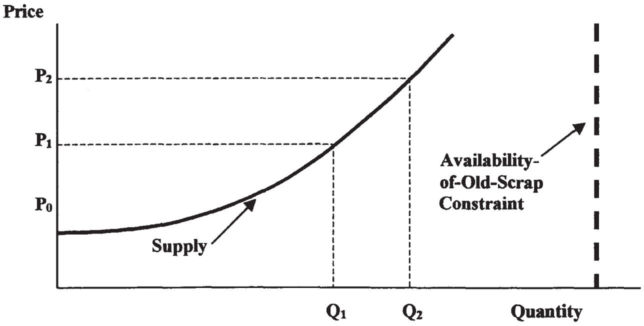

Fig. 4. Supply curve for secondary metal from old scrap.

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[3] Moison (1997) in an interesting analysis argues that most of the increase in secondary supply from old scrap that comes about when metal prices rise is not actually caused by the latter. Rather, it is the result of a downward shift in the supply curve, produced by an increase in the flow of old scrap onto the market (that is, by a rightward shift in the availability-of-old-scrap constraint). During an economic boom, construction increases, accelerating metal recovery from the demolition of old buildings and factories. During such periods, consumers also feel more secure financially, and are more likely to replace their automobiles and old home appliances. While metal prices may also rise during economic booms, it is the increase in old scrap availability, rather than the rise in metal prices, that Moison contends largely causes secondary production from old scrap to expand.

gent environmental policies governing mining, could cause the share of total metal supply coming from secondary producers to rise. The two sections that follow look more closely at this possibility, considering first mineral depletion and then environmental policies.

Mineral depletion[4]

Concern that society is running out of essential natural resources can be traced back at least to the 18th century and the Classical economists. Indeed, economics has since the time of Thomas Malthus been known as the dismal science as a result of his pessimistic assessment of the human condition, arising from the limited availability of land coupled with the tendency for population to grow geometrically.

In more recent times, fears of resource scarcity were particularly strong in the early 1970s, as a result of the sharp jump in oil prices induced by OPEC, the general rise in commodity prices due to a simultaneous economic boom in the major developed countries, and the publication of *Limits to growth* (Meadows et al., 1972) and other studies predicting the demise of the modern industrial economy as a result of mineral resource exhaustion. These fears sparked a vigorous debate regarding the future availability of mineral resources, a debate that is still quite active. There are, however, a number of issues on which one now finds widespread agreement.

First, early concerns that society would literally run out of oil, copper, or other nonrenewable resources — the problem of physical depletion — now seem baseless. Long before we could dig up the last atom of copper or recover the last drop of oil in the earth’s crust, costs would rise sharply, choking off demand.

Second, a more meaningful way to assess the threat of resource scarcity is the opportunity cost — or what we have to give up in terms of other goods and services — to obtain mineral resources. Here three measures are widely recognized — trends in the real prices of mineral commodities, trends in the real costs of producing mineral commodities, and trends in the real costs of developing new mineral reserves (Fisher, 1979).

Third, it is possible for mineral resources to become more available (that is, less scarce) over time. While the depletion of low-cost deposits tends over time to drive costs up and thus increase resource scarcity, the cost-reducing effects of new technology and innovations may more than offset this upward pressure on costs. So trends in mineral resource availability reflect the outcome of a race over time between the cost-increasing effects of depletion and the cost-reducing effects of new technology. Other developments, such as the discovery of new low-cost deposits, may also influence the outcome.

Fourth, over the past century, the available evidence indicates that this race has been won, and won by a substantial margin, by the cost-reducing effects of new technology. Real prices and costs have fallen substantially for most mineral commodities, and resources have become less rather than more scarce.

The best known and most influential study in this area is *Scarcity and growth* by Harold Barnett and Chandler Morse (1963), which assesses trends in resource scarcity within the United States from the late 1800s to 1957 for agricultural products, for both fuel and nonfuel mineral commodities, and for forest products. Examining trends in the labor and capital inputs required per unit of output, a type of production cost measure of scarcity, they found that the necessary inputs fell sharply for both mineral and agricultural products, as shown in Table 1. For forest products, the results were mixed. The required inputs rose during the early years of their analysis and then fell.

These findings were quite surprising at the time of their publication in 1963. Not only were resources apparently becoming more rather than less abundant, despite their extensive exploitation over time, but the decline in scarcity was greatest for the nonrenewable, mineral resources.

Subsequent research builds on and extends this seminal study. It uses other economic measures of scarcity, including real prices of mineral commodities. It examines resource availability outside the United States and takes into account energy and environmental costs, which Barnett and Morse largely ignored. It looks at the period after 1957 to see if the rising trend in resource availability has slowed or even changed direction in recent years.

The original findings of Barnett and Morse have held up well (Smith, 1979; Fisher, 1979; Tietenberg, 1996; Krautkraemer, 1998). Resource scarcity, and in particular mineral resource scarcity, has declined greatly over the past century, not just in the United States but around the world. While the rate of decline may be slowing, as some suggest, the evidence on this is mixed. Over the past several decades, for example, production costs for many metal mining companies have fallen dramatically. As a result, the real costs and prices for many metals are today as low as they have ever been.

The past, of course, is not a perfect guide to the future, and the debate over the availability of mineral resources continues in part because of differing assessments regarding the ability of new technology to continue indefinitely to offset the cost-increasing effects of depletion. Given what we know about existing mineral reserves and resources, population trends, growth rates, and technological developments, it seems unlikely that metal and other mineral prices will experience a significant increase in real price over the next several decades.

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[4] This and the following sections draw heavily from Tilton (1998).

Table 1
Labor and capital inputs per unit of extractive output (1929=100)[a]

	Total	Agriculture	Minerals	Forestry
1870–1900	134	132	210	59
1919	122	114	164	106
1957	60	61	47	90

[a] Source: Barnett (1979, p. 166).

In the longer run, of course, the picture gets cloudier, but it is far from certain that mineral depletion will drive real metal prices up.

Environmental costs and government policy

As the real costs and prices for many mineral commodities have continued to fall during the 1990s, the focus of the debate over resource availability has shifted. Mineral producing firms, thanks to new technology, may not face rising costs, but the environmental and other social costs associated with the production and use of mineral resources, it is now suggested, will nevertheless soon preclude their widespread use.[5]

The following quotes illustrate this shift. The first is by an economist (Young, 1992, p. 100):

> Are we running out? Recent trends in price and availability of minerals suggests that the answer is “not yet”…. The question of scarcity, however, may never have been the most important one. Far more urgent is, Can the world afford the human and ecological price of satisfying its voracious appetite for minerals?

The second is by a geologist (Kesler, 1994, p. iii):

> At the end of the twentieth century, we are faced with two closely related threats. First, there is the increasing rate at which we are consuming mineral resources, the basic materials on which civilization depends. Although we have not yet experienced global mineral shortages, they are on the horizon. Second, there is the growing pollution caused by the extraction and consumption of mineral resources, which threatens to make earth’s surface uninhabitable. We may well ponder which of these will first limit the continued improvement of our standard of living….

Another interesting example of this shift is found in the book, *Beyond the limits* (Meadows et al., 1992), written by the same authors who wrote *Limits to growth* (Meadows et al., 1972), the book noted earlier that contributed to the concern over resource availability in the early 1970s. Both books use a complex systems dynamics model to produce scenarios of the future. In the original work, the base scenario sees modern civilization collapsing during the 21st century as a result of mineral exhaustion. Twenty years later, in the second book, the base scenario foresees a similar collapse, but one coming from the environment damage arising from the production and use of resources, rather than their depletion.

This new concern raises an important question: Is it possible for new technology to reduce the environmental and other social costs associated with mining, just as it has reduced the labor, capital, energy, and material costs in the past? If the answer is yes, the environmental constraint on mining may be insignificant.

In addressing this question, it is useful to start by noting that a 100 years ago, even 50 years ago, mineral producing firms faced few environmental restrictions. The environment was largely perceived as a free good, for companies and others to use as they saw fit. As a result, firms had little incentive to reduce the environmental costs associated with their production. Sulfur dioxide, particulates, and other pollutants were pumped into the air. Other wastes were dumped on land or into nearby streams.

This situation has changed greatly over the past several decades, as governments around the world have imposed regulations and other controls on mineral producers. This trend has produced considerable evidence that environmental costs are just as amenable to the cost-reducing effects of new technology as capital and labor costs. Indeed, for a time they may even be more so given the modest efforts to reduce environmental costs until quite recently. While a full review of this evidence is not possible here, an example or two drawn from the copper industry will illustrate the possibilities.

Two major pollutants in the production of copper are sulfur dioxide and arsenic. As Fig. 5 shows, the Chuquicamata copper smelter in northern Chile undertook a major effort to reduce these pollutants over the 1980–98 period. The rise in captured emissions is striking — from 35 to 90% for arsenic and from 0 to 80% for sulfur dioxide. The costs were not trivial: Codelco, the state

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[5] There were earlier writers who anticipated the interest in the environmental constraint on resource exploitation of the 1990s. See, for example, Brooks and Andrews (1974).

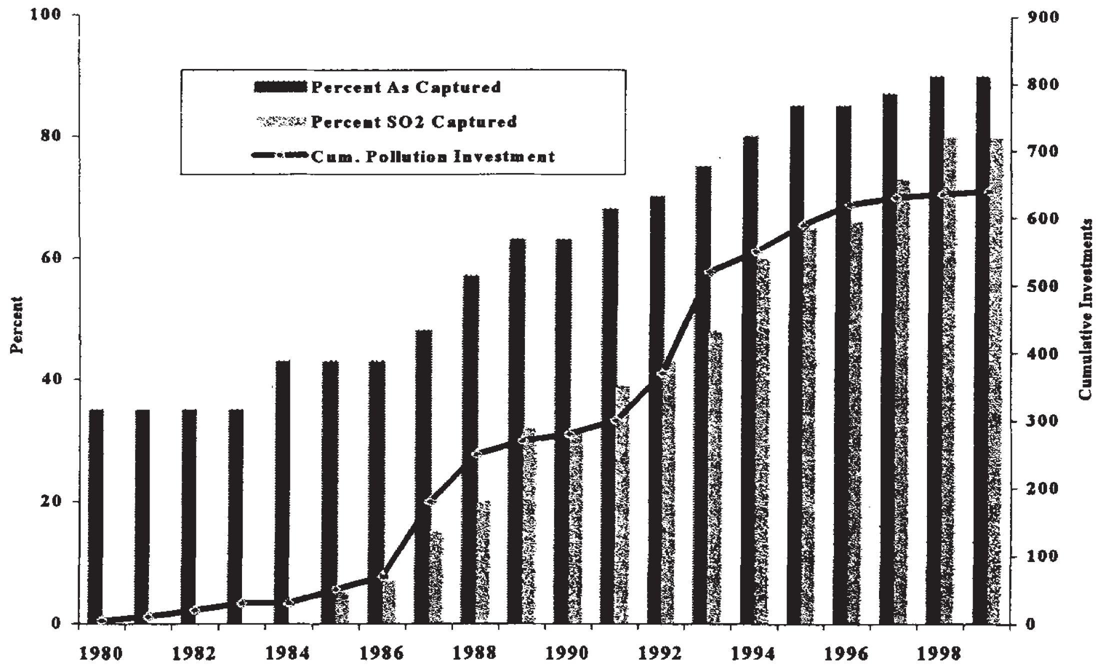

Fig. 5. Percentage of arsenic and sulfur dioxide emissions captured and cumulative investment in pollution abatement at the Chuquicamata smelter, 1980–99. Note: Data for the years from 1996 to 1999 are projections. Source: Corporacion Nacional del Cobre de Chile (Codelco).

enterprise that owns Chuquicamata, spent over US$600 million to realize these improvements. In addition to these capital costs, the higher recovery of emissions exerts upward pressure on operating costs. Chuquicamata nevertheless has managed to reduce its real operating (cash) costs by over 40% and to increase its output by 27% since 1980. Today it remains one of the world's largest and lowest cost copper producers.

While the reduction in sulfur dioxide emissions at Chuquicamata is impressive, the technology exists today to capture more than 99% of these emissions. As a result, smelters in countries with very stringent environmental standards — Japan, for example — capture all but 1 or 2% of their sulfur dioxide emissions. At the other end of the spectrum, where public policy is lax, it should be noted, a significant number of smelters still allow 100% of their emissions to escape into the atmosphere.

Finally, new technological developments have over the past several decades led to the widespread diffusion of a new and quite different technique for producing primary copper–solvent extraction electrowinning (SX-EW). This process, which now accounts for over a fourth of total primary copper output in both the United States and Chile, lowers operating and capital costs, allows the exploitation of low grade and oxide ores that the traditional technology cannot treat, and completely bypasses the smelting stage of production.[6] There are, as a result, no arsenic or sulfur dioxide emissions.

Thus, new technology has had a tremendous impact on sulfur dioxide and arsenic pollution, particularly where public policy forces firms to pay for their environmental costs. The best smelters are producing a hundred tons of copper with less sulfur dioxide pollution than smelters generated just several decades ago in treating a single ton of copper. Moreover, a significant portion of the world's copper is now produced without smelting by solvent extraction electrowinning.

There are, of course, instances where environmental or other social costs may preclude mineral exploitation, where mining is incompatible with preserving resources and other assets that society values highly. Activities that diminish the natural beauty of national parks, the pristine wilderness of remote areas, the culture and mores of indigenous people, and biodiversity are often cited examples. In these situations, no amount of technological change may reduce the costs to acceptable levels, and certain sites may quite appropriately be off-limits to

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[6] The traditional technology entails mining sulfide copper ore in underground or open pit mines. The ore is then moved by truck, rail, or conveyor belt to a mill where it is crushed and the copper bearing minerals separated from the waste material or gangue by flotation. The resulting concentrate (25–40% copper) is shipped to a smelter for partial purification (97–99% copper), and then on to a refinery for electrolytic purification (99.99% copper).

The SX-EW process involves first leaching existing mine dumps, prepared ore heaps, or in situ ore with a weak acidic solution. The solution is recovered, and in the next stage, the solvent extraction stage (SX), mixed with an organic solvent (referred to as an extractant), which selectively removes the copper. The copper-loaded extractant is then mixed with an aqueous acid solution, which strips it of the copper. The resulting electrolyte is highly concentrated and relatively pure, and is processed into high quality copper in the third and final stage by electrowinning (EW).

mineral exploitation. This, in fact, has been the case for some time in most countries. While making it more difficult for the cost-reducing effects of new technology to offset the cost-increasing effects of depletion, such excluded areas, even when growing in magnitude, are not incompatible with falling resource costs, as recent history shows.

The troubled history, for example, of the Panguna mine on Bougainville Island in Papua New Guinea in retrospect indicates that the central government and private companies should have paid more attention to the concerns of the local people. Some might even argue that the mine should never have been developed, as it has simply been too disruptive to the indigenous culture. Yet, despite the attractive nature of this mineral deposit, had this been the case, the effect on the long-run evolution of copper production costs would have been negligible. Indeed, given the large number of known but undeveloped porphyry deposits that could produce copper at costs close to many of today's operating mines, a number of the latter could have been excluded from development with little effect on the long-run costs of producing copper.

The future

Pulling together the information presented in the preceding sections, what can one say about the future of recycling? New scrap marches to its own drummer: namely, its own availability, rather than metal prices. New scrap availability varies over time with the level of metal consumption, with changes in production technologies in metal-using industries, and with shifts in consumer preferences that alter the allocation of metals among their end uses. Since forecasts of consumer preferences and technological change are notoriously poor, it is difficult to anticipate how the contribution of new scrap recycling to total metal supply will evolve. What is clear is that its future will be little affected by the costs of primary production, and hence mineral resource depletion and environmental regulations.

The recycling of old scrap is a somewhat different story, but only somewhat. Secondary production from old scrap does respond to changes in metal prices, and thus is more closely tied to developments in the primary metal industries. The evidence reviewed provides little support, however, for the widely held view that mineral depletion and more stringent environmental standards are likely to drive primary production costs up in the foreseeable future. Despite their greater use of energy and capital, and despite resource depletion, primary producers have managed over time to reduce substantially their real costs. The available evidence also suggests that primary producers can reduce the environmental and other social costs associated with their activities. Some day, the long downward trend in real metal prices may come to an end, but it would be naive to count on this happening soon.

For secondary producers recycling old scrap, this means that their future may not be as rosy as many have assumed. They will, of course, continue to recycle old scrap, particularly old scrap that can be collected and processed inexpensively. Just how much of future metal supplies will come from the recycling of old scrap, however, will depend on the outcome of a competitive struggle between primary and secondary producers to determine which can provide society with its needed metal supplies at the lowest costs.

In the past, secondary producers have managed to maintain and for some metals even increase their market share despite the continuing downward trend in real metal prices. This they have achieved in part by developing a host of minor and major innovations, such as the automobile shredders, collection systems for used beverage containers, and choppers for insulated wire and cable scrap. For those secondary producers that continue to pursue new technologies and other innovations, and so manage to reduce their costs as much or more than primary producers, the future should be bright. History suggests, however, that primary producers are formidable opponents.

This view of recycling's future holds promise in other ways as well. In particular, for society as a whole, the competitive struggle between primary and secondary producers increases the prospects for maintaining the long-run downward trend in the real metal prices.

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