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Opportunities and Challenges in Metals Recovery from Secondary Sources - US Perspective

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The mineral industry of the United States is going through a challenging time. The US as an industrial nation faces with increasing demand in raw materials to fuel various industrial sectors but, at the same time, meeting environmental constraints associated with excavating and extracting these raw materials. In addition, gradual depletion of material resources, and the necessity of handling more complex forms of resources of primary origin have led to a decline in her resource productivity, once a strategic advantage of the U.S.

As a result, the United States currently relies heavily upon foreign importation of various materials such as precious and strategic metals. However, since the US is the major consumer of most of these materials, the recovery of these values from scrap would help renew her position as a resource-producing nation, and ultimately help spur its domestic economy. Furthermore, recycling would also help maintain a clean environment and reduce energy consumption.

In this paper, the author attempts to discuss opportunities and challenges lied ahead of the US mineral industry in relation to recovering their much-needed resources from secondary sources. The need and demand in various metals in the US will be reviewed and discussed. The implication of resource recovery from secondary sources will also be discussed. Extraction methods treating secondary sources are inherently different from those for primary sources. There is a need for new technologies which are metallurgically efficient and environmentally benign in treating secondary sources. Ways to meet such a need will be examined and key factors to be considered in approaching these challenges will be discussed.

Trend in Materials Consumption

The United States is indisputably one of the most industrially advanced nations in the world. As a result, it uses more than one third of materials produced in the world. Because of its fast growing industries, the need of various materials, especially those of hi-tech is increasing in a very fast pace. In 1999, the US gross domestic product amounted to about $9,260 billion. Of this, about $422 billion was attributed to processed materials of mineral origin.[1] In addition, the US imported about $62 billion worth of processed materials of mineral origin in order to meet its fast growing industry sectors.

Since 1900, use of construction materials has grown fastest, namely from 35 percent to 60 percent of total non-food, non-fuel raw materials consumption followed by industrial minerals, metals, non-renewable organics and agricultural forestry products in that order. Consumption of non-food and non-fuel agricultural and forestry products has dropped from about 60 percent in 1900 to a mere 5 percent in 1995 of total raw materials consumption.[2]

Appropriate use of materials is essential to the development of the human culture and fuel to everyday life of the human society. The consumption of materials at the beginning of the 20th century was estimated about 2 metric tons per capita and this figure had increased to about 10 metric tons by 1995. However, it is noted that the need of various materials changes with time. Fig 1 illustrates raw materials consumed in the US for the period of 1900 and 1995.[2] It can be seen that the consumption of construction materials is by far the most of all raw materials used in the US for the same period. It is also noted a steady increase of the consumption of all materials with time, although there are depression in consumption of these materials reflecting the hardship went along with various conflicts such as World Wars and Oil Crisis occurred in the world.

Figure 2 shows selected materials consumed in the US for the period of 1960 through 1995.[2] It can be seen that the consumption of metals produced from the primary source was on the decline, while that of recycled sources was on the increase. For comparison, the consumption of wood products is on the increase.[2]

It should be noted that the US is still the second largest country in the world in the reserves of all of the raw minerals, following Russia. As be seen in Table 1, mine production and confirmed reserves of various metal ores are fairly respectful in comparison with the overall world scene. Also shown in this table is the ratio of ore reserve to the annual production of each metal ore reflecting the number of years lasting to supply the metal at the current consumption. It is notable that except a few metals such as aluminum and iron, many metals appear to be short-life.

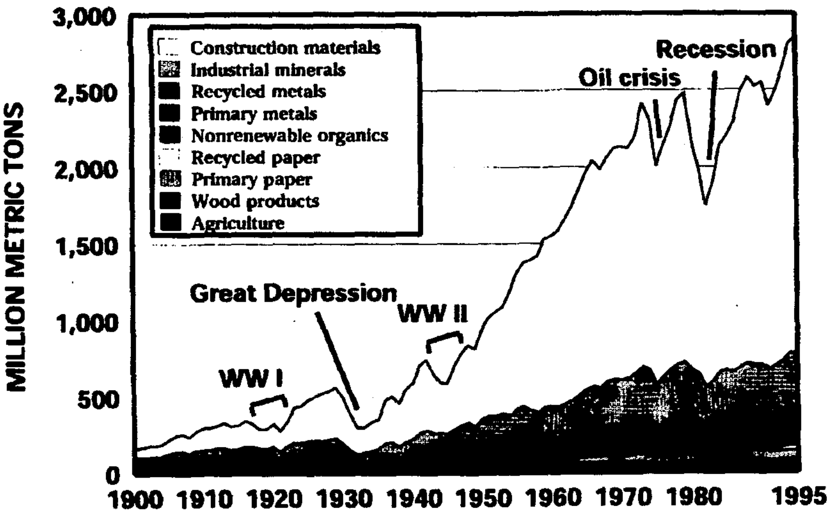

Figure 1. The amounts of raw materials consumed in the U.S. for the period of 1900 - 1995

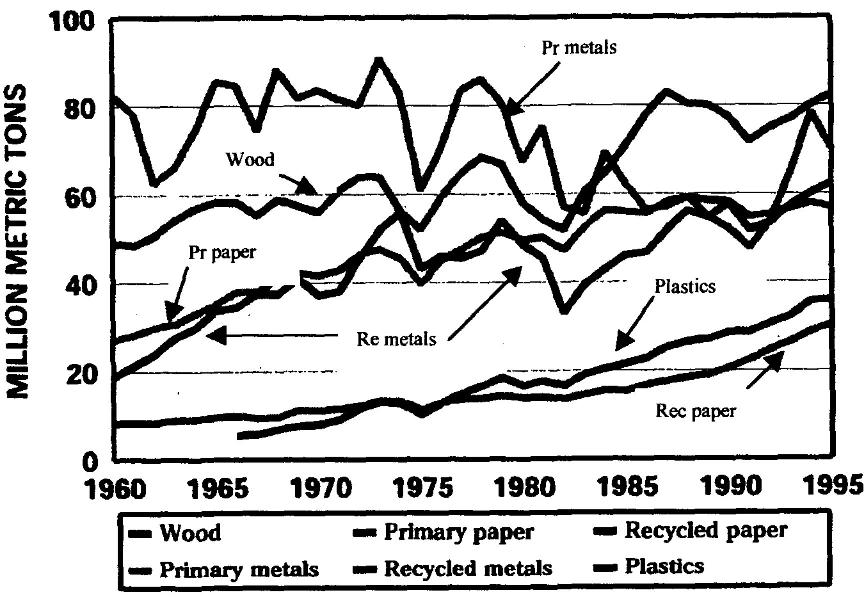

Figure 2. The amounts of materials consumed in the US during the period of 1960 - 1995.

Table 1. Mine production of various ores in 1999 and US and world reserves of the ores.
(all data in metric tons)

Mineral	Mine Production		Ore Reserves		Reserve/annual prod.	
	U.S.	World	U.S.	World	U.S.	World
Bauxite	-	1.23×10^8	2×10^7	2.5×10^{10}	-	203 yrs
Iron	5.7×10^7	9.92×10^8	6.4×10^{10}	1.4×10^{11}	112 yrs	141
Copper	1.7×10^6	1.3×10^7	4.5×10^7	3.4×10^8	27	27
Gold	340 2330	5.6×10^3	4.9×10^4	16	21	
Lead	5.2×10^5	3.1×10^6	6.5×10^6	6.4×10^7	13	21
Nickel	-	1.2×10^6	4.3×10^4	4.6×10^7	-	40
Cobalt	-	2.8×10^4	-	4.5×10^6	-	160
Pt-metals	13.4	275	730	7.1×10^4	54	26
Silver	1.9×10^3	1.6×10^4	3.3×10^4	2.8×10^5	18	18
Tungsten	-	3.1×10^4	1.4×10^5	2×10^6	-	64
Titanium	-	4×10^6	1.3×10^7	3.7×10^8	-	92
Zinc	5.1×10^5	7.64×10^6	2.5×10^7	1.9×10^8	31	25

The annual growth rates of various materials in the US for the periods of 1971-1981 and 1995-2000 are shown in Table 2. The growth rate of basic metals, agricultural minerals and non-metallic construction materials is moderate or even negative. On the other hand, that of the so called advanced materials is on the rise very rapidly. This is very understandable, since the booming of semi-conductor and hi-tech industries in recent years has spurred a fast rate consumption of these materials.

Table 2. US demand for selected materials.

	Annual growth rate	
	71 - 85[3]	95-00[4]
Basic metals		
Aluminum	2.3	3.8
Copper	0.7	4.3
Iron Ore	-3.6	-1.2
Iron & Steel	-0.7	1.4
Lead	-1.2	2.3
Zinc	-1.2	2.3
Agricultural minerals		
Phosphate rock	2.7	0.9
Potash	2.0	-1.5
Sulfur	1.8	-1.4
Non-metallic construction materials		
Cement	0.4	4.4
Sand & Gravel	-0.8	0.4
Advanced materials		
Cobalt	1.1	5.6
Gallium	8.7	12.0
Germanium	4.9	1.0
Plastics	6.2	
Platinum		1.1
Palladium		11.5
Rhodium		10.2

Trend in Recycling of Metals

In 1998, 150 million metric tons of metals valued at $43.2 billion were recovered from secondary sources in the US. Of various metals, iron and steel accounted for about 88.6% by weight followed by aluminum which was 40.1% of the total metals recovered from scrap.

Iron and Steel

In 1999, about 70 million tons of iron and steel worth $4.9 billion (see Table 3) were recovered from scrap. This is in comparison with about 137.9 million tons worth more than $70 billion produced from primary sources.

Table 3. Iron and steel production in the US for the period of 95-99. (data in million metric tons)

	1995	1996	1997	1998	1999
Primary	146.1	144.9	148.1	146.8	137.9
Scrap	79	77	79	76	70

Of 70 million tons of iron and steel derived from scrap, about 82% was consumed by the domestic steel industry to produce steel products for the construction, transportation, oil and gas, machinery and other consumer industries. The ferrous castings industry consumed the remaining 18% to produce cast iron and steel products such as motor blocks, pipe and machinery parts.

Automotive recycling industry recycles about 12 million vehicles annually through 200 car shredders to supply more than 13 million tons of steel. It is interesting to note that 96% of automobile steels are recycled, while only 75% and 57% of appliances and steel cans, respectively are recycled.

Aluminum

About 3.8 million tons of aluminum valued at $5.5 billion were produced from primary sources in the US in 1999. In the same year, 1.4 million tons representing about 27% of the total aluminum production were obtained from scrap. (See Table 4.)

Table 4. Aluminum production in the US for the period of 95-99. (data in thousand metric tons)

	1995	1996	1997	1998	1999
Primary	3,375	3,577	3,603	3,713	3,800
Scrap	1,510	1,570	1,530	1,500	1,400

Used beverage cans are the major component of processed scrap accounting for about one-half of the total aluminum scrap. It is remarkable to note that about 900,000 tons of aluminum were recycled in 1970, which is compared to 1.4 million tons in 1999. Aluminum scrap purchasing price runs about 35-44 cents per pound compared to 65.5 cents per pound for the refined product.

Copper

In 1999, domestic copper mine production was 1.66 million metric tons valued at $2.8 billion. This is compared to 240,000 tons of copper produced from scrap in the same year. This is about 13% of the total copper consumption in the US for the same year. (Table 5.)

Table 5. Copper production in the US for the period of 95-99. (data in thousand metric tons)

	1995	1996	1997	1998	1999
Primary	1,850	1,920	1,940	1,860	1,660
Scrap	352	345	383	336	240

The price the refiners pay for the copper scrap ranges 5.3 - 14.9 cents per pound which is compared to 78 cents per pound for the final product.

Gold

In 1999, 490 metric tons of gold valued at about $3.1 billion were produced. Of this, about 150 tons came from old scrap. (See Table 6)

Table 6. Gold production in the US for the period of 95-99. (data in metric tons)

	1995	1996	1997	1998	1999
Primary	317	326	362	366	340
Scrap	-	-	100	163	150

Gold has been known as a precious metal and people do exercise a special care to keep it safe. As a result, of 125,000 tons produced in history of gold mining, only 15% is unaccounted for. Of the remaining gold in the amount of 106,000 tons, 34,000 tons are kept in stocks and 72,000 tons are privately held. The US government intentionally releases gold from their stock piles as seen in 1998 information of Table 7.

Table 7. Domestic supply and distribution of gold in 1998.

Domestic supply		
	Release from stocks	303 tons
	Imports	276
	Production	446
	Total	1025
Distributions		
	Exports	431
	Investments	318
	Fabrication*	276
	Total	1025
*Fabrication:		
	Jewelry	173
	Electronics	9
	Dental	4
	Coin sheet	57
	Other	33

In 1998, it was practiced that the purchase price of gold scrap ranged $190 - $197 per ounce that could be compared to $295 per ounce for the final product.

Lead

The value of mined lead in 1999 was estimated to be about $500 million. As can be seen in Table 8, the lead production is fairly constant over the years. It is very interesting to note that the amount of lead recovered from scrap is significantly higher than any other metals.

Table 8. Lead production in the US for the period of 95-99. (data in thousand metric tons)

	1995	1996	1997	1998	1999
Mine	394	436	459	493	520
Scrap	963	1,030	1,040	1,060	1,050

Lead is recovered primarily from lead batteries as a secondary source. It is noted that 70% of the total lead produced in the US is consumed in transportation industries. This includes batteries, fuel tanks, solders, seals and bearings. About 20% of the total lead produced is consumed in electrical and electronic industries. Uses are found in communication uses, ammunition, television glass, etc. The remaining 10% of lead is consumed in counterweights, ceramics, crystal glass, tubes and containers.

Pt Group Metals

As can be seen in Table 9, the total amounts of pt-group metals (primarily platinum, palladium and rhodium) used annually are not significant. However, since these metals are precious metals and the price is very high, the monetary value attributed to the metal economy is more than most other metals.

Table 9. Pt-group metals production in the US and imports for the period of 95-99. (data in kilograms)

	1995	1996	1997	1998	1999
Mine prod.					
Platinum	1,590	1,840	2,610	3,240	3,200
Palladium	5,260	6,100	8,400	10,600	10,200
Imports, refined					
Platinum	71,500	75,800	77,300	97,200	75,300
Palladium	124,000	146,000	148,000	176,000	195,000
Rhodium	9,600	9,650	14,400	13,400	14,500

It should be noted that unlike most other metals, the consumption of these metals has been on the rise. What is more interesting about these metals is that the monetary value of these metals is extremely high in 2000 than 1999. Table 10 shows that dramatic increase in the monetary value of these metals in the past one year.

Table 10. The monetary value of three pt-group metals for 1999 and 2000. (in this example, the imported pt-group metals are used.)

	1999	2000
Platinum (75,300 kg)	$0.9 billion	$1.6 billion
Palladium (195,000 kg)	2.2	6.2
Rhodium (14,500)	0.5	1.0
Total	3.6	8.8

Zinc

About 30% of the total zinc is produced from scrap world-wide. In 1999, about 370,000 tons of zinc valued at $0.42 billion was produced from primary and secondary sources in the US. Of this, about 135,000 tons representing about 36.5% of the total zinc production came from scrap (Table 11). Zinc scrap comes from brass, diecasting scrap, flue dust, galvanizing residues and zinc sheet.

Table 11. Zinc production in the US for the period of 95-99. (data in thousand metric tons)

	1995	1996	1997	1998	1999
Mine	614	600	605	722	775
Scrap	131	140	140	134	135

Challenges in the Treatment of Secondary Sources

There are inherent differences between the treatment of metal extraction from primary sources and that from secondary sources. First of all, the nature of the various metals associated with primary sources is significantly different. Metals are frequently associated with oxygen, sulfur and other compounds in nature, while the same metals are present in finished products in their elemental form or more frequently in alloy forms. In general, it is more difficult to release the bond of these metals from other metals than oxygen or sulfur. After all, the metal-based products are usually built to last long, corrosion resistant, chemically inert and mechanically strong. It is for this reason that extraction metals from scrap is more difficult than from primary sources.

Comminution of secondary sources is also very different from primary sources. It requires more shredding than impacting or abrasion grinding. As a result, the crushing and grinding units used in secondary sources are designed differently. The subsequent treatment on physical separation of various metal-bearing components from the rest is very much different. Because of the unique nature of scrap, it is very difficult and frequently uneconomical to crush and grind to a size required to liberate the desired part from the rest.

Chemical treatment of secondary sources is usually being carried out in metropolitan areas since the source of scrap is originated in metropolitan area than rural area. As a result, there will be more stringent requirements on environmental concerns than when primary sources are treated in remote areas. Furthermore, metals are more concentrated in secondary sources than primary sources. For example, the gold content in some of the electronic scrap is known to be as much as 100 ounces per ton which is compared to a mere 0.05 oz per ton being treated in many US gold mines. This means that the gold extraction plant treating electronic scrap can be 1/2000 size to be equivalent to that for the primary source. As a matter of fact, metal extraction plants for secondary sources are usually much smaller than those treating primary sources.

There is another striking and unique property for secondary sources. Metal contents of scrap can be precisely traced provided the information of the manufacturers of the equipment where metals were used in well determined quantity. Therefore, the exact amount of the content of the metal used in the equipment can be known before extraction process. For example, the metal contents of electronic scrap are easily chased if one knows the company who manufactured that particular electronic component. On the other hand, because the amounts of such products are very limited, it is impractical to design a plant to handle just one kind of scrap. This forces therefore, that any company who wants to treat secondary sources to be flexible in designing the process flowchart to be able to treat various sources of scrap.

Iron and aluminum are extracted pyrometallurgically from scrap which is the same way practiced in primary sources. Other non-ferrous metals are extracted either pyrometallurgically or hydrometallurgically. Due to the nature of the occurrence of secondary sources as discussed earlier, there has been an increasing public pressure to design the process being environmentally benign. It is generally understood in the US industry that hydrometallurgical processes are more desirable than pyrometallurgical processes. This is simply because the public is far less tolerable with contaminated stack gas than solution effluent streams derived from a hydrometallurgical plant. However, the engineers should be mindful that any effluent streams from the treatment of secondary sources should meet the guidelines set out by EPA.

It is therefore for engineers and technical personnel to be concerned with the absolute minimum metal contents in the treatment effluent streams set by the governmental authorities.[5-7] Table 12 lists the limited amounts of various substances included in drinking water.

Table 12. US Public Health Service Drinking Water Standards.

Substance	Drinking Water Standards (ppm)
Arsenic	0.05
Barium	1
Cadmium	0.01
Chloride	250
Chromium	0.05
Copper	1
Cyanide	0.2
Iron	0.3
Lead	0.05
Manganese	0.05
Nitrate	45
Selenium	0.01
Silver	0.05
Sulfate	250
Zinc	5

It should be noted that the guidelines for the metal content allowable in the process effluents are slightly different from the guidelines given for the drinking water. Table 13 lists mining pollutant allowable in the mine water discharge. This is based on the so called the Best Available Technology Economically Achievable (BAT) effluent guidelines for Ore Mining Industry.[8,9]

Table 13. Pollutant Limitations for Mining Industry Discharge.

Pollutant	Daily Maximum (ppm)	30-Day Average (ppm)
Copper	0.30	0.15
Zinc	1.0	0.5
Lead	0.6	0.3
Mercury	0.002	0.001
Cadmium	0.1	0.05
Dissolved Fe	2.0	1.0
Aluminum	2.0	1.0
Chem Oxygen Demand	-	500

It is the environmental reason that in many states in the US, the use of cyanide in gold extraction is prohibited. There have been many alternative ways of treating gold. Many of these processes are still in its infancy and many more investigations should be made to make them commercialization.

In conclusion, no one would dispute that useful metals have their own life span and primary sources of many metals are getting depleted as the modern society progresses at a very fast pace. Therefore, there is an urgent need to recover these valuable metals from secondary sources. Treatment of these secondary sources is quite different from that of primary sources. Therefore, the society needs to encourage researchers to develop metallurgically efficient and environmentally benign technologies to handle such secondary sources.

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