

***"Materials-Cycle Optimisation in the  
Production of Major Finished Materials"***  
**CHAPTER 5: ZINC AND CADMIUM**

by

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This chapter is part of a report made for the EC DGXII on a project entitled ***"Materials-Cycle Optimisation in the Production of Major Finished Materials"***. This project aims at facilitating the identification of longer-term R&D needs for materials-cycle optimisation, especially by using wastes, co-products, or by-products from one process as inputs to other processes. Book publication is envisaged. Following is the list of chapters:

- Chapter 1: Summary and Overview (*Insead ref N°: 95/05/EPS*)
- Chapter 2: Alumina, Aluminium and Gallium (*Insead ref N°: 95/06/EPS*)
- Chapter 3: Copper, Cobalt, Silver & Arsenic (*Insead ref N°: 95/07/EPS*)
- Chapter 4: Chromium Sources, Uses and Losses (*Insead ref N°: 95/08/EPS*)
- Chapter 5: Zinc and Cadmium (*Insead ref N°: 95/09/EPS*)
- Chapter 6: Sulfur and Sulfuric Acid (*Insead ref N°: 95/10/EPS*)
- Chapter 7: Phosphorus, Fluorine and Gypsum (*Insead ref N°: 95/11/EPS*)
- Chapter 8: Nitrogen-based Chemicals (*Insead ref N°: 95/12/EPS*)
- Chapter 9: The Chlor-Alkali Sector (*Insead ref: N°: 95/13/EPS*)
- Chapter 10: Electronic Grade Silicon (EGS) for Semiconductors (*Insead ref N°: 95/14/EPS*)
- Chapter 11: Packaging Wastes (*Insead ref N°: 95/15/EPS*)
- Chapter 12: Scrap Tires (*Insead ref N°: 95/16/EPS*)
- Chapter 13: Coal Ash: Sources and Possible Uses (*Insead ref N° 95/17/EPS*)

All chapters are individually available as INSEAD Working Papers.

## CHAPTER 5. ZINC AND CADMIUM<sup>1</sup>

### 5.1. Summary

Zinc is an important industrial metal. Zinc is mined primarily from sulfide ores (sphalerite, ZnS), often associated with ores of copper and/or lead. Zinc ores normally contain significant quantities of copper and lead plus traces of arsenic and cadmium. (See *Chapter 3, Copper*). Zinc ores are sulfides, so smelting releases significant quantities of sulfur, unless it is recovered for use.

Zinc is extensively used both in metallic and chemical forms, predominantly the former. It has useful electrochemical properties, forms useful alloys (e.g. with copper and tin) and makes a good protective coating for iron or steel. It is also easy to smelt and easy to cast. However, zinc is not a "strategic" metal in the sense that chromium or cobalt are. It is produced in many countries. There are satisfactory substitutes for most, if not all of its uses. Only the fact that its uses are so widespread, and many of them are dissipative, gives cause for concern about zinc *per se* from an environmental point of view.

Cadmium has been used in the past mainly because of its low cost (as a by-product of zinc smelting and refining) and because some of its compounds are highly colored. Cadmium has many dissipative uses, as well as being a contaminant of some zinc chemicals, notably zinc oxide. In recent decades cadmium has found an important 'niche' market for rechargeable batteries. These batteries are getting smaller and smaller, and they are being used in more and more small appliances. Eventually they find their way into household — thence municipal — wastes, which may be incinerated. This is a legitimate cause for concern.

Zinc is an element required by growing plants, in trace amounts, and is found at the active sites of many enzymes. Zinc is moderately toxic in some forms, like copper, but it is not one of the more dangerous heavy metals. The major environmental problem of zinc is that cadmium (along with arsenic, copper and lead) is usually a co-product of zinc. It is, however, much more toxic than zinc. Because cadmium is chemically similar to zinc, it can be taken up and accumulated by plants and animals via the same biochemical mechanisms needed for zinc. The sulfide CdS and the oxide CdO are nearly insoluble, and not bio-available. However, "immobile" cadmium sulfide in soils and sediments may be re-mobilized by oxidation. The latter is promoted by increases with acidity (pH) and conversion to the bio-available Cd<sup>+2</sup> cation. Thus, as in the case of chromium (III) cadmium can be "toxified" by changing conditions [Stigliani undated], [Enquete 1994].

Because cadmium is a by-product of zinc, its supply tends to be proportional to the supply of primary zinc. It follows that there are two strategies for reducing environmental releases of cadmium. The first is to find and promote non-dissipative uses of cadmium that can "soak up" the available supply. In principle, nickel-cadmium (nicad) batteries might be such a use, provided they can be re-manufactured or recycled effectively. The technology is not too difficult. Unfortunately, the problem of logistics (i.e. collection and return) remains unsolved. Most nicad batteries, currently, are discarded with household solid wastes and find their way to landfills or incinerators. The only practical solution is to create a market for used batteries, probably by means of a returnable cash deposit.

Table 5.1. Zinc &amp; cadmium production 1991 (kMT)

Country	Zinc			1989 Zinc Oxide <sup>(a)</sup>	Cadmium Refinery (tonnes)	
	Mine Ore <sup>(a)</sup>	Primary	Secondary			Total
Austria	14.8			16.3		
Belgium				297.6	1807	
Finland	55.5	170.4		170.4	1.8	
France	27.1			299.6	41.0	
Germany (W)	54.0	305.5	39.0	346.5	44.6	
Germany (E)				2.0	20.0	
Greece	30.0					
Ireland	187.5					
Italy	37.5			265.0	207	
Netherlands				201.0	549	
Norway	18.9	124.6		124.6	227	
Portugal		5.0		5.0	4.0	
Spain	260.0			273.4	8.8 <sup>(b)</sup>	
Sweden	155.0				2.5 <sup>(b)</sup>	
UK	1.0			100.7	16.1 <sup>(c)</sup>	
Others					449	
<b>W. Europe</b>	<b>841.3</b>	<b>605.5</b>	<b>39.0</b>	<b>2102.1</b>	<b>121.8</b>	<b>6538</b>
Bulgaria	31.0		1.7	600		200
Czechoslovakia	7.0		1.3	1.7		
Hungary				1.3		
Poland	144.0			125.4		370
Romania	15.0			10.0		10
Yugoslavia	75.0			87.4	8.7	280
<b>E. Europe</b>	<b>272</b>		<b>3.0</b>	<b>285.8</b>	<b>8.7</b>	<b>990</b>
Canada	1148.2	660.6		660.6		1829
Japan	131.8	640.6	90.2	730.8		2889
Turkey	39.4	17.4		17.4		50
USSR	810.0	700	100	800	NA	2500
US	288.3	253.3	124.1	377.4	93.5	1676
<b>World</b>	<b>7282.4</b>	<b>4442.8<sup>(d)</sup></b>	<b>370.3</b>	<b>7081.7</b>	<b>417</b>	<b>20463</b>

Zinc Source: [USBuMines 1991], Zinc Oxide: [UNIS 1989], Cadmium: [USBuMines 1994]

(a) Zn content

(b) 1987

(c) 1984

(d) 2268.6 = "undifferentiated". We assume this to be split in the same ratio as primary/secondary

The other viable strategy for reducing cadmium pollution is to cut back on primary zinc production/consumption of zinc itself. Here two complementary approaches suggest themselves. One is to discourage unnecessary uses of zinc by raising its price, via a severance tax on the mine output (or a corresponding tariff at the border). The other would be to

discourage certain purely dissipative uses of zinc by regulatory means. For instance, zinc-based white pigments, zinc "dry cells", and most zinc chemicals could be replaced quite easily by other materials. It is also likely that the use of zinc oxide as an accelerator in tire production could be replaced by some other chemicals.

**Goals of Public Policy:** Reduce import dependence for raw materials; reduce zinc, arsenic, sulfur and cadmium emissions from mining, smelting and refining zinc; reduce dissipative uses of zinc; encourage recycling of zinc; reduce dissipative uses of cadmium; encourage recycling of cadmium.

## 5.2. Zinc Sources & Uses

Zinc is slightly more abundant than copper (70 ppm in the earth's crust, vs. 60 ppm for copper). Cadmium is much scarcer than zinc (0.12 ppm in the earth's crust). Production of zinc ores, smelter output, zinc chemicals and cadmium are summarized for in *Table 5.1*. The world's biggest producers of ore and concentrate are Canada and Australia, followed by the former USSR, China and Peru. Europe produces relatively little ore, but smelter output is considerably larger than mine output, due to imports and secondary production.

Zinc metallurgy is comparatively straightforward (compared to copper). Zinc emissions from mining and milling operations have been estimated at 0.1 kg per metric ton (Mg) of zinc mined [MRI 1980]. Zinc emissions from primary metallurgical operations have been estimated at 60 kg/Mg of zinc for electrolytic plants, 80 kg/Mg of zinc for vertical retort plants and 170 kg/Mg of zinc for horizontal retort plants. Emissions of sulfur, arsenic, cadmium, copper and lead are also significant. In North American and European refineries, most of the sulfur is recovered, as in the case of copper.

Slab zinc (from refineries) is the starting point of all metallurgical uses. The metallurgical uses are: galvanizing (coating) of sheet iron and steel to provide enhanced corrosion resistance, accounting for 50% of slab zinc; zinc-based thin-walled (hollow) die castings for a variety of purposes, especially in the auto industry (21%); brass and bronze products (14%), and other uses (15%), including rolled zinc for "dry cells", weather stripping and lithographic plates. The zinc content of an average U.S.-made car (1991) was 18 kg, of which die-castings accounted for about 8.6 kg, galvanizing 8.1 kg and other uses (including rubber), 1.3 kg. This consumption pattern is probably similar in Europe.

A significant amount of zinc is consumed in non-metallic form. Processing stages are shown in *Figure 5.1*. A small amount of slab zinc is used in the manufacture of zinc chemicals, but zinc oxide is made directly from ore concentrate or from scrap (by the so-called French process). Zinc chloride ( $ZnCl_2$ ), is made from metal (either slab or secondary). Zinc sulfate ( $ZnSO_4$ ), or "white vitriol", is made either from ore or from secondary zinc.

The single most important zinc chemical is zinc oxide ( $ZnO$ ). Zinc oxide ( $ZnO$ ), "zinc white" is a white, insoluble powder that was once widely used as a pigment for paints. Today it is mainly used as an accelerator/activator for hardening rubber products (e.g. tires). Roughly,

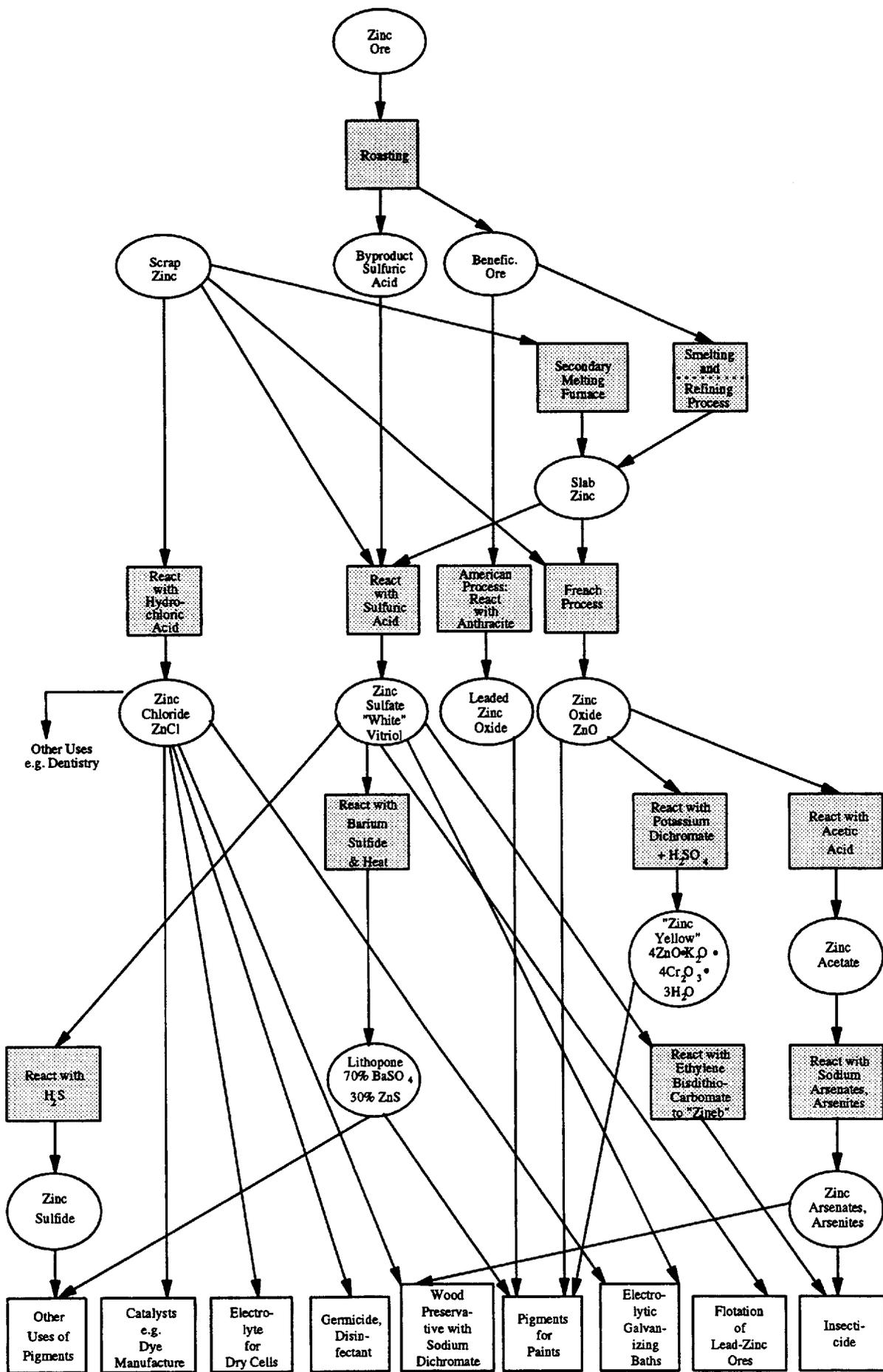


Figure 5.1. Zinc process-product flows

half of the output of lead-free zinc oxide has been used (since the early years of the twentieth century) as an activator for the vulcanizing rubber; it constitutes about 2% of the weight of a finished tire (See *Chapter 12, Tires*). Zinc oxide is dispersed to the environment by tire wear at the rate of 25 kg per million vehicle miles [Huntzicker & Friedlander 1975]. Because it is made directly from ore, the cadmium contamination of the ore is not removed and accompanies the zinc. As a consequence, tire wear is a significant source of cadmium dispersion into the environment. Consumption of zinc oxide in 1991 was as follows: rubber (58.6%), chemicals (21.2%), paints (4%), ceramics (3.1%), agriculture (19%) and other (12.5%).

Other major tonnage zinc chemicals include zinc chloride and zinc sulfate. Zinc chloride is used for vulcanizing rubber, in dry batteries as a mordant, for mercerizing cotton, and as a disinfectant. Zinc sulfate is used to manufacture the insecticide "Zineb" and in galvanizing by the electrolytic method. It is also a component of fertilizers and fungicides. Agricultural uses account for 65% of consumption in 1991. Zinc sulfide,  $ZnS \cdot H_2O$  is used as a pigment (in lithophone, a mixture of 70% barium sulfate and 30% zinc sulfide. Lithophone, in turn, has been largely displaced by titanium dioxide). It is also used for whitening rubber, for paper coating, and as the major component of phosphors. Zinc dithiophosphates are common additives to automotive motor oils. A typical zinc content for motor oil is 0.1% by weight [Huntzicker & Friedlander 1975]. This implies that as much as 3,800 ( $= 0.001 \times 45 \times 8.44 \times 10^6$ ) tonnes of zinc. In this case, too, a significant amount of associated cadmium contaminant is dispersed into the environment annually by the loss (by burning or dumping) of motor oil.

It is important to emphasize that until recently most uses of zinc, even metallurgical ones, were essentially dissipative (the major exception being brass/bronze). As in the case of cadmium, most zinc-containing products end in scrap iron/steel. Because of its volatility, the zinc is easily recoverable as baghouse dust. As recently as 1985, only 15% of this dust was reprocessed to recover zinc (and cadmium); the remainder went to landfills for disposal. At present, much more — perhaps over 50% — of the zinc in baghouse dust is recovered. There are six reprocessing plants in Japan, three in the U.S., one in Mexico, three in Germany, two in France, one each in Spain and Sweden. Zinc not recovered from secondary iron/steel works is presumably still disposed of landfills. In the latter case, an unknown but not insignificant amount of zinc may be leached by acidic surface water. A smaller fraction is vaporized and discharged to the atmosphere (where it condenses on dust particles). Major point sources of atmospheric zinc are smelters, hot dip galvanizing operations and waste incinerators. Other sources include tire dust, weathered paint, and auto exhaust (from burning of lube oil detergents) and incinerators. also, zinc is emitted by coal and residual oil combustion. Fly ash is of the order of 7.5ppm zinc (See *Chapter 12, Tires*).

### 5.3. Cadmium Sources & Uses

Cadmium is a very scarce element (0.1-0.2 ppm in the earth's crust), only slightly less scarce than silver (0.075 ppm) It is obtained primarily as a contaminant of zinc ore and thus as a by-product of zinc smelting. The Cd/Zn ratio varies; for purposes of estimating cadmium reserves, the U.S. Bureau of Mines uses the recovery ration 0.36% to zinc reserve data [USBuMines 1991 "Cadmium" p. 312]. World refinery production of cadmium was 20,673

tonnes in 1991. Japan was the biggest producer of refined metal, followed by the former USSR, Belgium and the U.S. See *Table 5.1*.

A number of techniques are used for cadmium recovery, depending on the method being used in the copper or zinc refinery. Efficiency of recovery is not especially high; the Bureau of Mines estimates 75% [USBuMines 1975]. About 4.4 kg of cadmium are typically recovered per metric ton of refined zinc. Unrecovered cadmium remains in tailings, slags or sludges, in the metallic zinc itself, or is emitted to the atmosphere during zinc smelting or refining. Emission controls at refineries have only been implemented since 1970 or so.

The ratio of cadmium recovery to zinc smelter production in all market economy countries from 1950 to 1989 has ranged from a high of 1:260 in 1960 to a low of 1:343 in 1950 and a more recent low of 1:341 in 1983 [Roskill 1990, Table 9]. In short, the relationship has been fairly stable, despite fairly significant changes in markets and technology.

**Table 5.2. Cadmium consumption patterns, tonnes/y**

<i>Use</i>	<i>West Germany</i> 1989 tonnes (%)	<i>United States</i> 1991 tonnes (%)	<i>1993</i> (%)	<i>Market Economy</i> 1988 tonnes (%)
Nickel-cadmium batteries	427 (48)	1,450 (45)	(65)	10,175 (55)
Pigments	282 (32)	520 (16)	(15)	3,700 (20)
Stabilizers	94 (11)	390 (12)	(12)	1,850 (10)
Electroplating	35 ( 4)	650 (20)	(7) <sup>a</sup>	1,850 (10)
Glass manufacturing	26 ( 3)			
Alloys	21 ( 2)		(5) <sup>b</sup>	555 (5)
Other	1 ( 0)	230 ( 7)		

*Sources: Germany [Enquete 1994]; U.S. [USBuMines 1991], Cadmium Association; Market Economies: [Roskill 1990]*

*a. Plating & coating b. Alloys & other*

Despite sharply declining use of cadmium for metal plating and in pigments, in recent years (due to environmental restrictions), demand has been relatively stable, though spot prices have fluctuated significantly. Usage varies somewhat from country to country, but the major uses at present are for rechargeable batteries, pigments, electroplating, stabilizers for plastic (PVC) and special alloys. See *Table 5.2*.

The use of cadmium in batteries, mainly rechargeable nickel-cadmium cells, has grown steadily since the 1960's. In 1970 it accounted for only 8% of consumption. It reached 37% on a worldwide basis by 1985, 50% in 1988 and 55% in 1989 (12,000 tonnes) [Roskill 1990, p. 214]. In Japan, this use is even more dominant, since Japan is the major producer of these batteries. Battery use accounted for 12% of Japanese consumption in 1970, 78% by 1986, and 91% in 1988, though the trend may have peaked temporarily [ibid p. 214]. Data for Europe is extremely scattered. For Germany, batteries accounted for 35% of demand in 1988 [ibid p. 207]. The only other country for which there is explicit data is the U.K. where batteries were included with "misc." uses at 17% in 1988 [ibid p. 211].

The biggest use of cadmium, historically, is for anti-corrosion protective electro-plating of iron and steel.<sup>2</sup> Cadmium is consumed in the electrolytic plating process as metallic ball anodes; cadmium oxide is added to plating baths, while cadmium chloride is the usual electrolyte [NMAB 1979]. An OECD study concluded that very little cadmium is lost to the environment from the electroplating process *per se* [OECD/ED 1974]. However this comforting conclusion is sharply disputed by others. In 1973, Ottinger [Ottinger *et al* 1973] estimated that up to 18% of the cadmium used in electroplating or nearly 500 Mg/yr was lost as a liquid, solid or sludge during the plating operation, mostly to sewers. In 1976, Yost re-estimated the loss to water at 49.4 Mg/yr [Battelle 1977]. Application of pollution abatement practices, presumably implemented since 1976, would have cut even this loss rate by over 90% in the last decade, with two-thirds of the formerly lost cadmium recovered for re-use and most of the remainder concentrated to sludge and shipped to landfills. Plating accounted for 29% of 1991 U.S. consumption [USBuMines 1991], 7% of Japanese consumption in 1988 [Roskill p. 208], 13% of U.K. consumption in 1988 [ibid p. 211] and 6% of German consumption in 1988 [ibid p. 207].

The second most important cadmium use category until the mid-60's was in pigments, based on cadmium sulfide and cadmium sulfo-selenide. Cadmium yellows (ZnS-CdS), and reds (CdSe-CdS and HgS-CdS) are exceptionally brilliant, stable in the presence of heat, light, moisture and oxygen, insoluble in water and most paint solvents, and modest in cost. These pigments are widely used in plastics, rubber, paints, enamels, and printing inks. Cadmium acetate is used to produce iridescent effects on porcelain and pottery ware, while cadmium nitrate imparts a reddish-yellow luster to glass and porcelain. Pigment uses have fluctuated considerably from year to year, but appear to be declining on the average since the 1960's. Still, pigments accounted for 16% of U.S. consumption in 1991 [USBuMines]. According to Roskill [ibid] pigments accounted for 5% of Japanese consumption and 26% of German consumption in 1988. Pigments and stabilizers were combined in U.K. statistics (58% in 1988). For the market economies as a whole, pigments continued to hold a 20-29% market share in the 1980's, despite increasingly tight environmental restrictions.

Organic cadmium salts (notably cadmium stearate and cadmium benzoate) have been used in significant quantities as stabilizers for clear polyvinyl chloride (PVC) plastic packaging material. Cadmium salts are generally used in combination with barium salts. Other metal salts (of zinc, aluminum and lead) are also used for this purpose. Apparently other stabilizers, including purely organic systems and tin-based organic compounds have partly, but not totally, displaced cadmium-based stabilizers since the early 1970's [NMAB 1979]. Use for this purpose peaked in the U.S. in 1971, and declined because of concern about cadmium in the environment. However, it has increased again since the mid-1980's to about 10% of total consumption in 1988 [Roskill 1990, p. 252].

The other important use of cadmium is metallurgical. Cadmium-nickel and cadmium-silver alloys (98.5% Cd) were introduced for high-speed, high pressure bearings in the 1930's. This use was continued into the 1950's, but has declined since [USBuMines annual]. Cadmium is a component of various low-melting alloys, including silver-brazing alloys (18-20% Cd) that are widely used in the electrical and electronics industries. Cadmium is also alloyed with silver in most electrical contacts. The most popular composition is 10% cadmium oxide, dispersed in silver. An alloy of cadmium (0.2%) with copper was introduced by the automobile industry in some 1969 models to improve the performance of copper radiators.

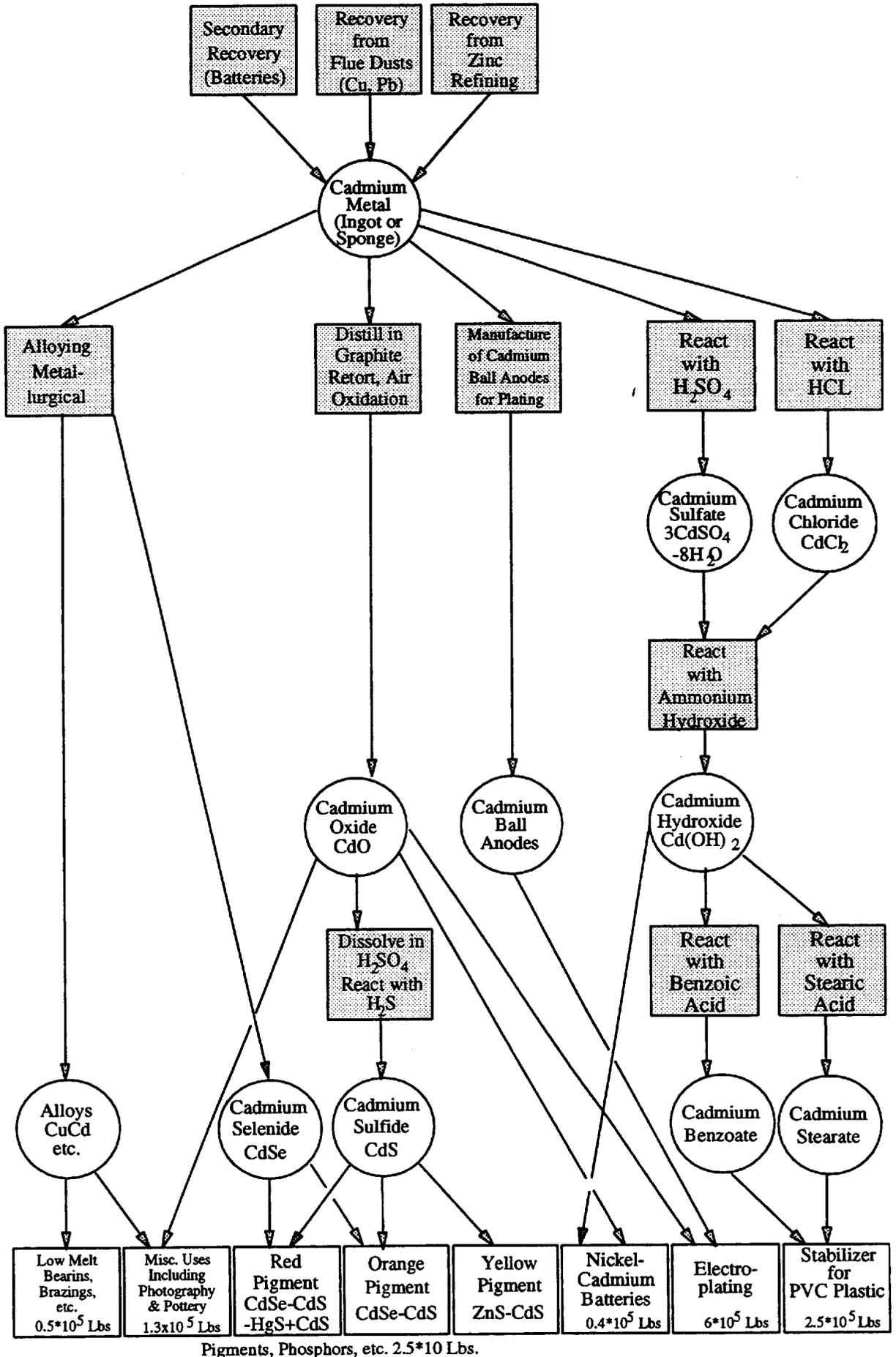


Figure 5.2. Cadmium process-product flows

It is not known how much of this alloy is used at present. Cadmium is alloyed with copper to increase strength and wear resistance (0.5% to 1.2%) Overall, metallurgical uses of cadmium have fluctuated around 3%-6% of total demand in market economies for the past two decades.

A graphical summary of cadmium process-product flows is shown in *Figure 5.2*. Virtually all uses of cadmium are inherently dissipative. Only about 5% is recycled (from batteries) in the U.S. We have no figures on recycling for Europe. In Germany, dealers will take back worn out batteries, but the recycling figure is also less than 10%, though battery recycling is quite feasible (batteries contain up to 19% cadmium by weight) [Enquete 1994]. In Europe some cadmium pigments are being recycled from yellow and red beer bottle cases [ibid]. There is a proposal by the Association of Window and Facade Manufacturers to take back and recycle cadmium stabilizers in PVC window frames, on a voluntary basis [ibid].

Much cadmium in the past was embodied in anti-corrosion plating or alloys, and some of this ends up in solid waste in landfills. The fate of cadmium plated or alloyed items once they are discarded is still in doubt. However, cadmium, even in metallic form, is currently regarded by EPA as a hazardous waste; even the presence of a few cadmium plated bolts or cadmium alloyed bearings can render an automobile carcass unsuitable as a feedstock for secondary steel production. When cadmium plated iron or steel items are remelted as scrap, some of the cadmium escapes into the atmosphere, as vapor or dust, while some is ultimately trapped in slags. Cadmium in silver-brazing or electrical contacts may escape into the environment by a similar route when scrap copper and brass containing equipment is remelted. Cadmium-containing pigments are likely to be disposed of in land fills or incinerated.

Currently very little cadmium is recycled, even from nickel-cadmium batteries, where there is no technical difficulty, only an economic and logistical problem of collection. This situation may be improved in the U.S. as a result of newly introduced (1994) legislation to encourage battery recycling. For the future, continued growth in the market for nickel-cadmium batteries, especially in larger sizes (e.g. for electric cars) would offer a relatively painless way to reduce cadmium emissions and increase recycling. The two French automobile companies, Renault and Peugeot, have both announced that they will introduce a small electric "city car" in the spring of 1995, to be powered by a nickel cadmium battery weighing 250 kg. These batteries would, most likely, be leased rather than sold, and would be 100% recycled. This is a promising development. One can hope that this trend will spread.

## **5.4. Zinc and Cadmium in the Environment**

It has been estimated that natural geological processes move about 330 KMT of zinc into the oceans each year, as compared to losses from mining alone of 4 MMT [Waldichuk 1977]. This represents an anthropogenic increase in zinc mobilization by a factor of 12. For airborne emissions, anthropogenic contributions have been estimated at 132 KMT (mostly from mining and smelting) vs. natural processes (volcanos, dust, fires, etc.) of 45 KMT, for a mobilization enhancement factor of 4 [Nriagu 1990].

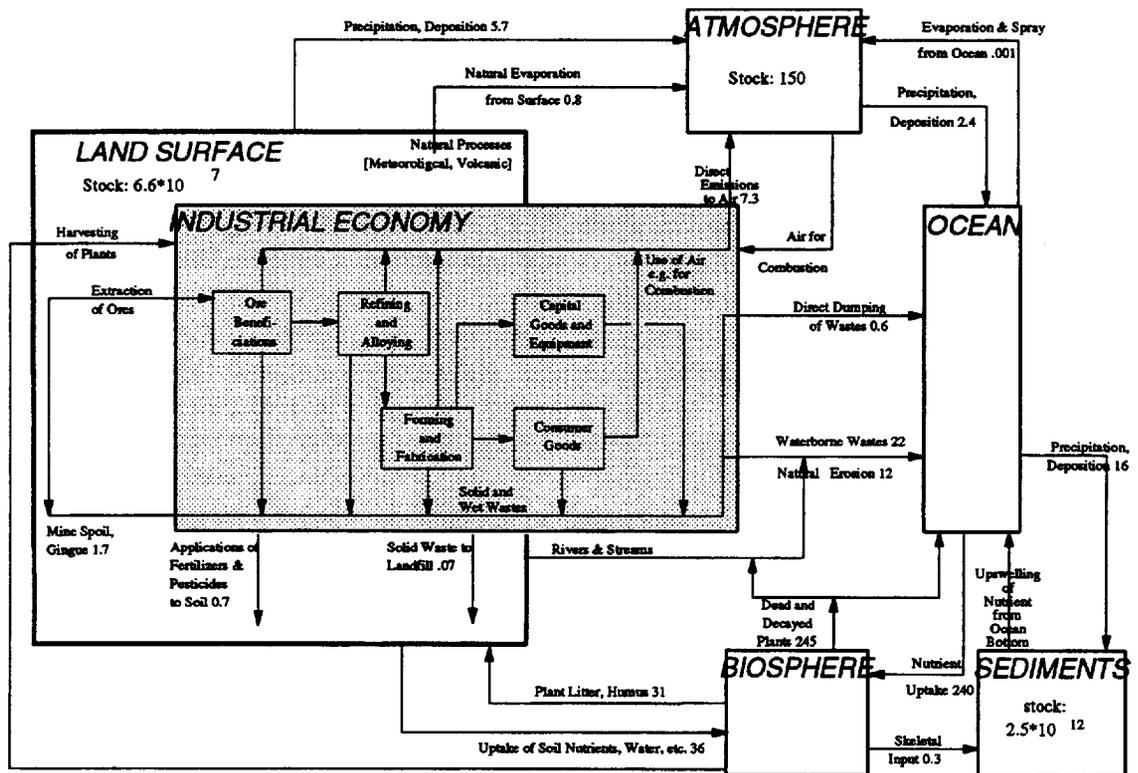


Figure 5.3. Global cadmium cycle c1980 (kMT)

In the case of cadmium, which is of greater concern, a global cadmium cycle (c. 1975) was compiled from various sources (see Figure 5.3.). Waterborne cadmium flux (to the oceans) from anthropogenic sources was about 20 KMT/y as compared to about 11 KMT from natural erosion and runoff processes, for a ratio of 2:1 and a mobilization enhancement factor of 3. In the case of airborne emissions, the corresponding figures are 7.6 KMT (again, mostly from smelting and mining) vs. 1.4 KMT [Nriagu 1990]. The mobilization enhancement factor for cadmium is over 6-fold. For 1975 Nriagu provided a detailed estimated breakdown of the sources of airborne cadmium emissions, as follows [ibid]:

zinc smelting & refining	2.8
copper smelting & refining	1.6
lead smelting & refining	0.2
cadmium processing	0.11
phosphate production	0.21
secondary n.f. metals	0.6
waste incineration	1.4
wood combustion	0.2
coal combustion	0.06
Other	0.1

The picture is complicated, however, by the fact that cadmium is readily cycled by atmospheric processes and by living organisms. Cadmium emitted to the atmosphere is redeposited via precipitation on land (6.4 KMT) and oceans (2.7 KMT). Annual cycling of cadmium in the marine biosphere is estimated to be 240 KMT, while terrestrial plants take up 36 KMT and recycle 31 KMT to the soil in plant litter and humus, and 5 KMT to rivers and streams [Ayres *et al* 1988].

With this perspective, it is clear that, while a large amount of biologically available cadmium has been moving around in the marine environment, a relatively small amount is being cycled by terrestrial plants where it can get into the human food chain. (Yet cadmium is taken up by plants, rather easily, precisely because of its chemical similarity to zinc, which is a necessary trace nutrient). To this small stock of circulating cadmium, phosphate fertilizers alone add 0.7 KMT, while atmospheric deposition via rainfall adds another 6.4 KMT. The buildup of biologically available cadmium is, moreover, not uniformly distributed over the land surface, but heavily concentrated in industrial areas, especially northwest Europe. Thus the growing concern in Germany, the Netherlands and Sweden is more than justified.

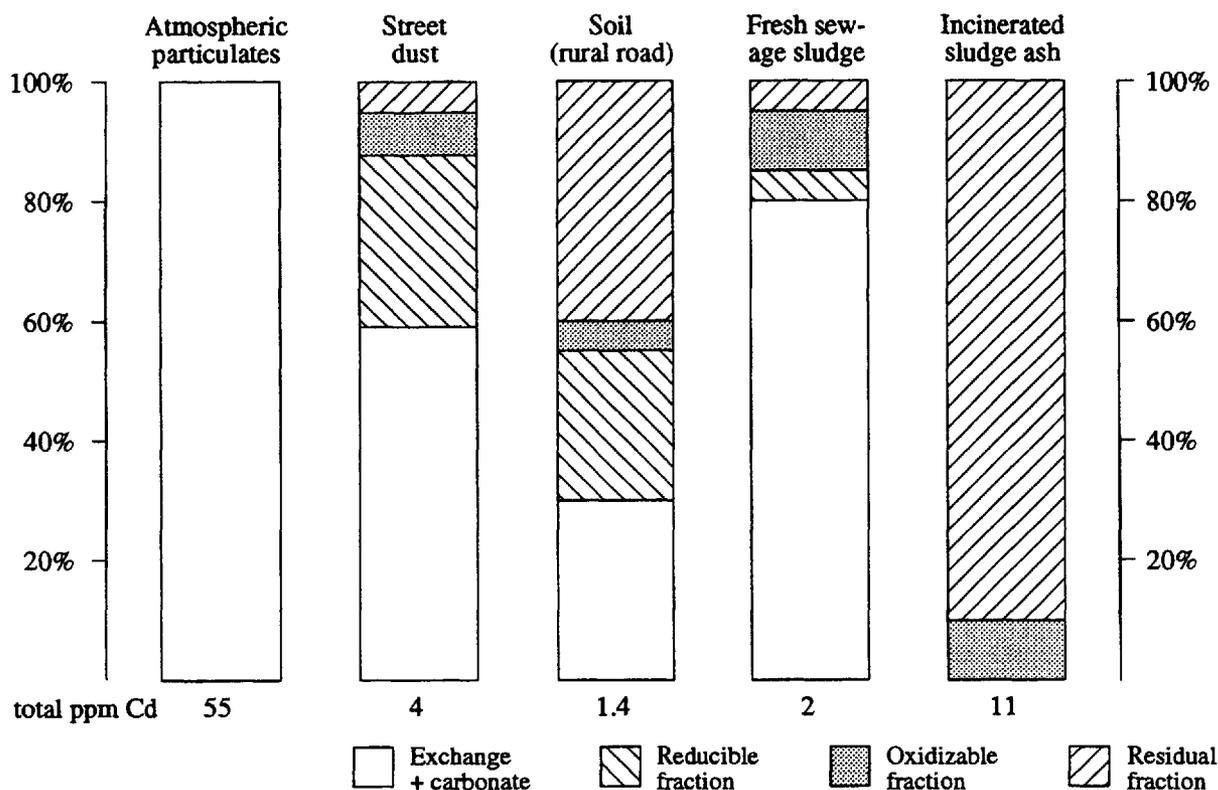


Figure 5.4. Mobility of cadmium in various environmental forms. Source: [Stigliani undated, from Lum et al 1982, Harrison et al 1981, Foerstner et al 1981, Fraser & Lum 1982]

It is important to distinguish the different cadmium-containing waste streams in terms of mobility. This issue has been investigated, particularly, by [Harrison et al 1981], [Lum et al 1982]; [Fraser & Lum 1983]; also [Stigliani undated]. Generally speaking, airborne cadmium particulates are 100% mobile; street dust and sewage sludge are 95% mobile; in rural soils 60% would be typical; incinerated sludge reduces the mobility to 10%. (Figure 5.4.)

The Netherlands is a densely populated and heavily industrialized country. It is also the unwilling recipient of many pollutants from other countries by way of the Rhine river (which can hardly be excluded from the ground water). Cadmium is one of the most worrisome. For soil, a cadmium content of 1 ppm defines it as contaminated. Calculations of cadmium buildup in Dutch soils are disquieting. Over the period 1960-1980, the average for Dutch agricultural soils was 3 ppm [Stigliani undated]. Based on emissions and mobility estimates undertaken by Dutch researchers and IIASA, cadmium content is expected to increase by

2010 to between 28 ppm (10% mobility assumption) and 44 ppm (60% assumed mobility) [ibid].

The likely effects of this buildup will be seen in kidney damage to people over 50 years of age, and bone damage to those most acutely affected. Data suggest that the margin of safety for cadmium intake through food is already approaching a factor of two for much of Europe and North America. A sharp increase in mobilizable cadmium in soils would have serious public health consequences. In conclusion, it is clear that dissipative uses of cadmium, which contribute to this growing threat, must be discouraged to the utmost, and recycling must be promoted.

## 5.5. Implications

It can be concluded that cadmium is already on the way to becoming a public health hazard in the Netherlands. Some other regions, at least, must also be approaching their limits in terms of cadmium "absorption" capacity. There are no feasible — even plausible — strategies to "clean up" cadmium-contaminated soils or sediments. The only thing that can be done is to reduce the rate of input to a level below the annual level of cadmium dispersal to the deep oceans or other environmental sinks. Then, wait patiently for the cadmium "overload" in the environment to fall. This means that we must focus on measures to reduce primary cadmium use, or — failing that — to reduce primary zinc use.

As regards the more direct approaches for reducing (dissipative) cadmium use, there are really two possibilities. The first is to use public policy to raise the price of cadmium *vis a vis* other competing metals (including zinc itself). A tax on cadmium at the zinc refinery would, however, tend to discourage cadmium recovery, leaving more unrecovered cadmium in tailings, slags, dusts and so on. A slightly cleverer approach would be to tax the *unrecovered* cadmium, being the difference between the cadmium content of the zinc ore and the cadmium recovered for sale. However this would also be counter-productive unless accompanied by an effective restriction on dissipative uses of the recovered cadmium. An outright ban on the use of cadmium-based pigments, cadmium-based stabilizers for plastics, and other such chemical uses should be considered. A ban on the use of zinc chemicals contaminated with cadmium (such as zinc oxide used in tire manufacturing) would also be a possibility.

Still, the major single use of cadmium, namely in rechargeable nickel-cadmium (nicad) batteries, should not be banned or even heavily taxed. What is needed is a much more effective encouragement to remanufacture or recycle these batteries. A returnable deposit of several cents on each battery is probably the answer. The money would be collected from battery purchasers at the point of sale and returned (plus a bonus) by the manufacturer to the retailer-collector. Many retailers would probably object to having to undertake this additional responsibility, but experience with returnable bottles and other such items suggests that the scheme would be effective if put into effect. As a very strong inducement, retailers could be *required* by their suppliers to collect and return a certain quota of batteries previously delivered as a condition of obtaining additional supplies.

Of course, the returned batteries would simply accumulate unless an effective remanufacturing or recycling system were also developed. This is a fairly straightforward task from the chemical and metallurgical perspective, since the cadmium-content of the batteries is significantly higher than the cadmium content of the original zinc ore, or even the zinc concentrate as it arrives at the refinery. The possibility of recovering zinc at the same time would be economically attractive, also. The major problem with implementing such a scheme is simply the lack of any existing incentive for manufacturers or retailers to do so. This would necessarily be the role of government.

The other general approach to reducing cadmium losses to the environment is to reduce the supply. This could be done by discouraging unnecessary uses of (primary) zinc. The obvious method for accomplishing this objective would be to tax primary zinc itself, either at the mine or at the refinery. The zinc content of imported materials and products would also have to be taxed as a tariff. The idea behind such a tax is to raise the price of primary zinc, both in absolute terms and *vis à vis* less harmful direct competitors. (The most obvious of the latter is secondary zinc). The most immediate impact would be to encourage more efficient recovery and recycling of secondary zinc, especially from galvanized sheet and zinc-based primary cells. (The latter could be collected and recycled by the same basic mechanism suggested above in connection with nicad batteries, namely a returnable deposit). To the extent that more zinc is recovered and recycled, less primary zinc would be needed and less cadmium would be produced as a by-product. Apart from reducing the cadmium load on the environment, increased recycling of zinc would also reduce overall energy consumption at least modestly.

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## Endnotes(5)

1. Some material in this chapter was adopted from Robert U. Ayres, Leslie W. Ayres and others *An Historical Reconstruction of Major Pollutant Levels in the Hudson-Raritan Basin 1800-1980* Technical Memorandum (NOS OMA 43), 3 Volumes, National Oceanic and Atmospheric Administration, Rockville, Md., Oct. 1988

2. Cadmium and zinc are direct competitors for this purpose. In fact zinc provides slightly better corrosion protection. Cadmium has always been more expensive than zinc, but the plating process for cadmium was more reliable and controllable until improvements in the zinc electroplating (galvanizing) process began to strongly favor zinc [See NMAB 1979].

**CHAPTER 5. ZINC AND CADMIUM** . . . . . 62

    5.1. Summary . . . . . 62

        Goals of Public Policy . . . . . 64

    5.2. Zinc Sources & Uses . . . . . 64

    5.3. Cadmium Sources & Uses . . . . . 66

    5.4. Zinc and Cadmium in the Environment . . . . . 70

    5.5. Implications . . . . . 73

    References(5) . . . . . 74

    Endnotes(5) . . . . . 75

Figure 5.1. Zinc process-product flows . . . . . 65

Figure 5.2. Cadmium process-product flows . . . . . 69

Figure 5.3. Global cadmium cycle c1980 (kMT) . . . . . 71

Figure 5.4. Mobility of cadmium in various environmental forms. Source: [Stigliani undated, from Lum et al 1982, Harrison et al 1981, Foerstner et al 1981, Fraser & Lum 1982] . . . . . 72

Table 5.1. Zinc & cadmium production 1991 (kMT) . . . . . 63

Table 5.2. Cadmium consumption patterns, tonnes/y . . . . . 67