A. Robertson

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

NOAA Technical Memorandum NOS OMA 43

An Historical Reconstruction of Major Pollutant Levels in the Hudson-Raritan Basin: 1880-1980

VOLUME II
Heavy Metals and Fossil Fuels

Rockville, Maryland
October 1988

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National Ocean Service

Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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NOTICE

An Historical Reconstruction of Major Pollutant Levels in the Hudson-Raritan Basin:
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March, 1985
(Revised May, 1988)

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1. Introduction to Volume II: Metals

This volume covers the sources, production processes, consumptive uses of and environmental emissions of eight heavy metals (silver, arsenic, cadmium, chromium, copper, mercury, lead, zinc).

Data on production and consumption was mostly obtained from US Bureau of Mines publications, *Minerals Yearbooks* for 1924 through 1983 and its predecessor series *Mineral Resources* for 1883 through 1913 [USBM annual]. These reports were the primary source for metal production/ consumption data in *Historical Statistics of the United States* [Census 75]. The *Census of Manufactures* for 1900 [Census 00] included a great deal of data, especially on regional activity, that was absent from earlier and later versions. We have also made extensive use of the Bureau of Mines *Mineral Facts and Problems* for 1956, 1960, 1965, 1970, 1975, 1980 [USBM 75 etc.]. A supplementary source of data for non-ferrous metals was the Amercan Bureau of Metal Statistics [ABMS annual]

Use data for metals can be found in all of the above, especially since WWII. Use data in prior years is sporadic. During the late 1960's the National Materials Advisory Board published a series of *Trends In Usage* reports for minor strategic metals, including silver, chromium, cadmium and mercury [NMAB various].

Specific uses of arsenic, mercury, lead, chromium, copper, and zinc in pesticides and herbicides is also available from publications of the US Tariff Commission (*Synthetic Organic Chemicals*, various editions between the 1920's and 1980 [USTC annual] and annual publications of the US Department of Agriculture (USDA), especially *Agricultural Statistics*, 1936, 1940, 1942, 1943, 1950, 1959, 1961,1970, 1975, 1980 [USDA annual]. The USDA undertook major surveys of pesticide use by farmers in 1941, 1952, 1958, 1964, 1966, 1971, 1976. The first was extensively used by Shepard [Shepard 51]. The 1952 and 1958 surveys were published in USDA Economic Research Service *Statistical Bulletin No. 314*; the 1964, 1966, 1971 and 1976 data are given in *Agricultural Economic Reports* [USDA 68, 68a, 71, 73, 80]. County data on pesticide use can be found in *Agricultural Census* reports for 1964, 1969, 1974, 1978. The history of pesticide use prior to WWII is also covered by Roark [Roark 38] and Whorton [Whorton 74].

General sources on metallurgical processes of copper and lead are [ANL 80; AD Little 76-xiv; Hofman & Hayward 24; Hofman 18; Newton & Wilson 42]. General sources on chemical processes are [Rao &

Sittig 73; Lowenbach & Schlesinger 79; Faith, Keyes & Clarke 75]. Histories of the copper industry include [Marcosson 49] and [Navin 78].

Environmental emissions of metals from industrial processes have been studied primarily by EPA since the late 1960's. A number of early surveys for particular metals were carried out by W.E. Davis Associates [WEDavis 71, 72 & 80]. Later reports that have been particularly valuable include the following: arsenic [Davidson et al 78; Lowenbach & Schlesinger 79], cadmium [Konz & Walker ??; Goeller et al 72; Davidson et al 78; GCA 81], chromium [GCA 73], copper [PEDCo 80, chapter 29; AD Little 76-xiv], mercury [EPA 71; URS 75], lead [Drill et al 79; Davidson et al 78; Watson & Brooks 79; PEDCo 80, chapter 27; EPA 84], and zinc [Davidson et al 78, MRI 80].

Emissions from coal combustion are surveyed in [Torrey 78; Green 82; Davison et al 74; Lowry 63]. Data on combustion emission control are given in [Green 82; EPRI 82; Chow & Malbetsch 84; Carlton-Jones 74; Welch 33; EB 55 *smoke*; ConEd 84]. A series of comprehensive studies of environmental health problems associated with metals has been carried out by the National Academy of Sciences (NAS), National Research Council (NRC), and by J.O. Nriagu. These include arsenic [NRC 77a], cadmium [Nriagu 80a], copper [Nriagu 80; NRC 77c], lead [NAS 80; Nriagu 78], and zinc [Nriagu 80z].

2. Anthropogenic Silver Sources and Flows

Silver is now mined only in the western states of the U.S., although in the 19th century there were some small mines in the southern Appalachian mountains. About two thirds of silver output is obtained from copper and zinc ores, with the remaining third from silver ores [USBM 75]. U.S. mine production is tabulated in Table 2-1.

Table 2-1: U.S. Silver Production & Consumption (tonnes)

Yr	Mine Production	Refinery Production from Domestic Ores	Imports Excluding Coinage	Secondary Production	Total US Supply	Exports Excluding Coinage	Total US Demand	Net Consumption Industry & Arts
1880	943.0							
1885	1211.8							
1890	1693.5							
1895	1728.9							
1900	1726.6							
1905	1719.6							
1910	1822.2							
1915	2256.1							
1920	1765.9							
1925	2010.8							
1930	1362.8							
1935	1474.3							463.2
1940	1976.0							1761.2
1945	1018.3	967.2						3420.8
1950	1209.6	1220.7						3140.1
1955	1173.2	1164.8	4232.9			166.4		3040.7
1960	1043.0	1144.6	5162.1			85.0		3137.7
1965	1165.7	1179.6	1766.7	1076.2	13269.8	2095.5	9780.0	4508.3
1970	1234.4	1311.2	2042.0	1624.8	12061.3	1767.7	4713.4	4329.9
1975	1111.5	1076.3	2545.7	1492.3	10190.1	617.2	5351.7	5313.9
1980	1185.2	1290.7	2851.5	1314.1	9652.2	1195.5	4348.3	4215.3
Sources:	MIN YB & Hist Stat	MIN YB	MIN YB 'General' to 1972 'For Consumption' 1973 on	MIN F&P	MIN F&P	MIN YB	MIN F&P	MIN YB

All values except 1880 are five year averages centered on year shown
Net Industrial Consumption not available prior to 1932

All commercially important silver minerals at present are sulfides. A number of concentration/reduction processes have been used in the past, including several variants that utilized mercury to amalagamate native silver and (gold). Around 1900 the cyanidation process was introduced. Soon afterward this was replaced by the current flotation and smelting process. Silver in lead ores is separated from the lead only after smelting, by the Parkes process.[1] In the case of copper ores, the silver is carried away as an impurity of the blister copper and is separated in the electrolytic refinery as anode slime. This is collected and smelted to recover the silver bullion which is dissolved by nitric acid and finally refined electolytically.

Both lead and copper have been refined in the New York area (mainly at Laurel Hill, Queens, NY, and Perth Amboy and Carteret, NJ). The Anaconda Copper Co. (Raritan works) and the American Smelting and Refining Co. (ASARCO) both operated silver recovery units. The U.S. Mint also operated a silver bullion refinery in Newark NJ until 1968 [Navin 78]. Trace amounts of silver may have been discharged into the waterborne wastes from these plants, mainly in past decades. Silver can also be lost in electroplating operations. The silverware and silver-plating industry is partly located in the northern NJ, NY area. There are six secondary silver processing plants in NJ and six in NY of a total of 44 such plants nationwide [EPA 83].

Major silver chemicals are as follows:

Silver bromide, AgBr
is the major photosensitive component of photographic film.

Silver chloride, AgCl
is used in silver plating solutions. It is also a component of some photographic films. In crystalline form, it is also used for radar screens.

Silver cyanide, AgCN
is widely used in silver plating baths.

Silver iodide, AgI
is used in small amounts to increase the light sensitivity (speed) of photographic film.

Silver nitrate, $AgNO_3$
is the major intermediate form of silver, because of its solubility. It was used for silvering mirrors, for silver plating, in medicine, to make indelible inks, and to manufacture other silver chemicals.

Silver potassium cyanide, $KAg(CN)_2$
is used in silver plating.

Silver sulfide, AG_2S
is used for inlaying in jewelry and decorative metal work. It is also used for self-resetting circuit breakers.

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[1] In this process zinc is stirred into the crude molten lead, which is allowed to cool. The zinc floats to the top, carrying most of the silver and all the gold with it. The zinc "crust" is then skimmed off and retorted to recover the zinc for reuse. Lead impurities oxidize in a cupola to litharge and the remainder is a silver/gold alloy known as dore metal.

Until demonetization the major uses of silver were:

- coinage
- sterling silverware, silverplate and jewelry
- photography

Other significant uses include:

- Electrical contacts (alloyed with cadmium)
- Soldering and brazing alloys (alloyed with cadmium)
- Silver-zinc and silver-cadmium batteries
- Catalysts
- Dental alloys
- Mirrors, bearings, pharmaceuticals, ceramic colorants, etc.

Total consumption is given in Table 2-1. Breakdown by use category is shown in Tables 2-2 and 2-3.

Table 2-2: Summary of U.S. Silver Consumption (tonnes)

	Gross Consumption Industry & Arts	Gross Consumption Coinage	Gross Consumption	Secondary Returned from Industrial Use
1880				
1900				
1920				
1925	1238.8			
1930	1089.9			
1935	1227.6			764.6
1940	2485.1			723.8
1945	4809.1			1388.3
1950	4157.2			1017.1
1955	3840.0	1167.6	5007.6	799.3
1960	4678.7	1609.9	6288.6	1541.0
1965	5674.0	4556.8	9791.4	1541.9
1970	4329.6	382.4	4712.1	1624.8
1975	5245.9	37.8	5283.8	1492.3
1980	4214.8	14.4	4229.1	1314.1
		na prior to 1959	na prior to 1959	

Values are five year averages centered on year shown except 1925=single year & 1930=average 1930,1931

Source: [USBM annual]

Table 2-3: Details of U.S. Industrial Silver Consumption (tonnes)

	Silver-ware (Electro-plate & Sterling)	Jewelry & Arts	Photo-graphy	Refrig-eration & Appli-ances (Brazing Alloys& Solders)	Bat-teries	Electri-cal Equip & Compo-nents (Contacts & Conduc-tors)	Coins, Medal-lions, etc.	Cata-lysts	Other
1880									
1900									
1920									
1940									
1942	1057.5	513.2	609.6	329.7		289.3	217.7		1070.6
1945									
1950									
1955									
1960									
1965	1542.7	185.6	1514.7	630.4	366.0	907.2			298.6
1970	1119.7	130.0	1215.5	503.9	171.1	852.2	220.8	79.3	261.3
1975	1022.7	265.6	1598.1	431.7	136.9	1009.6	380.7	200.9	199.7
1980	530.3	182.7	1797.0	296.3	158.6	921.4	114.3	160.2	183.5
					included in elec-trical in 1940		included in other cate-gories in 1965	included in "Other" category prior to 1970	

Category change after 1970. New categories shown in parentheses where different.

Source: [USBM 75]

Except for sterling silverware, plateware, jewelry and coinage, the uses are largely dissipative, although some spent silver batteries and wastes from film processing facilities can be recycled. This is more common now that real silver prices have risen well above the old (1967) monetary value of $1.30/oz.

Consumptive uses of metallic silver have included solders, brazes, plated bearing surfaces, electrical contacts, and silver gauze catalysts, silver impregnated glass used for protective spectacles. Metallic silver is relatively unreactive except in the presence of sulfur, and most silver salts are quite insoluble. Chemical uses include pharmaceuticals (especially silver nitrate) which is used to treat warts, boils, bites, small growths, ophthalmia, gastirc ulcers, gonorrhea and chronic dysentery [Shepard 51]. Silver chemicals are also used in batteries, and photographic films. By far the most important chemical use today is in photography, with silver based batteries and catalysts distant runners up.[2] An important dissipative use of silver before WWII was in the manufacture of mirrors [EB 55 *Mirror*]. Chemically deposited silver replaced the older mercury-tin amalgam towards the end of the 19th century (beginning about 1860). It was largely replaced, in turn, by aluminum or aluminum/chromium, deposited in a vacuum, beginning in the early 1930's.

Photographic film is a multilayer material consisting of a colloidal dispersion of silver halide (chloride, bromide, chloro-bromide or iodide) grains in a special gelatin that performs the functions of mechanical binder, and sensitizer. The gelatin is usually supported by a paper backing. The manufacturing process is extremely complex and many of the details are proprietary. However, the starting point is a solution of sodium or potassium halides and gelatine. To this is added silver nitrate ($AgNO_3$) and ammonia are added at 40°C-50°C and the silver halides grains are precipitated under suitable conditions. Typical inputs for the manufacture of 1000 m^2 of film would be as follows [Shreve 56]:

Table 2-4: Inputs to Film Manufacturing (kg)

potassium bromide (KBr)	10 kg
potassium iodide (KI)	0.25
silver nitrate ($AgNO_3$)	9
gelatin	36
cellulose acetate	200
glycerine	20
Total	275

Solvents (ethyl alcohol and acetone) are recovered. Very little silver is lost in film manufacturing [Shreve 56].

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[2] Important chemical processes (mostly partial oxidation) utilizing silver-based catalysts include the following:

- acetaldehyde from ethanol
- acetone from isopropanol
- acrylonitrile from propylene
- ethylene oxide from ethylene
- formaldehyde from methanol

Silver use for catalytic purposes apparently peaked in 1976 or 1977 at a level of 9 million oz. per year (net). It would appear that net consumption, in this case, is tantamount to loss.

In the sensitized but unexposed film there are tiny activated centers of silver sulfide (Ag_2S) created by a reaction between the halides and sulfur-containing compounds (such as allyl iso-thiocyanate) in the gelatin. When the film is exposed to light, the Ag_2S molecules within the silver halide grains liberate a free silver atom the reaction

$$Ag_2S + \text{photon} \dashrightarrow AgS + Ag$$

and the presence of free silver nuclei constitutes the "latent image". The process of developing the latent image into a visible image involves a chemical reduction of the silver halide grains with silver nuclei in them to metallic silver, but leaving the grains without such nuclei unaffected. A typical developing agent would be ferrous oxalabe (FeC_2O_4) or sodium sulfite (Na_2SO_3).

The final step is to fix the visible image and render it permanent by dissolving away the unreacted silver halides. Evidently both the developed film and the fixing solution or 'hypo', which typically includes a silver halide solvent (sodium or ammonium thiosulfate), and other preservatives and hardeners.

In the "black and white" era much of the developing was done in small laboratories and significant quantities of silver-containing chemicals were discarded. Color film was, and is, more likely to be processed in a centralized facility where silver recovery is practicable. The movie and publishing industries are major users of film, and much of this is recycled in small 'film stripping' facilities to recover silver. Thus silver loss in photography has not by any means been proportional to total film production. However, consumptive use has ranged around 30% of net industrial consumption of silver since the 1950's. It rose from 19.6 million oz. in 1942 and around 27 million oz. in 1958 to a high of 66 million oz. in 1979 [USBM annual].

Breakdowns of silver use prior to 1942 have not been uncovered, although data on total industrial consumption goes back to 1930. Our estimating procedure can be outlined briefly as follows. It is known that the major "industrial" usage of silver, apart from photography, was in the manufacture of sterling silver tableware (mainly in Providence, RI), jewelry and silverplate. In 1942 these uses alone accounted for 50 million oz., out of a total of over 131 million oz. used in that year of rearmament. It seems reasonable to assume that the 1942 consumption for silverware and jewelry was equal to the 1929 consumption for the same purposes, but that consumption of silver for these luxury items dropped sharply to a low of 13,000,000 oz. in the worst year of the depression (1933). This assumption is roughly consistent with data on the total output of the combined "jewelry, silverware, clocks and watches" sectors, which had an output of $403 million in 1929 but only $108 million in 1933, rising again to $273 million in 1937 (the last year for which data was collected in this form by the U.S. Census [Census 75].

It can be assumed that consumption of silver for photographic film also declined from 1929 to 1933, though by a much smaller percentage since the use of cameras by the public was rapidly growing. Summarizing, we estimate that total industrial use of silver in 1929 must have been close to 72 million oz., of which roughly 11 million might have been used in film manufacturing. In 1933, the 13 million assumed (above) for silverware and jewelry plus 8 million for film and 8 million for all other uses (including brazing, alloying, electrical contacts, mirrors, pharmaceuticals, and dentistry) would account for actual consumption of 29.3 million oz. in that year. Extrapolating back to 1919, we conjecture that about 33 million oz. was consumed, of which 4 million was used for photographic purposes.

Silver losses to the environment are probably mostly attributable losses in film developing (especially in smaller facilities) and losses via the disposal of used film in refuse, to landfills and incinerators. Use and disposition of other silver-based products such as mirrors, batteries, solders, brazes, and electronic equipment can be considered to be secondary sources. Silver is also dispersed into the environment via the combustion of coal and oil.

3. Anthropogenic Arsenic Sources and Flows

Arsenic is a byproduct of the processing of copper ores in the U.S. (Montana, Utah and Arizona) and various copper, zinc, lead and gold ores elsewhere in the world. About 15% of all commercial copper, zinc, lead and uranium ores are classed as arsenical, with an average Cu/As ratio of 50:1 (In non-arsenical ores the ratio is 500:1). In arsenical ore districts, mine wastes contain about 81 ppm As, which accounts for 40% of the arsenic orginally in the ores. In non-arsenical ores the mine wastes would average about 8 ppm. Emissions to water can occur from mining/milling operations. One zinc mine operated (until recently) in Ogdensburg (Sussex Cy) NJ on a tributary of the Hudson River. The mine yielded 29,000 tonnes of recoverable zinc in 1980. On the average 1.2 kg of arsenic is emitted to water per metric ton (Mg) of zinc mined, which implies total emissions (to the Hudson) of about 350 Mg (As) per year [NRC 77a].

In smelters, arsenic is normally allowed to remain in the concentrator tailings, since it has a low commercial value. It is recovered (if at all) at copper smelters[3] in a preliminary roasting/sublimation stage, where there are also significant losses to slags and flue dusts. Primary smelter emissions of arsenic to the air in 1979 were estimated as 1.5 kg/Mg of copper smelted [OECD/ED 74a] in the U.S., or 1500 Mg in 1980, of which none were in the Hudson-Raritan basin. Most of the arsenic in the ore is retained in slag, which is typically dumped on land. It happens that a number of copper smelters and a lead smelter to process imported ores were at one time located in Queens, NY and near Raritan Bay [Navin 78]. These refineries have unquestionably constituted major point-sources of atmospheric arsenic emissions in the past. Electrolytic copper refineries also release some arsenic directly to water (spent electrolyte). For purposes of an initial estimate, we can assume that arsenic emissions from these .smelters were in proportion to smelter output during the years they were operational. The possibilty of arsenic leaching from old slag heaps in areas of significant rainfall (e.g. the eastern U.S.) has not been investigated. It must be recognized, in any case, that arsenic emissions at non- ferrous metal smelters vary. widely, depending both on the composition of the ore and on the design of the smelter. Use of average figures is, therefore risky.

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[3] Since 1973 only one U.S. smelter recovers arsenic commercially (ASARCO, at Tacoma, WA). This plant processes arsenical ores and flue dust from other U.S. smelters.

Eastern coals range from 8.3 to 10 ppm arsenic [Torrey 78; NRC 77a]. While some of this is presently recaptured with fly ash by electrostatic precipitators, a significant percentage (35% to 60%) may escape, either as vapor or very fine particulates. In the past, much more coal was burned in the NY area than is now the case, and fly ash control was incomplete until the late 1960's. Thus coal-related arsenic emissions were much greater in the past than currently. Iron ore contains arsenic, but insignificant quantities are lost during iron/steel production. Almost all of it is embodied as a minor impurity in iron/steel products. Most arsenical solid wastes from iron/steel mills and foundries (such as flue dust, fly ash and slags) are insoluble and environmentally immobile. Although quite large annual tonnages of arsenic are involved (~100,000 tons/year in the U.S.) these contribute little to environmental hazard. Total atmospheric emissions of arsenic from ferrousmetallurgical smelting/refining operations in the U.S. have been estimated at 2230 Mg/year in 1968 [NRC 77a], of which virtually none was in the Hudson-Raritan basin. Small amounts of arsenic are also emitted in phosphate rock processing (of which none is in the Hudson-Raritan basin) and in phosphate fertilizer. However, the Hudson-Raritan basin had significant iron and steel operations in the late 19th and early 20th centuries.

Arsenic production and primary consumption figures are shown in Table 3-1. On the average, more than half of the arsenic consumed in the U.S. over the past century has been imported. Arsenic is processed into a number of chemical forms and into a small amount of metallic arsenic, usually starting from the intermediate form arsenic trioxide, AS_2O_3, which is 0.757 arsenic by weight. The major processing stages are shown graphically in Figure 3-1 [Lowenbach & Schlesinger 79]. Data on consumption of large tonnage arsenicals is given in Table 3-2.

Arsenic (as "Paris green") was introduced as an insecticide in 1867 to fight the Colorado potato beetle and other insect pests. Lead arsenate was introduced in 1892 to fight the gypsy moth and the codling moth. Calcium arsenate was developed to help control pests of cotton, especially the boll weevil [Whorton 74]. Other major 19th century uses of arsenic were primarily as coloring agents, and mordants (fixatives) for dyes. Paris green and Scheele's green were widely used pigments [Coates, Fabian & McDonald 81]. Arsenic was used in manufacturing fuchsia (bluish-red), magenta, safranin (red), some analin maroons and browns. It was used in fireworks. It was also used in tanning, as a depilatory (to loosen hair) and as a preservative, especially for furs. Other uses were in "health tonics", such as Fowler's solution (ibid).

Table 3-1: U.S. Arsenic Production & Consumption (1000 tonnes)

	Total US Sales White Arsenic AS2 O3	Total US Production White Arsenic AS2 O3	Imports for Consump. White Arsenic AS2 O3	Exports White Arsenic et al	Apparent Consump. (Sales+ IMP-EXP) White Arsenic AS2 O3	Imports for Consump. All Forms Arsenic	Exports Total Arsenic	Apparent Consump. (Sales+ IMP-EXP) All Forms of Arsenic	Primary Demand Contained Arsenic
1880		0		0	1.234	1.234	0	1.234	
1885		0		0	1.933	1.933	0	1.933	
1890		0		0	3.138	3.138	0	3.138	
1895		0		0	3.011	3.011	0	3.011	
1900		0		0	3.801	3.501	0	3.801	
1905		0.706		0	4.437	3.732	0	4.437	
1910	2.350	2.038	1.927	0	4.419	4.425	0	6.055	
1915	4.503	4.503	1.227		5.730	3.203	0.017	7.689	
1920	7.016	5.994	2.309		9.325	5.651	0.021	12.658	
1925	11.686	11.918	8.811		20.497	9.392		21.078	
1930	12.700	14.091	8.973	1.542	21.056	9.349	3.279	20.738	
1935	13.301	12.733	13.900	1.579	25.622	14.403	3.937	23.766	
1940	22.636	22.711	11.881	1.670	32.847	12.470	5.527	29.579	
1945	22.123	21.883	12.154	1.313	32.964	12.436	4.425	30.133	
1950	11.988	13.893	8.674	0	20.662	9.028	2.564	18.453	
1955	12.006	10.435	6.050	0	18.056	6.257	1.545	16.718	14.356
1960	9.916	10.440	10.943	0	21.766	11.176	0.989	17.894	17.336
1965		7.394	18.529	0	24.730	19.013		25.062	22.205
1970		8.183	16.882	0	25.065	17.443		25.626	18.762
1975		6.954	8.980	0	15.935	9.850		16.804	16.852
1980		2.306	12.739	0	18.474	13.907		19.669	13.509
	(a)	(b)			(c)	(d)	(e)	(f)	

(a) Includes processed output of imported AsO_3 ore.

(b) [USBM annual] through 1953 ("Crude plus Refined"),
[USBM 75] from 1954 ("Total Refinery")

(c) Estimated 1959-1964 and 1980-1982. Production used 1880-1909 and 1965-1979.

(d) General Imports used 1880-1909. Sum of detail used from 1913 on.

(e) Sum of detail from 1928 on. Estimated 1943

(f) Estimated 1959-1964 and 1980-1982. Production used 1880-1909 and 1965-1979.

All values are five year averages centered on the named year

Source: [USBM annual]

There have been some major shifts in usage since the 19th century although all the newer uses are still dissipative. The second major new use of arsenic after 1900 was as a weed-killer for railroad rights of way and similar applications. It was also widely used as sheep and cattle dip to kill ticks and other

Table 3-2: U.S. Consumption of Major Arsenicals (tonnes)

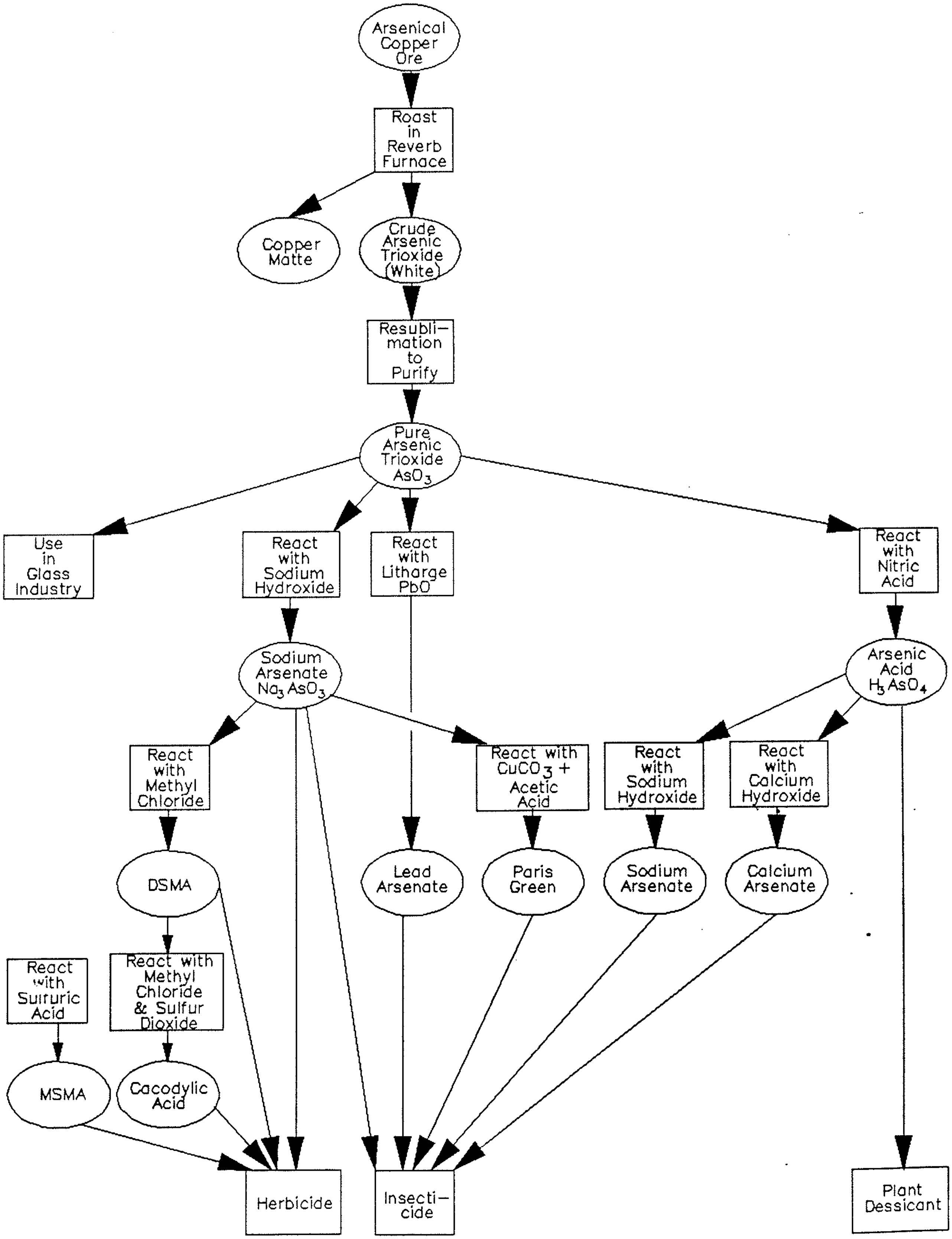
	Apparent Supply (Prod+ Imp-Exp) Calcium Arsenate Insecticide	Apparent Supply (Prod+ Imp-Exp) Lead Arsenate Insecticide	Apparent Supply (Prod+ Imp-Exp) Other Arsenic Insecticides	Wood Preserv. Consump. Compound Arsenic Total	Wood Preserv. Consump. N.E.C.	FCAP FluorChrome Arsenate Phenol (Wolman Salts)	CCA Chromated Copper Arsenate
1905			59				
1910			77				
1915			1617				
1919	1361	5216	3340				
1924	18168	8203	2577				
1930			1314				
1935	14703	28236	901				
1940	21855	27988	1809	727	109	672	
1945	18276	28363	2253	471	13	464	
1950	10688	10529		607		607	
1955	4468	5643		1493	707	920	
1960	5268	3908		2300	1143	1164	
1965		2114		3445	1693	1880	1057
1970	795	2355		4780	469	1386	2924
1975	590	1790		7726	576	776	6806
1980				16422		102	16023

Source: [USBM annual], [USBM 75]

All values are five year averages centered on year shown, but data are sparse. 1919= single year, 1924=1923 & 1924

Average 1979-1981 use of ACA (Ammoniated Copper Arsenate) = 498 metric tons

FIGURE 3-1: Arsenic Process-Product Flows



parasites. Insecticide use grew rapidly in the 1920's, and remained high for three decades, but declined after the introduction of organic pesticides after WWII [Roark 38; Whorton 74]. Herbicides and wood preservatives have been most important in recent years [USBM annual]. The major arsenical chemicals are as follows [USBM 75; Shepard 51]:

Calcium Arsenate, $Ca_3(AsO_4)_2$
was used primarily (~75%) for cotton bollweevils, cotton bollworms and white fringed beetles mainly in the southern and southwestern states (Table 3-3). About 25% was used to fight pests of potatoes, tomatoes and other vegetables grown in the mid-Atlantic states. No longer important. Toxicity: 150.[4]

Lead Arsenates, $PbHAsO_4$; $Pb_3(AsO_4)_23$; $Pb_4(PbOH)(AsO4)_3$; $Pb_5(PbOH)_2(AsO4)_4$
were used primarily (~66%) for controlling codling moths, a pest of apple and other fruit trees; also used against moths, Japanese beetle grubs, and other pests of fruit trees, shade trees and home gardens, and sometimes used to control pests of potatoes and vegetables. Many of these uses were in the eastern and northwestern U.S. The most intensive uses were in orchards [Neal et al 41]. Some areas in the Pacific Northwest apple orchards accumulated as much as 1400 lbs of arsenic trioxide per acre [Whorton 74, p.164] (See Table 3-4). No longer very important, but still manufactured. Toxicity: 100.

Sodium Arsenite, $NaAsO_2$
is still a widely used domestic insecticide. It was used by the USDA for poison bait to control Mormon crickets and grasshoppers and for white-fringed beetles (especially during the 1930's). It was widely used to control crabgrass in the 1950's. Toxicity: 10.

Sodium Arsenate, Na_3AsO_4 and Na_2HAsO_4
is mainly used as a herbicide; also for livestock sprays and dips.

Copper Aceto-Arsenate,$3Cu(AsO_2)_2$. $Cu(C_2H_3O_2)_2$ or "Paris green"
A green pigment that became the first arsenical pesticide. It was used primarily (~50%) against cotton pests and secondarily against Colorado potato beetles, other vine beetles and pests of garden vegetables (Table 3-5). No longer important. Toxicity: 22.

Copper Arsenate, $CuHAsO_3$ or "Scheele green"
In the 19th century "Paris Green" and "Scheele green" were used widely for wallpaper, lampshades, artificial flowers, housepaint, etc. Currently used as an insecticide and wood preservative.

Arsenic Acid, H_3AsO_4
is extensively used in the Texas Panhandle and Oklahoma as a dessicant for cotton plants (to remove their leaves prior to mechanical harvesting by cotton strippers). There has been increasing use since the 1960's. Toxicity: 48 (young rats); 100 (older rats).

MSMA and DSMA, CH_3AsO_3HNa and $CH_3AsO_3Na_2$ (monosodium methanearsonate and disodium methanearsonate)
introduced after 1961 as a selective herbicide to control Johnsongrass, a cotton pest that infests over four million acres of cotton soils. Also used for crabgrass control in lawns and ornamental plantings. Growing in importance. Toxicity: 1800

Cacodylic Acid, $(CH_3)_2AsOOH$
dimethylarsenic acid, is a broad spectrum contact herbicide and dessicant. As "agent

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[4] Toxicity figures are LD50s; i.e., the dose necssary to kill 50% of an exposed rat population, in mg/kg of body weight.

blue" it was used in South Vietnam. It is also used for weed control in non-crop areas, especially lawns. Toxicity: 830.

Zinc Arsenate, $ZnHAsO_4$

was a partial substitute for lead arsenate because it leaves no lead residue. Used on potatoes but too phytotoxic[5] for orchards, bush crops or forage crops. No longer important.

The U.S. began production of arsenic in 1901 and became a significant producer in the 1920's. The U.S. has been a net importer, however, except for a few years during WWII. Consumption in the U.S. reached an annual level of over 20,000 short tons in 1923 and rose above 30,000 tons during the late 1930's and during WWII. A second brief peak occurred during the Korean war (1950-52), and a third during the Vietnam War when cacodylic acid ("agent blue") was widely disseminated over jungle areas [USBM annual & 75].

In 1930 insecticides, primarily for cotton pests, accounted for 70% of all arsenic uses [USBM annual]. This had fallen to 66% by 1939, but insecticide uses still predominated over all other uses through the mid-1960's, although quantities used for this purpose had fallen sharply from their earlier peak levels as organic pesticides proved more effective. Arsenical insecticides are no longer widely employed [USBM annual & 75]. A breakdown of arsenic pesticide use by crop for 1941 is shown in Tables 3-3, 3-4 and 3-5.

Table 3-3: Breakdown of U.S. Calcium Arsenate Use in % (1941)

(75,208,856 lb, of which 37.7% was arsenic by weight)

Cotton	72.8
Potatoes	13.3
Tomatoes	9.9
Other vegetable Crops	2.3
Gov't control programs	0.7
Miscellaneous	2.4
	100.0

Source: [Shepard 51]

Herbicidal uses of arsenic have fluctuated; a sharp increase occurred in the late 1960's, as noted above (USBM 75). In 1978 about 6% of U.S. herbicides were classed as arsenical, accounting for 13,800 tons of active ingredient (mainly arsenic acid, cacodylic acid, MSMA and DSMA), probably 36-40%

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[5] phytotoxicity means toxicity to plants

Table 3-4: Breakdown of U.S. Lead Arsenate Use in % (1941)

(62,885,021 Lb, of which 16.7% was arsenic & 69.1% was lead, by weight)

Apples	55.6	
Home garden & orchard	9.3	
Peaches	4.8	10.5
Pears	4.8	
Cherries	0.9	
Nurseries	3.2	
Shade & Ornamental Trees	3.2	
Grapes	2.4	
Cotton	2.4	
Potatoes	1.6	
Lawns & golf greens	1.6	
Cabbage & cole crops	1.4	
Gov't control programs (gypsy moth, Dutch elm)	6.4	
Miscellaneous	2.4	
	100.0	

Source: [Shepard 51]

Table 3-5: Breakdown of U.S. Paris Green in % (1941)

(4,000,000 lbs, of which 25.6% was arsenic & 43.3% was copper, by weight)

Cotton	50.
Home gardens	25.
Potatoes	12.5
Tobacco	8.7
Mosquito control	3.8
	100.0

Source: [Shepard 51]

arsenic. Wood preservatives are the other major use of arsenic. Sodium arsenite (Wolman salts) has long been used for this purpose ("Wolmanizing"). The most common wood preservative at present is chromated copper arsenic (CCA),[6] of which 1,165 tons were made in 1967. This increased to 4,874 tons in 1972, 16,882 tons in 1979, and 23,193 tons in 1981 (ibid). This material is about 15% arsenic, by weight. In fact, whereas industrial chemicals (including wood preservatives and flotation reagents for ore

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[6] This material is not listed as such in the chemical dictionary. It may be a commercial mixture of basic copper-arsenate (~33% Cu, 29% As) and copper-chromate ($CuCrO_4 . 2CuO . 2H_2O$). Copper arsenate is listed as an insecticide, while copper-chromate is listed as a wood preserver. Both are insoluble in water. Copper sulfate and sodium chromate are also used as wood preservatives.

recovery) accounted for only 5% of all arsenic consumed in 1973 (as compared to 82% for agricultural purposes) the situation has since changed dramatically. The industrial uses increased more than 10-fold to 55% by 1982, with 35% still going to herbicides and plant dessicants (ibid).

Other minor uses of arsenic in 1982 include: glass and ceramics, where arsenic has long been used as a decolorant and fining agent (~5%); additive to chicken feed (~1%); treatment of syphilis and African sleeping sickness (~1%); alloying agent for lead in lead-acid batteries (to strengthen posts and grids) and to increase the tensile strength of copper (~3%). A breakdown of recent uses of arsenic by major industrial classification is shown in Table 3-6 (ibid).

Table 3-6: Recent U.S. Arsenic Use by Industry Group (tonnes)

	Agriculture	Industrial Chemicals	Ceramics & Glass	Nonferrous Alloys & Electronics	Other	Total
1964	18869	1683	1361		726	22639
1965	18597	1433	1724		635	22389
1966	18597	1161	1633		635	22026
1967	19777	1724	1814		907	24222
1968	18053	1089	1905		635	21682
1969	14787	907	1905	635	454	18688
1970	14606	907	1905	544	454	18416
1971	14152	880	1814	517	454	17817
1972	13698	853	1724	499	435	17209
1973	17872	1089	1814	726	445	21945
1974	20684	1270	1996	771	499	25220
1975	12701	726	1270	454	272	15422
1976	6804	1996	454	272	181	9707
1977	8346	2359	635	363	263	11966
1978	9344	2722	635	417	272	13390
1979	10251	2994	726	454	272	14696
1980	5516	5515	617	372	236	12256

Source: [USBM 75]

As noted previously arsenic is also released into the environment as an impurity (~1 ppm) in phosphate fertilizers and detergents.

Arsenical organics degrade in soil primarily to inorganic arsenates that are bound into slightly soluble complexes with iron, aluminum, calcium and magnesium. However, organic arsenicals like MSMA and cacodylic acid are reduced in part by bacteria and molds (both aerobic and anaerobic) to volatile arsines

(See Figure 3-2). Inorganic arsenates are also reduced to volatiles, but at a much slower rate as shown in Table 3-7.

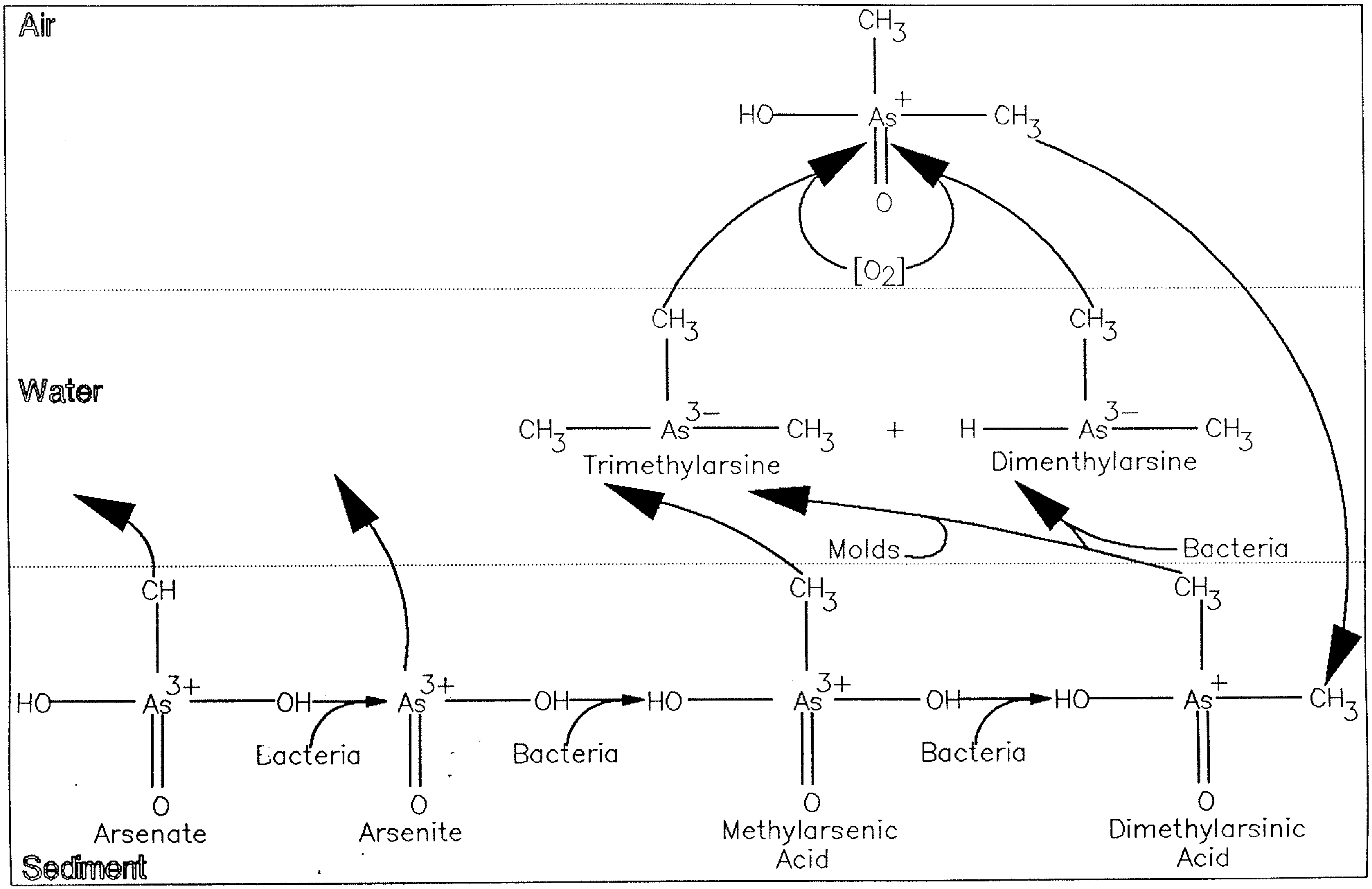
Table 3-7: Inorganic Arsenates Volatized in 150 Days (percent)

Arsenate	0.64	1.60
MSMA	8.22	0.84
Cacodylic acid	14.10	4.48

Source: [NRC 77a]

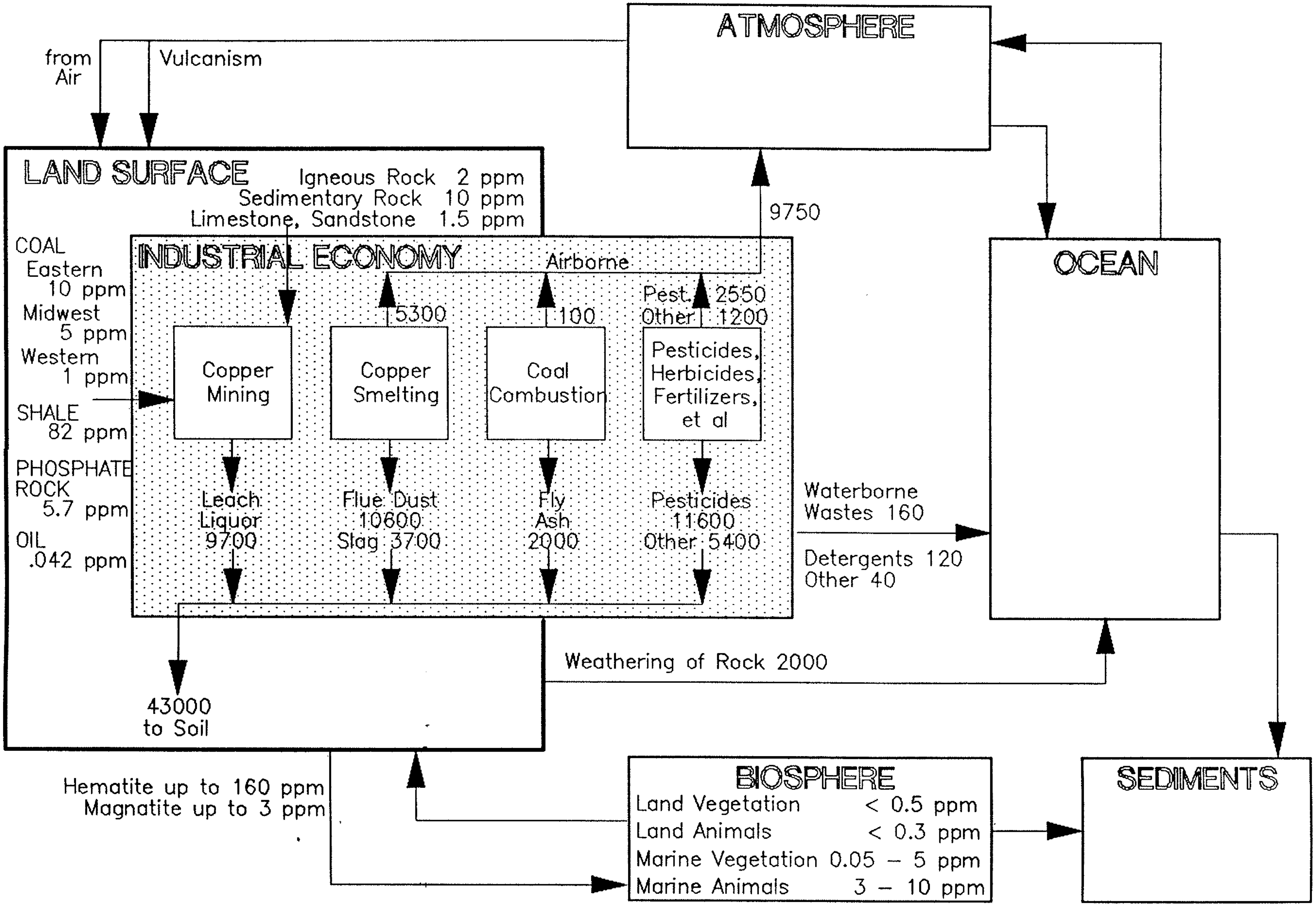
A rough global balance for arsenic is shown in Figure 3-3.

FIGURE 3-2: Biological Cycle for Arsenic



Source: [*Wood* 74]

FIGURE 3-3: U.S. Arsenic Cycles (units = metric tons)



4. Anthropogenic Cadmium Sources and Flows

Cadmium is primarily a by-product of zinc ores, most of which (in the U.S.) are mined in western states. A small amount is recovered from copper and lead refineries [USBM annual & 75]. The only zinc mines in river basins of concern in this study are in Ogdensburg (Sussex County), NJ (draining into the Hudson River basin at Kingston, NY, and Lehigh County, PA. Ogdensburg ore was shipped to the NJ Zinc Company refinery in Lehigh, PA where the cadmium is still recovered, although the zinc refinery is now closed. The Cd/Zn ratio for these ores is about 0.42% [Nriagu 80a, p.49]. Cadmium is also recovered from flue dusts of copper and lead refineries. Some flue dusts are imported into the U.S. for cadmium recovery.

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% [USBM 75]. About 4.4 kg of cadmium are recovered per metric ton of refined zinc. Unrecovered cadmium remains in tailings, slags or sludges, in the Zinc itself, or is emitted to the atmosphere. Emission controls at refineries have only been implemented since 1970 or so. Zinc smelting and refining is also the major single source of cadmium emissions, nationally (ibid). U.S. production of cadmium began in 1906, but early uses were very limited, mainly as yellow, orange and red pigments. U.S. Production only reached 45 tons in 1919, when Cd electroplating of iron and steel by the Udylite process was first introduced. Production jumped sharply to 1240 tons in 1929. After a slump in 1931-32, the trend continued upward erratically to a peak of over 6000 tons in 1969, declining sharply in the 1970's and '80's. See Table 4-1.

U.S. consumption began to outpace production in the 1960's. Consumption also peaked in 1969 at 7150 tons, and has declined somewhat since then, but imports now supply more than half of domestic supply. Cadmium is consumed both as metal and in various chemical forms. Various processing stages and intermediates are as shown in Figure 4-1. Use data is compiled in Table 4-2. Cadmium chemicals of importance are as follows:

Cadmium acetate, $Cd(C_2H_3O_2)_2.3H_2O$
is used as a stabilizer and to produce iridescent effects on porcelain and pottery.

Cadmium carbonate, $CdCO_3$
is an intermediate used in manufacture of other cadmium compounds.

Cadmium chloride, $CdCl_2$is a reagent used in photography; also used in cadmium plating, and as a mordant in dyeing and printing calicoes.

Table 4-1: U.S. Cadmium Production & Consumption (tonnes)

	Primary Production of Metallic Cadmium	Primary Production of Compounds	Primary Production Total	Secondary Production	Primary+ Secondry Production	Apparent Primary Consumption	Producers Shipments (Primary+ Secondary)	Total Primary Demand
1906	3		3		3			
1910	9		9		9			
1915	53		53		53			
1920	50		50		50			
1925	152	77	291		291			
1930	815	144	959		959	988		
1935	1491	266	1756		1756	1897		
1940	2601	208	2773	140	2857	2867	3357	
1945	3537	147	3684	73	3757	3592	3752	
1950	3717	101	3817	107	3924	3723	3822	
1955	4550	50	4557	75	4602	4674	4436	
1960	4388		4388		4575	4837	4826	4597
1965					4538	5180	4768	4968
1970					4444	5529	4475	5529
1975					2492	4686	2428	4685
1980					1533	4246	1782	4718
	(d)	(c)	(e)	(e)	(f)	(g)	(h)	

(c) Excludes compounds made of metal. No data 1954-1974, 1974 estimated from text.

(d) No production prior to 1906

(e) 1940-1954 from [USBM annual]

(f) 1955 on from [USBM annual]

(g) 1940-1944 is Primary plus Metal

(h) No data prior to 1940

Source: [USBM annual], but the last column is from [USBM 75]

All values are five year averages centered on year shown except 1906=avg(1906,1907)

Cadmium hydroxide, $Cd(OH)_2$
is an intermediate used in the manufacture of cadmium compounds.

Cadmium oxide, CdO_2
is used for the cathodes of nickel-cadmium batteries, for cadmium plating, and as a coating for luminescent powders (e.g. CdS,ZnS).

Cadmium nitrate $Cd(NO_3)_2$
is used as a catalyst and as an intermediate for the manufacture of cadmium yellow pigment. It is also used in ceramics and glass manufacturing.

Cadmium stearate $Cd(C_{18}H_{35}O_2)_2$
is a metallic soap, formerly used as a stabilizer for clear PVC plastic packaging material.

Cadmium sulfide, CdS) or "cadmium yellow"
is the purified form of the mineral greenockite. It is a brilliant yellow pigment (combined with ZnS); it is also a luminescent powder.

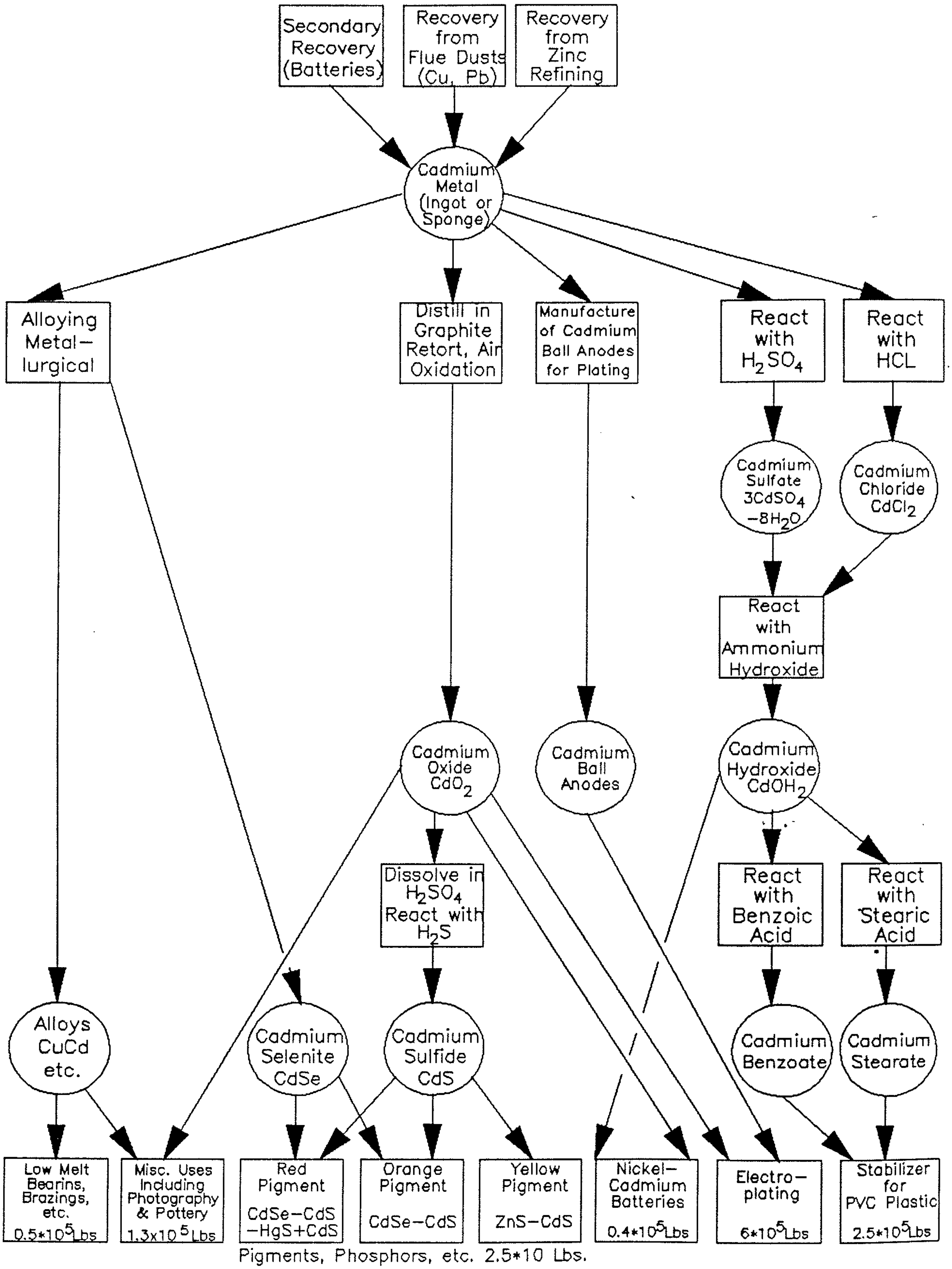
Table 4-2: U.S. Cadmium Use Data (tonnes)

	---------	------- Cadmium Use Data -----			U.S. Demand Pattern			U.S.
	Plating-Transport Related	Other Coating/ Plating	Total Plating	Batteries	Pigments	Plastics& Synthetics	Other	Primary Demand =sum uses
1958								3604
1959								5063
1960			3100					4432
1961								4475
1962								5409
1963			2960	380	770	900	130	5140
1964								3932
1965			2447	279	1160	385	414	4685
1966	830	2860	3690	180	910	1080	683	6543
1967	770	2220	2990	180	500	1000	350	5030
1968	900	2650	3550	180	610	1150	556	6046
1969	1000	2960	3960	230	660	1230	752	6832
1970								
1971	800	1250	2050	140	590	1080	250	4110
1972	960	1500	2460	160	700	1290	322	4932
1973	1130	1720	2850	410	860	1130	477	5727
1974	1130	1580	2710	560	1020	900	495	5685
1975	1000	1630	2630	540	1000	900	418	5488
1976	540	820	1360	410	540	500	245	3055
1977	910	1810	2720	1180	670	600	211	5381
1978	650	1300	1950	840	500	420	108	3818
1979	770	1530	2300	990	590	500	130	4510
1980	840	1670	2510	1080	640	540	155	4925

1960 & 1963 calculated from estimates of percent of total demand

Source: [USBM 75]

FIGURE 4-1: Cadmium Process-Product Flows (1969)



Cadmium sulfate, $CdSO_4$

is used to manufacture "cadmium red" pigment (by calcining with selenium sulfate); also an electrolyte for nickel cadmium and silver cadmium cells, and as a pharmaceutical.

There are five major categories of cadmium uses [USBM annual; NMAB 79]. The biggest, since the 1920's,is anti-corrosion protective electro-plating of iron and steel. About 3000 tons were used for this purpose in the peak year of 1969, but this figure had dropped to only 900 tons in 1975 and continues to hover around 1000 or 1100 tons per year.[7]

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 79]. Very little cadmium is lost to the environment from this process, according to one source [OECD/ED 74].

However this comforting conclusion is sharply contradicted by other evidence. In 1973, Ottinger [Ottinger et al 73] 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 77]. 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. An EPA survey of independent jobbing electroplaters carried out in 1975 determined that 14% of them were in NY and NJ, while an independent Bureau of Mines survey reported that 11% of all cadmium was consumed in NY state alone [Battelle 77].

The second most important use category until the mid-60's was pigments, based on cadmium sulfide and cadmium sulfoselenide. 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

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[7] 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 was more reliable and controllable until improvements in the zinc electroplating (galvanizing) process began to strongly favor zinc [See NMAB 79].

have fluctuated considerably from year to year, but appear to be declining on the average since the 1960's.

For about a decade, from 1966 through 1974, organic cadmium salts (notably cadmium stearate and cadmium benzoate) were used in significant quantities -- peaking at 1400 tons of cadmium in 1971 -- as stabilizers for clear polyvinyl chloride (PVC) plastic packaging material. Cadmium salts were generally used in combination with barium salts. Other metal salts (of zinc, aluminum and lead) were also used for this purpose. Apparently other stabilizers, including purely organic systems and tin-based organic compounds have largely, but not totally, displaced cadmium-based stabilizers since the early 1970's [NMAB 79]. Use for this purpose in 1980 was around 350 tons [USBM annual].

The fourth important use category 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 [USBM 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. (Silver-brazing alloys are estimated to have consumed 110-115 tons of cadmium, alloyed with 13 to 15 million troy ounces of silver, in 1969; see [NMAB 77; NMAB 79]). Cadmium is also alloyed with silver in most electrical contacts. The most popular composition is 10% cadmium oxide, dispersed in silver. About 25 tons was probably used for this purpose in 1969. 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. 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 400 tons or less for the past two decades.

The fifth important use category, and the only growing one, is in batteries, mainly rechargeable nickel-cadmium cells. Cadmium oxide (CdO_2) is the active ingredient in the cathode plate of these cells. Cadmium consumption for this purpose has been rising steadily since the early 1960's and now amounts to 20% of total cadmium consumption [USBM annual; NMAB 79]. Battery manufacturing is known to have been a major source of cadmium into waterborne wastes, as noted later.

Other minor uses include photography, lithography, dyeing and printing of calicoes, pharmaceuticals and phosphors.

Virtually all uses of cadmium are inherently dissipative. Only about 5% is recycled (from batteries). Most cadmium is embodied in anti-corrosion plating zor alloys, and some of this ends up in solid waste in landfills. 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.

Cadmium in the environment arises from a variety of natural as well as anthropogenic sources including plant uptake from the soil, dust and leaf-fall. See Figure 4-2 [Nriagu 80a, p.9]. Atmospheric cadmium is, however, 90% anthropogenic -- which means that the cadmium content of particulate "fallout" is much more (ten times) concentrated in areas near sources of airborne Cd emissions (such as smelters, coal-burning power plants and incinerators) than in areas far from such activities.[8] It is clear that in heavily urbanized areas much of this fallout is deposited directly on roofs or paved areas and some is carried directly into rivers and streams via urban runoff.

Various attempts to account in detail for anthropogenic Cd flows and emissions differ quite widely as Table 4-3 shows. Most are deficient in that they omitted important known sources or were inconsistent with materials-balance considerations. Our preferred source is the latest one [GCA 81], although it appears to neglect significant contributions from phosphatic fertilizers and detergents (which appear in sewage sludge) and from wood burning.

Several other studies probably underestimated the airborne Cd emissions from incineration. Clearly, such emissions originate in Cd-containing products (e.g. pigments and plastic stabilizers) that end up in combustible refuse. Materials balance calculations, applied to EPA's 1975 study [Nriagu 80a, Chapter 3, Table 4], suggest that the airborne emissions from incineration of refuse must be larger than is indicated,

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[8] Cadmium (like zinc) has a relatively low boiling point (765°C), which accounts for a relatively high rate of loss to the atmosphere in smelters, scrap processing and incinerators.

FIGURE 4-2: Global Cadmium Stocks & Flows (units = 1000 tons/year)

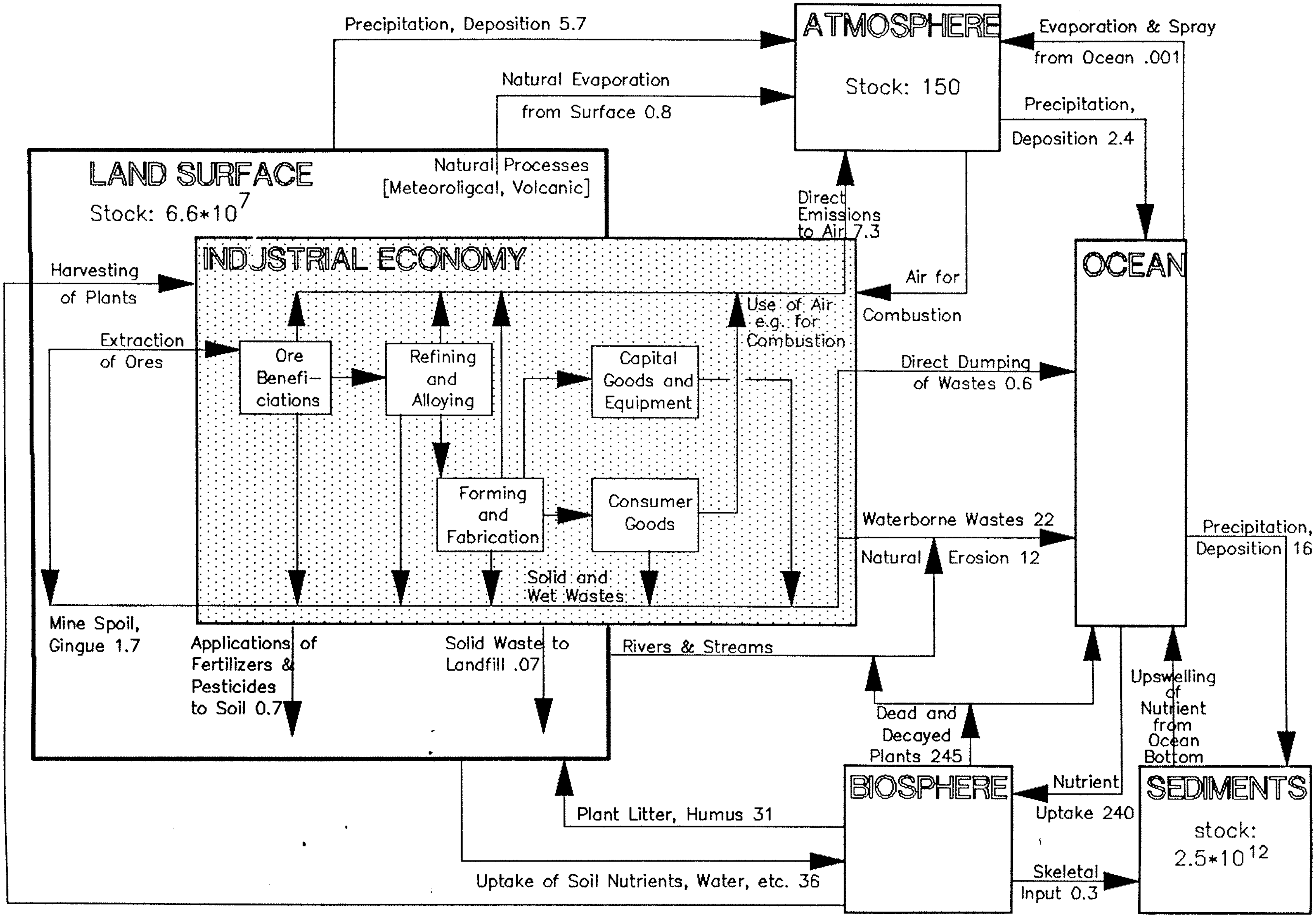

Table 4-3: Comparison of Cadmium Emission Estimates from Various Published Sources for the U.S. (tonnes/year)

Source of Emission	Davis & Associates (1970)	Goeller et al. (1973)	Duncan et al. (1973)	U.S. EPA (1971)	U.S. EPA (1976)	U.S. EPA (1975b)	U.S. EPA (1978)	U.S. EPA (1975a)
Mining (Zn+Pb+Cu)	<1	<1	<1	<1	<1	<1	<1	<1
Primary Metals								
Zinc	-	-	619	644	500	102	529	584
Lead	1050	1050	55	163	65	-	48	148
Copper	-	-	388	234	110	-	108	212
Cadmium	-	-	-	60	50	-	43	54
Secondary Metals								
Steel scrap	1000	<110	1000	78	400	10.5	104	71
Zinc	-	?	-	2	2	2.2	1	19
Copper	125	?	125	65	70		38	59
Manufacturing								
Pigments	11	11	11	7	11	9.5	9	6
Stabilizaers	3	3	3	4	3	2.7	3	3
Miscellaneous	<2	<2	<2	<1	<2	<1	<1	<2
Incineration	95	95	95	48	150	16	131	44
Fossil fuel combustion	-	145-1100	-	198	250	130	59.2	179
Sewage sludge incineration	-	-	-	138	12	20	<1	125
Motor oil	1	1	-	-	<1	-	<1	-
Rubber tires	6	6	-	6	6	5.2	5	5
Gasoline	-	-	-	-	-	50	13	-
Forest & agricultural burning	-	-	-	-	50	-	-	-
Other	-	-	-	-	<2	-	4	-
Total	2294	1425-2380	2305	1650	<1688	300	1100.2	1511

Source: [Nriagu 80a, Chapter 3, Table 3]

since end products are either incinerated or sent to land fills. Incineration accounts for a substantial percentage of refuse disposal, especially in the NY metropolitan area where land fill sites are becoming scarce.

One of the major discrepancies in the various estimates is the Cd associated with fossil fuel (coal, oil) combustion. Here the data are deficient; early estimates of emissions based on the Cd content of coal might be very misleading, since most of the metals are actually associated with ash. Bottom ash was always disposed of in landfill[9] and most of the fly ash is now removed by electrostatic scrubbers. It is also disposed of in landfill. Available evidence suggests that most of the associated cadmium is also trapped

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[9] Indeed, substantial portions of Manhattan and Western Long Island are built on fill, much of it ash.

and removed in this way [Torrey 78]. (See Chapter 10 for details). This hypothesis is consistent with the observed sharp decline in atmospheric cadmium between 1969 and 1974 in a number of Eastern cities [Nriagu 80a, Chapter 3, Table 8]. Those years saw widespread installation of smoke control facilities in fossil-fuel burning electric power plants, as well as pollution controls in foundries etc.

An atmospheric cadmium mass-balance was carried out for the Los Angeles basin by Davidson [Davidson et al 78, Chapter IIIC] in 1976. On the input side the authors identified probable major contributions from particulate emissions for known zinc, cadmium and brass metallurgical operations in the L.A. area, as estimated in tons/day by the L.A. County Air pollution Control District. The quantitative emissions estimates from these sources were so uncertain, however, as to be almost useless. The authors also estimated Cd emissions from tire wear, gasoline and motor oil. With regard to Cd from tire wear, their direct estimates were reasonably consistent with national estimates [Nriagu 80a, USBM annual]. Their estimates of Cd emissions from motor oil and gasoline were a factor of two lower than would be expected on the basis of the lower of the two explicit national estimates (which is also our preferred estimate). Davidson et al neglect any contribution from open refuse incineration which has been banned in LA for many years, although some unlicensed incineration undoubtedly occurs.

Taking into account the above facts, it would appear that most of the anthropogenic Cd in the rivers of the Hudson-Raritan basin must be attributable to waterborne wastes (e.g. from plating or detergent use) and from atmospheric deposition in the urbanized New York City metropolitan area. Of this amount the largest contributions are due to copper refining and secondary recovery activities, fossil-fuel (coal, oil) combustion and incineration, rather than cadmium usage *per se*. Motor vehicle operations (tires, gasoline and motor oil) generate cadmium containing aerosols that are subsequently deposited as dry dust or rainout over the metropolitan area. Phosphate fertilizers and detergents contribute some cadmium, as noted above, in proportion to their phosphorus content. Cadmium electroplating and cadmium battery manufacturing may also contribute some waterborne effluents, mainly at point sources. However much of the cadmium emitted directly to water in urban areas is actually removed in sewage sludge.[10]

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[10] It is noteworthy that sewage sludge from 11 New York sewage treatment plants contained 3 ppm to 18 ppm cadmium. However 4 other plants had 77 ppm to 163 ppm. Evidently there are major polluters (battery manufacturers or electroplaters) dumping wastewater into the sewers.

As regards airborne cadmium, given the relatively higher humidity and higher frequency of rain, the "near" component of atmospheric deposition would be larger than for the Los Angeles basin (where 50% or more of the Cd emissions are apparently advected out of the area). Much of that surface fallout will then find its way into the rivers via runoff and sewers. There may have been some cadmium influx from airborne emissions in other locations, especially the zinc smelter in Lehigh County, PA (directly West) and even from coal combustion and phosphate fertilizer use in the midwestern states. Their contribution can probably be neglected to first order.

In the Hudson River, a major point source in the past has been Foundry Cove, located near Peekskill, NY where one battery plant outfall discharged a total of between 18 and 23 tonnes of Cd into the cove over a period of years prior to 1970-71. Dredging has removed sediment containing 5.5 tonnes from the cove, but estimates based on cove samples suggest that about 11 tonnes remain [Nriagu 80a, chapter 11]. Allowing for considerable uncertainty in all the estimates, roughly half of the original contamination may have been carried downstream by tidal action over the years.

5. Anthropogenic (Hexavalent) Chromium Sources And Flows

Chromium is derived in practice entirely from chromite ore. Chromite ore consists of variable mixtures of chromium oxide (Cr_20_3), iron oxide (Fe_20_3), and aluminum oxide ($A1_20_3$). This ore was mined in Maryland, Virginia, and Pennsylvania starting in 1827, but U.S. production declined rapidly after 1860 when more productive Turkish mines were opened. The U.S. has imported virtually all chromite ore domestically consumed since 1880, although a few minor potential sources do exist in Montana (mainly), California, and Oregon. Historical data on imports and consumption are given in Table 5-1.

Chromite ore is processed by three basic routes (See Figure 5-1). The first is in the manufacture of refractory bricks for high temperature uses e.g. open hearth furnace, electric furnace or reverberatory (non-ferrous) furnace liners. This route involves physical processing (grinding and compaction) only. The metallurgical route involves smelting with coke and fluxes in an electric furnace to yield ferrochrome, an alloy of iron and chrome used mainly as an alloying component in the production of stainless steel, other chromium steels, and chromium cast iron. Both refractory production and ferrochrome production generate fairly large quantities of chromium emissions. In fact, on a gross tonnage basis, these are by far the dominant source of environmentally mobile chromium.

An EPA-sponsored study in 1973 concluded that more than 50% of all uncontrolled Cr emissions (and 68% of post-control emissions were due to ferrochromium production in electric furnaces [GCA 73]. Another 20% arises from the production of chromite-based refractory bricks and chromium alloy steels. As of 1973 there were 3 ferrochrome producers in (NY-NJ) out of 13 nationwide, and 56 chrome-steel production plants, of 143 nationwide. We do not know how many are located in the H-R basin. It is important to point out, however, that emissions from these metallurgical operations are of the trivalent form.[11] The chemical route begins with the manufacture of sodium dichromate (or bichromate) by a hydrometallurgical process involving roasting of chromite ore with sodium carbonate and lime to yield sodium chromate. This is followed by leaching, with sulfuric acid, evaporation, and crystallization of the sodium dichromate. Statistics on chromium usage and chromate and dichromate production are given in Table 5-2.

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[11] Chromium takes both trivalent and hexavalent forms. Chromic oxide Cr_2O_3 and other trivalent chromic salts are moderately toxic. Chromates and dichromates (e.g. CrO_4,Cr_2O_7),on the other hand, are highly toxic and probably carcinogenic. In general, the hexavalent form of chromium is the most dangerous [Windom & Duce 77,Chapter 12].

Table 5-1: U.S. Chromium Production & Consumption (1000 tonnes)

	Chromium Metal & Ferro-Alloys Production (Cr Content)	Crude Chromite Domestic Mine Sales (Gross Weight)	Crude Chromite Imports for Consumption (Gross Weight)	Crude Chromite Apparent Supply (Gross Weight) =Mine + Imports	Apparent Supply (Cr Content)	Crude Chromite Consumption (Gross Weight)	Crude Chromite Consumption Average Cr2 O3 (Percent)	Chromium Content of Consumption
1880		2.325	0.000	2.325	0.674			0.674
1885		2.581	1.228	3.809	1.105			1.105
1890		2.026	4.190	6.216	1.803			1.803
1895		1.556	7.172	8.727	2.531			2.531
1900		0.167	22.215	22.382	6.491			6.491
1905		0.141	38.005	38.146	11.062			11.062
1910		0.301	40.143	40.445	11.729			11.729
1915		19.282	82.166	101.448	29.420			29.420
1920		18.421	98.300	116.721	33.849			33.849
1925		0.196	169.802	170.012	49.303			49.303
1930		0.273	236.233	236.524	68.592		49.1	69.424
1935		0.877	293.850	294.727	85.471		44.0	86.571
1940		24.507	650.172	674.679	195.657	681.948	43.6	162.834
1945		40.783	826.500	867.283	251.512	760.091	43.2	224.759
1950		5.954	1304.110	1310.131	379.938	893.779	42.4	259.730
1955		135.942	1812.686	1948.456	565.052	1350.028	43.1	399.121
1960		75.803	1145.774	1276.227	370.106	1108.398	43.0	326.019
1965	203.851					1276.953	44.5	389.133
1970	219.041		1137.005		363.841	1154.483	45.3	358.157
1975	189.004		1080.094		345.630	1038.545	43.0	307.092
1980	144.853		802.677		256.857	840.960	38.8	259.460

Source: [USBM annual] with calculation of Chromium Content as follows:
Cr2 O3 percent in Chromite Ores assumed 42% unless explicit
Pure chromium= 68.4% of Cr2 O3 by weight.

All values except 1880 are five year averages centered around year shown

Cr2 O3 percent in imports assumed the same as in Chromite Ores (~42% or explicit)

Prior to 1940 Consumption data is not available. Apparent Supply has been substituted.

FIGURE 5-1: Chromium Process–Product Flows (1968)

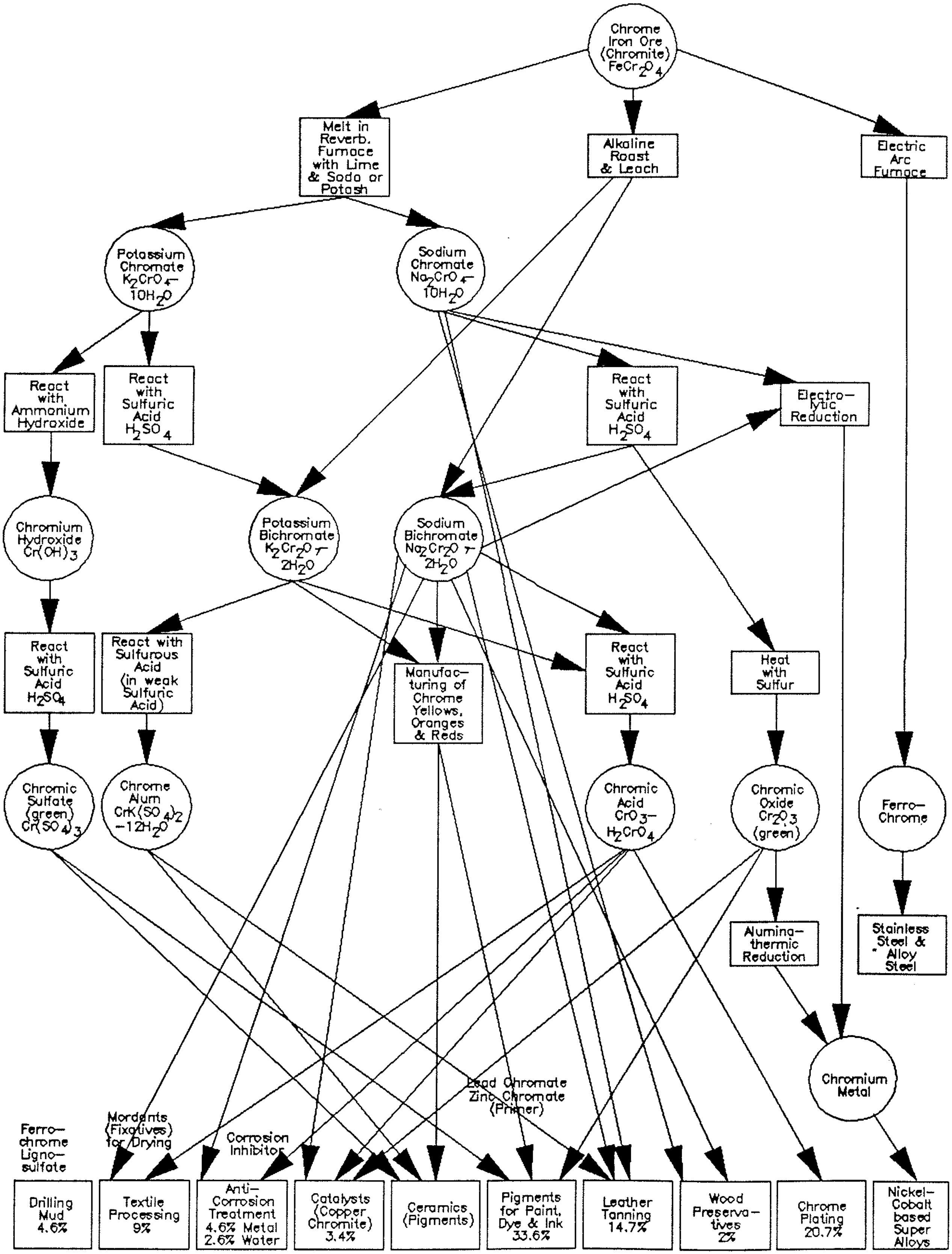

Table 5-2: U.S. Chromium Usage except for Pigments (1000 tonnes)

Year	Total Chromium Consumption (Cr Content =.68 * Cr2 O3 % of Chromite)	Chemical Industry Chromium Consumption (Cr Content =.68 * Cr2 O3 % of Chromite)	Ratio of Chemical Industry to Total Consumption Percent	Chromic Acid Consumption (Cr Content = .52*amount of acid	Sodium Dichromate & Chromate Production (Cr Content = .34*amount of chemical
1880	0.674				
1885	1.105				
1890	1.803				
1895	2.531				
1900	6.491				
1905	11.062				
1910	11.729				
1915	29.420				
1920	33.849				
1925	49.303			0.212	
1930	69.424			0.852	
1935	86.571				
1940	162.834	34.708	21.32%		
1945	224.759	36.145	16.08%	4.529	26.653
1950	259.730	40.000	15.40%	5.349	30.579
1955	399.121	41.933	10.51%	7.359	34.979
1960	326.019	44.812	13.75%	7.642	36.941
1965	389.133	54.030	13.88%	10.402	43.430
1970	358.157	56.012	15.64%	11.298	46.596
1975	307.092	58.183	18.95%		48.432
1980	259.460	63.911	24.63%		

All values are five year averages centered on year shown, except 1880 = actual and chemical data is for 1927(1925) and 1929(1930)

Percent is percent of average, not average of percents

One of the five U.S. plants currently producing chromium chemicals is Essex Chemical Co., located in Kearney, NJ. It is likely that other producers operated in the Newark area in the past, e.g. see [NYRPA 28]. A list of the major chromium chemicals and their uses follows:

Basic chromic sulfate, $Cr(OH)SO_4$
is the tanning compound that actually combines with collagen in skins to form leather. It is usually produced from sodium dichromate in the tanning process itself.

Basic lead chromate, $PbCrO4.Pb(OH)_2$
is an orange-red pigment.

Chrome alum, $CrK(SO_4)_2.12H_2O$
is used in ceramics, leather tanning and as a hardening agent in photo film processing.

Chromic acid, H_2CrO_4
is used in chromium plating, anodizing, etching copper, in electric batteries and in tanning.

Chromic chloride, $CrCl_3$
is used in tanning, as a mordant, and in flame metallizing.

Chromic oxide, Cr_2O_3
is used as a green pigment. It is also one starting point for the manufacture of pure chromium metal.

Chromic sulfate, $Cr(SO_4)_3$
is a green pigment used in ceramics, dyes and inks.

Chromium metal, pure
is used in the manufacture of nickel-based alloys such as "nichrome" and cobalt based alloys ("superalloys").

Chromium phosphate, $CrPO_4$
is "Plessy's green" pigment.

Chromium stearate, $Cr(C_{18}H_{35}O_2)_3$
is used in ceramics, plastics, plastic waxes and as a catalyst.

Chromium trioxide, CrO_3, or chromic anhydride
is the anhydrous form of chromic acid.

Chromous chloride, $CrCl_2$
is used as an oxygen absorbent and for chromizing steel.

Copper chromate, $CuCrO_4.2CuO.2H_2O$
is a wood preservative, combined with copper arsenate.

Sodium chromate, $Na_2CrO_4.10H_2O$
is the primary intermediate used to manufacture sodium dichromate and chromium metal. It is also used directly in leather tanning and wood preservatives.

Sodium dichromate, $Na_2Cr_2O_7.2H_2O$
is used to manufacture most chrome pigments (e.g. zinc and lead chromates) and catalysts (e.g. copper chromite). It is used directly in textile processing, anti-corrosion treatment of metal surfaces, leather tanning and wood preservatives.

Strontium chromate, $SrCrO4_4$
is a lemon yellow pigment.

Zinc bichromate, $ZnCr_2O_7$
is an orange-yellow pigment.

Zinc chromate, $4ZnO.K_2O.4CrO_3.3H_2O$, "zinc yellow"
is a pigment.

Metallic uses of chromium do not cause significant environmental risks. Metallic chromium that cannot be recycled is ultimately embodied as a tramp contaminant in iron or steel foundry products, or is discharged to slag heaps and landfills in insoluble form. However very little gets into air or water [GCA 73].

As noted previously environmentally hazardous or toxic forms of chromium are almost entirely derived from chemical uses, especially those involving hexavalent chromium compounds (chromates and derivatives). In 1968 these were as follows: pigments (33.6%); chrome plating (20.7%); leather tanning (14.7%); anticorrosion surface treatment of metals (anodizing) (4.6%); water treatment (2.6%); textile treatment (3%); wood preservatives (2%); catalysts (3.4%); and drilling mud (5%) for the petroleum industry. (Percentages given above refer to 1968; see [NMAB 70, Section IV]). Tanning has been declining in relative importance, although it was once the most important use of chromium chemicals.

Chromium has been used for pigments since before the 19th century [EB 55, *Chromium*]. In fact, the name chromium was inspired (Greek: Chroma=color) by the fact that its salts are so highly colored. Consistent statistics are hard to find because new pigments have been introduced (notably the oxides and hydroxides) and categories have changed. Figures for chrome pigment use in 1927, 1929, 1951, 1953, 1967, and 1972 are shown in Table 5-3.

Table 5-3: U.S. Chrome Pigment Usage (1000 tonnes)

	1927	1929	1951	1953	1967	1972
Chrome green	7.06	8.18				
Chrome yellow	7.16	8.20				
Chrome orange	2.33	4.98				
Chrome green (a)			7.77	7.15	2.7	NA
Chrome oxide green			11.60	9.69	5.4	5.9
Chrome yellow & orange (b)			31.05	25.52	29.8	32
Molybdate chrome orange (c)			4.02	4.14	10.1	12.3
Zinc yellow (d)			8.14	6.91	7.6	5.9
Total	16.6	21.4	62.6	53.4	55.6	>56.1
				~5%		~60%

(a) Chrome green is a mixture of Prussian Blue (iron-based) and chrome yellow (see text)

(b) Chrome yellows and oranges are mixtures of sodium dichromate with lead acetate or lead nitrate

(c) Molybdate chrome orange is a mixture of lead chromate, lead sulfate and lead molybdate

(d) Zinc yellow is zinc chromate

It appears that the use of chromium for pigments actually peaked around 1940, as can be determined by subtracting other known uses of chromium chemicals (e.g. tanning and plating) from total chemical use.

The so-called 'chrome tanning' process was introduced around 1910. It greatly speeded up tanning operations (reducing the time required from 2-4 months in the case of vegetable tanning, to 1-3 weeks. It also resulted in much longer-lasting products. By 1945 85% of leather tanned was used in shoes and 90% of the output of upper shoe leather was chrome tanned [Shreve 56, chapter 26]. In the two-bath chrome tanning process 5 kg of sodium dichromate (1.8 kg Cr) is consumed per 100 kg of raw hides, in the production of 80 kg of chrome tanned leather (ibid).

The sodium dichromate is reduced by sulfur dioxide to basic chromic sulfate $Cr(OH)SO_4$ in the first bath (ibid). In the one bath process, basic chromic sulfate is supplied directly. The chrome salt apparently combines permanently with the collagen in the prepared skins to form the leather. Relatively small amounts of chromium are lost directly to the tannery wastes, only 2% of which arise from chrome tanning *per se* (ibid). Most of the chromium is physically embodied in the leather products which contain about 2% chromium, by weight. It is slowly liberated when the worn-out shoe uppers or other leather products are discarded, mainly to landfills or incinerators.

In 1967 tanning consumed 8300 tonnes of chromium, and this use was declining at a rate of 1.1% p.a. [NMAB 70], due to a decline in shoe production in the U.S. and continued substitution of synthetic materials for leather. On this basis we assume 1960 consumption of 9000 tonnes, falling to 8000 tonnes in 1970 and ~7000 tonnes in 1980. Tanning requirements for chrome in earlier years can be estimated approximately on the basis of shoe production, viz.

Table 5-4: U.S. Tanning Requirements for Chrome 1920 -1970

Year	US Shoe prod. million pairs	Chromium used in tanning 1000 tonnes
1970	350	8.0
1960	380	9.0
1950	297	7.0
1940	254	6.0
1930	190	4.5
1920	200	4.7

An increasingly important use of chromium chemicals is for electroplating copper or steel. The process was first introduced commercially in 1924 and became important in the 1930's. There are two kinds of chrome plate: "decorative" (e.g. for automobile trim) Decorative plate is thin (.00002" to .00004") and not effective against corrosion. and "hard" Hard plating is thicker (.0001" to .05"). It is used mainly for industrial applications such as dies and rolls. Electroplating is generally done from a chromic acid bath, and most chromic acid is used for this purpose. Plating accounted for 20.7% of chromium chemicals consumed in 1967, or 9750 tonnes of chromium (as chromic acid). This was second only to pigments. In that year, decorative plating required 5100 tonnes of chromium, industrial hard plating required 2300 tonnes and other metal finishing processes such as anodizing and stripping consumed the remainder.

Another major historical use of chromium chemicals is in so-called mordant dyes, applied mainly to wool. These dyes are typically based on azo or anthracene (anthroquinone) complexes. The role of the chrome is to fix the dye to the fiber, making the fabric washable. Examples of mordant dyes are alizarin, chrome blue-black, Gallocyanine and some others [Shreve 56, p.900]. Mordant dyes constituted over 5% of all dyes used in the 1934-38 period, but declined in relative importance to around 2.5% in the mid 1950's. However, mordants still consumed 3% of all chromium chemicals in 1968.

Of all the chemical uses noted above, the ones with the greatest environmental impact are leather tanning, pigments used in paint and ink, catalysts, and water, wood, and textile treatment. Plating and anodizing apparently generate very little chromium-containing waste since the chromic acid bath is easily recycled.

Several chroium chemical uses, especially aluminum anodizing, corrosion control, and aluminum surface deoxidizers (for cleaning) result in relatively high concentrations of hexavalent chromium effluents. As much as 30,000 tons a year is apparently lost by this route [Vlahakis & Ouellette 76, p.54]. Methods of recovering this chromium for use are currently being explored [ibid].

Chromium used in ceramics is essentially permanently immobilized. Chromium containing pigments are generally insoluble, but some pigmented final products -- especially paper -- are incinerated and may escape into the environment by that route. Paints used on roads or metal surfaces are gradually reduced to powder and dissipated by wear and weathering processes. The use of chromium is shown in Table 5-2.

One other source of chromium in the atmosphere is the combustion of coal. Chromium is present in bituminous coals in trace amounts (~13-17 ppm). It is associated with fly ash almost exclusively in the toxic trivalent chromite (Cr_2O_3) form.

6. Anthropogenic Copper Sources and Flows

Copper is now mined predominantly from relatively low grade porphyry ores from large open pit mines. There are a number of such mines in the western U.S., but none in the east[12]. In the late 19th and early 20th century, however, the copper smelting and refining industry was well represented in the New York metropolitan area, especially near the mouth of the Raritan River, Perth Amboy, NJ and the lower New York Bay (Staten Island and Brooklyn). Electric power was comparatively cheap, (based on coal-fired steam generators), and the big copper wire and cable manufacturers were conveniently nearby, as were the brass foundries and mills around Bridgeport in southern Connecticut. [See Lawfear 28; Navin 78; Trescott 81]

Four major copper smeltering/refining complexes to treat imported ore were built before 1910 around New York Harbor [Navin 78]. The earliest was Nichols Copper Co. (later Phelps-Dodge) complex on Newtown Creek (Laurel Hill, Queens, NY) built in the 1880's. Their first electrolytic refinery was built in 1891. It was replaced by a newer refinery in 1905 to refine blister copper from Phelps-Dodge. Next came the American Smelting & Refining Co. (ASARCO) complex at Maurer (Perth Amboy) NJ, built 1895. The so-called First Raritan Works was built in 1898 by International Smelting and Refining Co. It was followed by the Second Raritan Works, a few years later (bought by Anaconda in 1905). The last and biggest was US Metals Co. at Chrome (Carteret) NJ, built in 1902[13]. In addition to these four, Balbach Metals Co. (Newark) added copper refining in the 1890's to its 1883 silver-lead refinery. Also, Orford Copper Co. (later International Nickel Co.) built a small electrolytic refinery in Bayonne, NJ, and NJ Extraction Co. built a refinery in Elizabethport, NJ, in the 1890's. The Balbach works closed in 1919.

All the big facilities except the Anaconda unit included blast furnaces. However, US Metals replaced its two blast furnaces by reverberatory furnaces in 1921. This facility was modernized and doubled in capacity to 200,000 tonnes of ore p.a. in 1946 and even expanded again in 1953. ASARCO operated its blast furnace until 1930. Phelps-Dodge closed its Laurel Hill smelter in 1963.

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[12] Copper was mined for a time from magnetite-pyrite-chalcopyrite ore in Cornwall, PA (Lebanon County) by Bethlehem Steel Company, but effluents from this mine drained into the Susquehanna River, not of concern in this study

[13] US Metals became American Metal Co. in 1926. It was acquired by Phelps-Dodge in 1938, then spun off and merged with American Metal Climax (AMAX) in 1957.

In 1899 NJ accounted for a comparatively small amount of primary copper smelting (around 1450 tons or 1.5% of the U.S. total) but the NJ-NY refineries produced 117,000 tons of refined copper ingots, bars and wire products, or 39% of the U.S. total [Census 00]. The same area produced 7400 tons of copper sulfate (blue vitriol) or 54% of the national total. Copper refiners in the NJ-NY area also produced 7,900,000 fine oz. of by-product silver in the same year (ibid). The peak period for copper smelting and refining in the New York Harbor area was the 1920's, when NJ-NY smelter capacity reached its maximum (455,000 tons of concentrate per annum), or about 4% of U.S. smelter output.[14] As of 1933, however, the NJ-NY area only accounted for roughly 1.5% of the U.S. total. Thereafter, smelter capacity in the NJ-NY area remained roughly constant until 1963, while capacity and output elsewhere increased. Capacity was reduced in 1962 but some smelting was done by AMAX at Carteret until 1980.

All four major copper companies (AMAX, Anaconda, ASARCO, Phelps-Dodge) also operated electrolytic copper refineries at the same locations until recently. In fact, NY harbor accounted for almost 40% of U.S. refinery output in 1899 [Census 00] and 63% in 1918, dropping to 55% by 1919 [Battelle 77]. Two refineries (ASARCO and Anaconda) closed in 1975; AMAX and Phelps-Dodge both phased out in 1981-83. However as late as 1970, New York Harbor still accounted for 25% of U.S. copper refining [USBM 75]. The four big refineries had a total capacity of close to 570,000 tonnes per annum in 1973, mostly electrolytic [USBM 75].

There were also at least four secondary copper smelters recently located in the Hudson-Raritan watershed. Two are in northern New Jersey. (Barth Smelting and Refining Co., Newark; and Kearney Smelting and Refining Co., Kearney.) One is in Tottenville, Staten Island directly (Nassau Smelting and Refining Co.), and one is in Brooklyn (Belmont Smelting Co.). Refinery emissions have clearly been a significant past source of water pollution in the Raritan River and the lower Hudson. Furthermore, at least 5 firms have recently manufactured copper sulfate in the area: Gamma Chemical Co., Great Meadows, NJ; CP Chemicals, Inc., Sewaren, NJ; Filo Color & Chemical Co., Newark, NJ; Food Additives Inc., Old Bridge, NJ; and Southern California Chemical Co. Inc., Bayonne, NJ. Most of these firms consume scrap copper as a source. Data on smelting and refining of primary and secondary copper in the U.S. are shown in Tables 6-1 and 6-2. Data on production and use of copper sulfate are shown in Table 6-3.

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[14] Evidently NJ-NY smelters processed rather low grade ore [Battelle 77]. (We have assumed 10% Cu).

Table 6-1: U.S. Copper Production (1000 tonnes)

	Mine Production (Recoverable Copper Content)	Smelter Production	Primary Refinery Production From Domestic & Foreign Ores	Secondary Production From Old Scrap	Secondary Production Total	Secondary Production Recovered as Refined
1880	27.433	27.433				
1885	69.453	69.453				
1890	121.746	121.747				
1895	183.097	183.097				
1900	268.788	268.787				
1905	377.705	379.763	478.895			
1910	502.168	494.976	630.766	74.843	102.512	
1915	705.189	669.194	858.581	121.648	216.630	
1920	524.142	531.602	714.583	151.141	273.157	
1925	738.200	740.999	1006.316	273.028	397.240	
1930	612.261	617.793	867.912	292.899	403.757	101.068
1935	412.052	416.761	597.700	312.888	395.732	117.112
1940	762.467	768.930	1075.084	313.507	552.602	92.831
1945	778.829	787.664	1042.842	415.700	872.492	125.903
1950	789.359	792.861	1026.913	407.685	816.221	175.577
1955	898.386	904.230	1223.666	410.777	827.339	197.131
1960	957.610	900.760	1293.929	388.007	792.900	228.393
1965	1123.983	1130.942	1416.751	440.224	1055.029	347.760
1970	1389.059	1362.125	1525.941	454.152	1161.630	380.564
1975	1422.077	1354.816	1451.861	400.942		361.967
1980	1331.996	1162.639	1271.163	567.051		552.331

Sources: [USBM annual; Census 75]. Secondary Production from [BEA biennial]

The metallurgy of copper (along with lead and zinc) is incredibly complex. Each smelter and refinery is different. A general process-product flow chart for copper is shown in Figure 6-1. A materials balance for the smelting and refining processes in aggregate is given in Figure 6-2, while a still more detailed flow sheet for the electrolytic refining process is given in Figure 6-3. Gaseous waste streams from copper smelters and converters arise from roasters (if present),[15] reverberatory furnaces (which separate a copper-iron-sulfide "matte" from iron-silicate slag) and from the anode (or "fire refining") furnace where blister copper is further purified and cast into anodes for the subsequent electrolytic refining stage. Reverb gas streams are too low in SO_2 concentration to permit economical recovery of sulfuric acid, so they are vented to the atmosphere after waste heat recovery (if any) and partial recovery of flue dust.

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[15] Apparently the NJ-NY smelters did not utilize roasters.

Table 6-2: U.S. Copper Consumption (1000 tonnes)

	Net Imports	Apparent Consumption Refined Copper	Apparent Consumption New (Primary) Copper	Apparent Consumption New (Primary) & Old Scrap	Consumption Refined Copper
1880	0.272		27.669		
1885	-22.534		46.920		
1890	-34.654		87.271		
1895	-92.950		94.075		
1900	-88.305		181.618		
1905	-134.263		248.931		
1910	-197.948		314.430		
1915	-226.978		500.947		
1920	-89.448		466.105		
1925	-130.344		639.504		
1930	40.904		550.970	727.411	
1935	-39.134		445.327	773.035	
1940	227.866		976.167	1739.526	
1945	505.062		1287.839	1957.704	1327.483
1950	402.463		1160.652	1568.341	1226.768
1955	360.878		1199.661	1610.253	1302.826
1960	146.492		1049.613	1422.465	1312.351
1965	273.208		1335.013	1775.179	1816.728
1970	232.602	1905.595	1518.264	1972.401	1870.252
1975	323.843	1876.524	1561.933	1962.785	1883.860
1980	439.440	1978.630	1655.600	2222.200	1960.426
	(b)	(a)	(a), (b)	(b)	(c)

Sources: [a. Potter & Christy 62], [b. USBM annual], [c. BEA annual]

Values are five year averages centered on year shown

The other major solid waste is slag, of which 3 tonnes is produced per tonne of blister copper on the average (current practice) although the ratio appears to have been more like 10 to 1 for the concentrates used in NJ-NY smelters. The slag is mostly inert oxides (e.g. Fe_2SiO_4) but it does contain some copper (0.28%-0.46%) and other trace metals [Hofman & Hayward 24, Table XLIX]. Slag is normally sent to landfills for disposal. In the case of the NJ-NY smelters much of the slag was apparently dumped on refinery sites, which were all in low-lying marshy areas.

Impurities in smelter ore concentrates are highly variable. Typical levels for domestic concentrates are shown below. (Unfortunately, NJ-NY smelters used imported concentrates, for which we have no specific data). Table 6-4 is compiled from EPA data [PedCo 80, Chapter 27, Table 15].

Table 6-3: U.S. Copper Sulfate Production & Uses (1000 tonnes of copper content)

	Production	Shipments	Exports	Apparent Consumption	Agricultural Use	Industrial Uses
1880				1.000		
1885						
1890						
1895						
1900			2.539	2.500	2.000	0.500
1905						
1910				4.000	3.000	1.000
1915						
1920			0.822	5.000	3.500	1.500
1925			0.299	5.500	3.000	2.500
1930			0.647	6.000	3.000	3.000
1935	5.903		0.375	5.529	3.000	2.500
1940	11.890		0.890	11.000	7.000	4.000
1945	28.734	28.281	8.341	19.726	14.700	5.000
1950	21.068	21.117	8.643	12.638	5.919	5.205
1955	16.049	16.105	7.422	8.683	4.037	4.400
1960	10.682	10.564	1.791	9.163	4.717	4.105
1965	9.575	9.218	0.292	9.431	3.847	5.126
1970	9.634	9.450	0.544	8.906	3.273	4.877
1975	8.514	8.205	0.429	7.776	3.938	4.174
1980	8.816	8.430	-0.147	8.577	3.499	4.779
			(a)	(b)	(c)	

Source: [USBM annual] and 1900 Census

All consumption data prior to 1945 is estimated based on relatively greater importance of copper sulfate relative to copper as a product in 1899. Assumes U.S. consumption equaled exports in that year. All other values are averages of available data centered on year shown

(a) After 1978 imports begin, amounting to 5% of supply by 1982.

(b) When no shipment data, calculated as production minus exports.

(c) Adjusted to account for exports when "other" is insufficent.

FIGURE 6-1: Copper Process-Product Flows

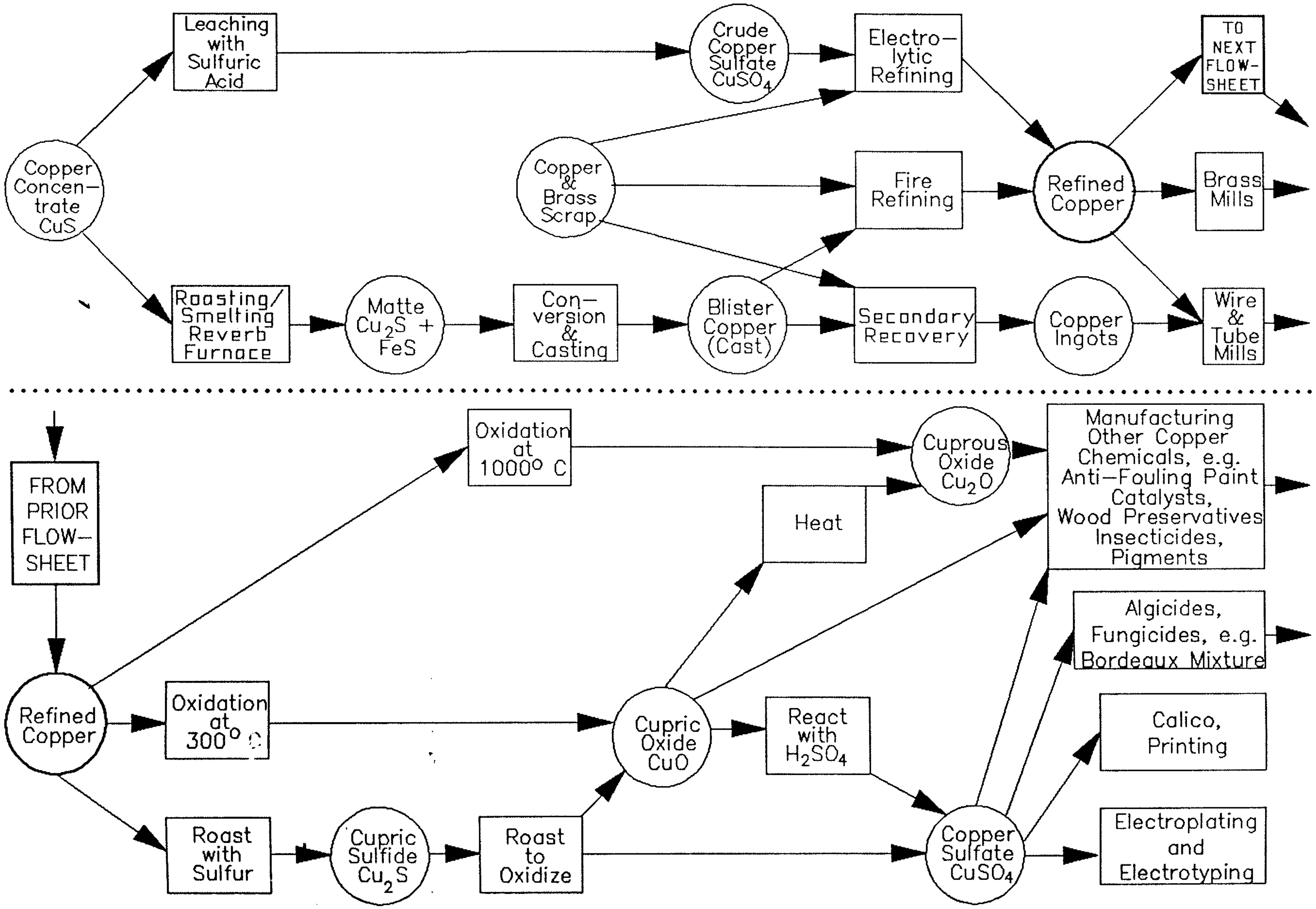
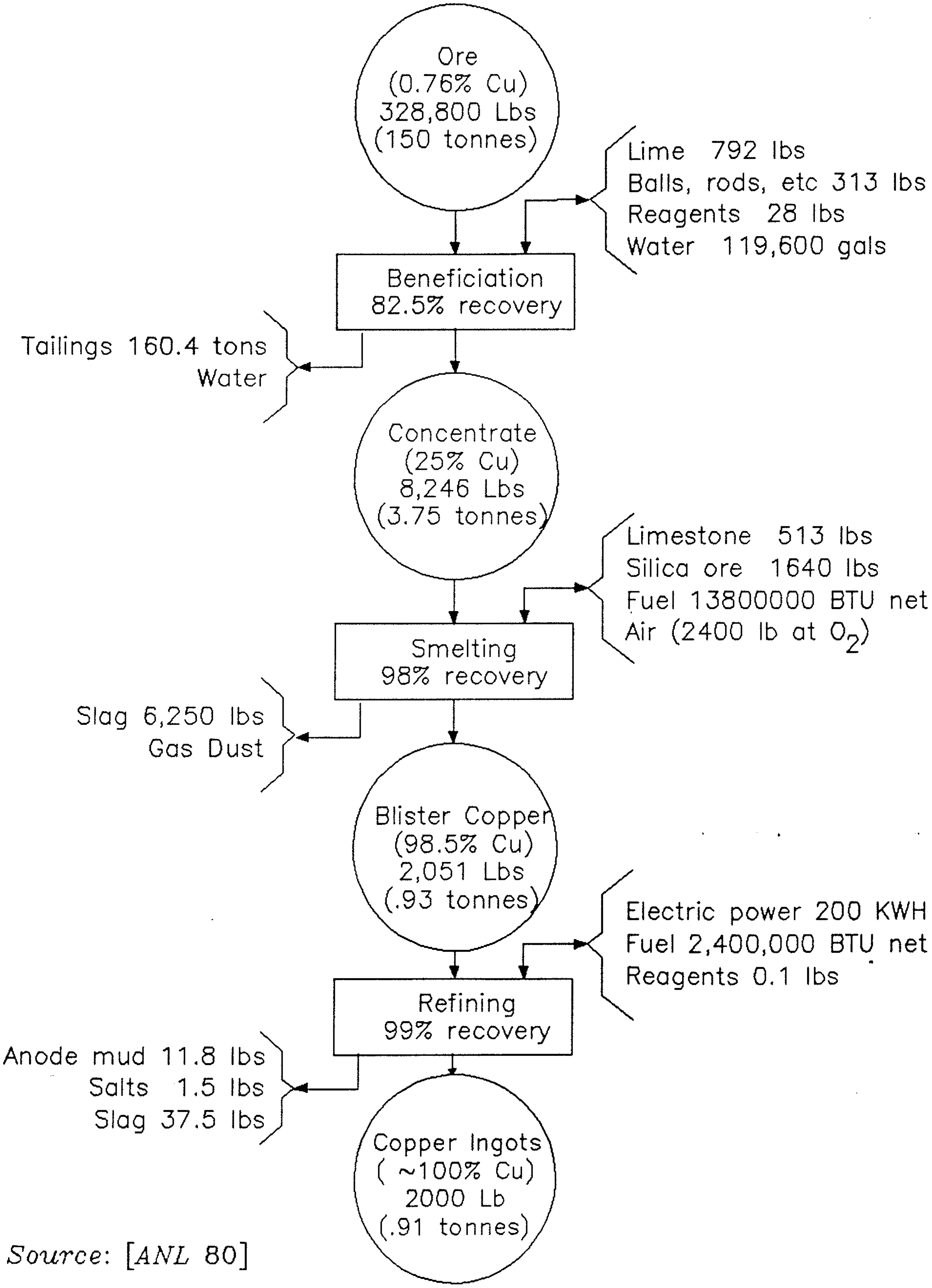
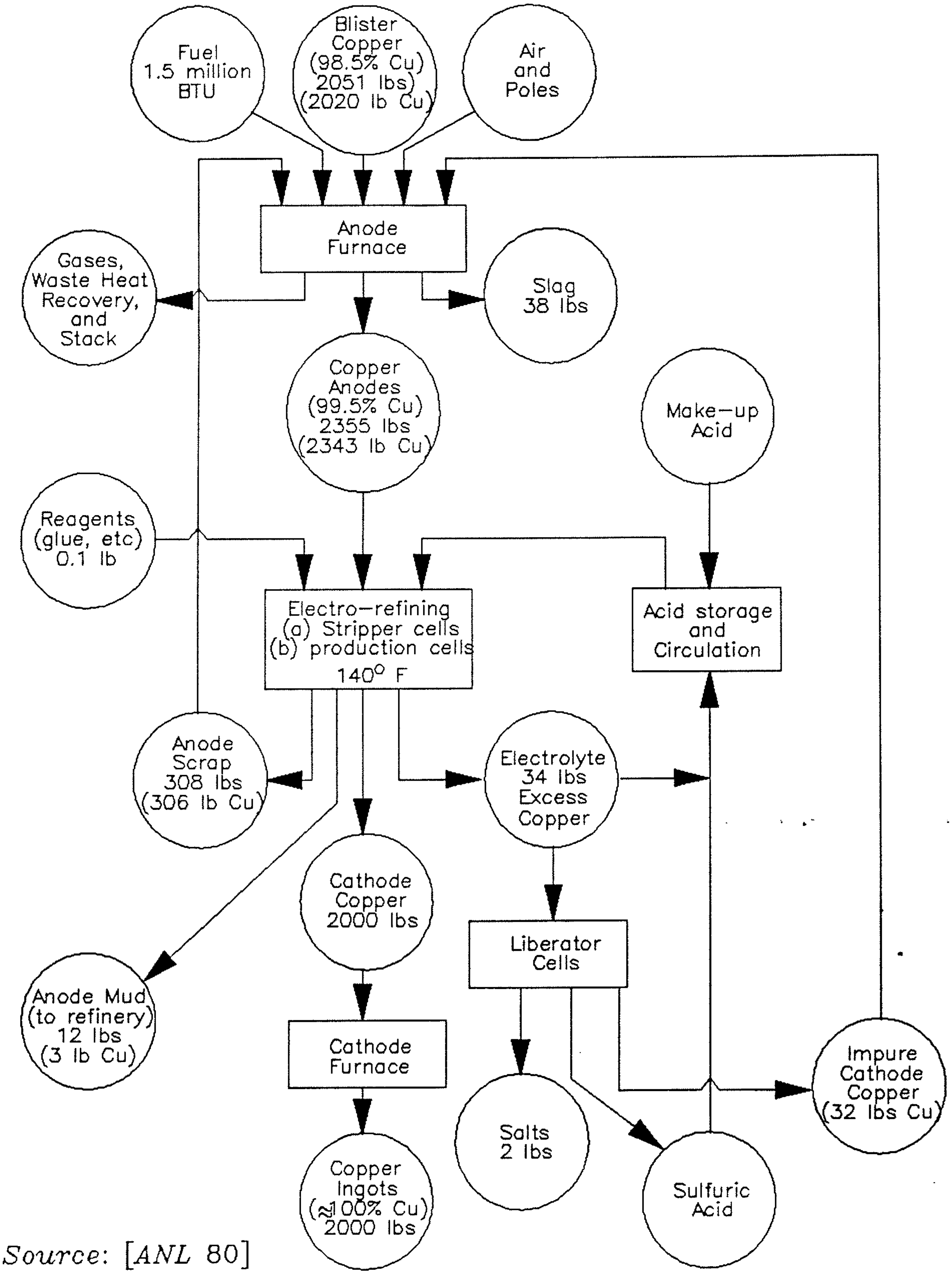


FIGURE 6-2: Materials Balance for Primary Production of Refined Copper



Source: [*ANL* 80]

FIGURE 6-3: Flowsheet & Materials Balance for Electrolytic Refining



Source: [*ANL* 80]

Table 6-4: Smelter Feed Composition

	Concentration (ppm)	Percent in Range
As	>10,000 (1%)	2
	1000-10,000	10
	200-1000	88
Cd	<1000	100
Pb	>20,000	2
	5000-20,000	2
	<5000	96
Zn	10,000-40,000	1
	<10,000	67 (incomplete)

Source: [PEDCo 80, Chapter 27]

Impurities in waste streams obviously depend on the composition of the feed concentrate. An "average" is hard to determine. Estimates of losses to various waste streams can be made on the basis of the composition of feeds, furnace slags and known fractionation of impurities among various process streams as shown in Table 6-5 [ANL 80, Table 3.10, p.44].

Table 6-5: Estimated Distribution of Impurity Elements during Smelting/Converting

Element	Blister Copper (% of original impurity remaining)	Vapor[a] (% of original impurity remaining)	Slag[b] (% of original impurity remaining)
Ag	90	0	10
As	15	75	10
Cd	0	80	20
Hg	10	90	0
Pb	5	85	10
Zn	0	30	70

Source: [ANL 80]

(a) Not including ejected droplets of matte and slag

(b) Including entrained matte

Assuming 25% copper content in feed, 3 tons of slag is generated per ton of copper. Based on a typical slag composition shown below and the above fractionation implied furnace feed composition, and emissions as vapor can be estimated as shown in Table 6-6.

Table 6-6: Copper Smelter Emissions to Atmosphere (Uncontrolled)

Element	Concentration in Slag ppm(Slag)	Implied Feed Concentration ppm(Cu)	Implied Vapor Emission ppm(Cu)
As	800	8000	6000
Cd	~10	~150	120
Cr	~100	300	Neg.
Cu	4000-7000	25%(assumed)	---
Hg	<1	?	?
Pb	~100	3000	2550
Zn	7800	33,500	10,000

Comparing the "implied" feed concentrations above with Table 6-4 , and other studies, does not reveal any major discrepancies except (perhaps) in the case of zinc. Arsenic emissions depend entirely on the source of the ore. We have no information on the arsenic content of ores used by NJ-NY smelters in the past. Figures in Table 6-6 are based on the U.S. arsenic cycle (Figure 3-3). Obviously most of the "emissions" are recovered as flue dust.

Reverberatory furnaces generate between 7 and 20 kg of particulate matter (flue dust) per ton of input materials consisting partly of unreacted ore particles and partly of condensed vapors. The flue dust is partially recovered and recycled, depending on the efficiency of available recovery techniques, mainly Cottrell electrostatic precipitators. Recovery efficiency as of 1980 ranged from 50% to 99.9% [PEDCo 80, Chapter 27, p.48]. (The lower figure can be assumed to apply to small secondary recovery units -- not necessarily the older (NJ-NY) plants. Indeed, primary copper smelters were achieving 90% to 97% recovery as early as 1933 [Newton & Wilson 42, Table 5, p.245].

The recovered fraction is copper rich (~25%), so it is usually returned to the furnace feed. However this results in a buildup of other minor contaminants that eventually affects the quality of the blister copper. Hence contaminated dust is periodically discarded or sent out to specialized refineries to extract precious metals. Ratios of metallic elements in smelter and converter flue dust vary widely depending on feed composition and process. Analyses of dusts from 9 smelters gave a range of 7.8% to 17.1% Cu-content for reverberatory furnaces; and 26% to 62% Cu for converters [Hofman & Hayward 24, Table LXIII, p.238]. Lead content ranged from essentially zero to 20.3%. At a single smelter, dust composition also varies widely depending on where it is taken.

Arsenic and lead tend not to recondense completely in the stack on particles, i.e. they partly escape as fumes (vapor). Copper losses depend on particulate generation and recovery. Assuming no recovery and the maximum 20 kg of flue dust (25% Cu) per metric ton of feed (25% Cu) yields an emission factor of 5 kg/Mg (Cu) or 5000 ppm. An average national emission factor of 5000 ppm was estimated by EPA in 1968 [PEDCo 80]. A lower figure (2500-4100 ppm) was estimated in a more recent EPA study [Nriagu 80]. However these figures clearly do not allow for flue dust recovery, as noted above.

After the ore is melted in reverberatory furnace, and the slag is separated from the matte it is 'converted' by oxidation. This yields a sulfur-rich gas stream (that is suitable for by-product sulfuric acid manufacture) but no other significant airborne or waterborne emissions. Slag from the converter is returned to the reverberatory furnace. The resulting "blister copper" is then further refined in another furnace and cast into anodes for the final electrolytic purification. Water is used to cool the anodes, but emissions by this route are very small per unit of copper produced, viz. 30 ppm Cu, 0.9 ppm Zn, <.01 ppm As [PEDCo 80, Table 32, p.91].

In the electrolytic refining process, contaminants accumulate in the electrolyte or the "anode slime" or "anode mud". The partition is shown in Table 6-7 [ANL 80, Table 3.22, p.67].

Table 6-7: Properties of Anode Impurities Entering Residues and Electrolyte

Metal	% into Anode Residues	% into Electrolyte
Au	99	<1
Ag	98	2
Pb	98	2
As	25	75

Source: [ANL 80]

Data on anode mud composition for several NJ refineries (1912) have been given in [Hofman & Hayward 24, Table CI, p.381]. Silver content ranged from 26.6% to 53.7%; copper content from 0 to 12.9%; lead content from 3.6% to 11%; arsenic content from 4.9% to 7.1%. Other impurities, including tin and gold are also present. The electrolyte includes 40-50 gm/liter of excess copper, 0.5 to 12 gm/liter of arsenic and 2-20 gm/liter of nickel. Based on the assumed feed concentration in Table 6-6, the blister copper might contain 1200 ppm arsenic, of which 25% remains with anode residues and 900 ppm is in the electrolyte (Table 6-7). The copper and nickel are chemically reclaimed, but the arsenic is generally discharged with wastewater. The anode slime from the bottom of the cells is processed to recover the precious metal content.

A major source of water pollution from copper refineries located in the NJ-NY area may well be leaching from old slag piles. Analyses of metallic effluents from slag granulation (i.e. rapid quenching of hot slag in holding ponds) have been done from three plants, as shown in Table 6-8 [PEDCo 80, Table 19].

Table 6-8: Effluents from Cu Slag (mg/l)

	Plant #1	Plant #2	Plant #3
As	3.7	0.048	5.70
Cd	0.001	0.001	0.042
Cu	0.12	0.05	0.604
Pb	0.04	0.07	7.4
Hg	0.0001	0.0001	0.0001
Zn	0.44	0.023	36

Variability is obviously enormous, depending on the composition of the concentrate. It is not known how leachate composition might vary with the age of the slag pile.

Note that almost all the silver and gold remains in the anode mud, which is accumulated and sent to specialized silver refineries where the precious metals are recovered. There is relatively little pollution at this stage. Residues in the electrolyte are harder to recover. Although only 15% of the arsenic originally in the copper ore remains in the blister copper, most (75%) of this fraction remains in the electrolyte.[16] The electrolyte also accumulates some excess copper which is worth recovering, so electrolyte is recycled in "liberator cells". However, some impurities (such as arsenic) are discharged to the environment, generally in waterborne wastes containing copper and other metallic salts, amounting to about 0.75 kg per metric ton of product. Virtually no copper is emitted to the air from refineries. About 1/3 of commercial copper sulfate is produced as a refinery by-product. The remainder is manufactured by specialists, mainly from scrap copper.

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[16] An acid solution of $CuSO_4$.

Historical data on production and consumption of copper are summarized in Tables 6-1 and 6-2. Uses of copper are mostly as metal. Pure refined copper is generally used for wire and wire products and copper tube, while copper alloys -- especially brass (an alloy of copper and zinc) -- are or were used for a variety of other products, such as architectural hardware, clocks and watches, bearings, coins, batteries, bronze castings, screws, ammunition, automobile radiators, air-conditioning, heat exchangers, and so on. Wire mill products accounted for about 51% of copper consumption in 1936 (the earliest available statistics) and only 43.5% in 1940, but since World War II this has risen steadily to 70% in 1980. The relative importance of brass products has, by contrast, decreased sharply. The manufacture of these products, much of it in southern Connecticut (around Bridgeport), has also created a substantial amount of air and water pollution in the past, though not in the Hudson-Raritan basin.

Copper is recovered and recycled to a significant degree, but a good deal of metallic copper is lost in solid wastes, especially discarded appliances. This copper probably contributes modestly to water pollution, by way of leachate from landfills (~0.13 mg/l). The leaching rate may be accelerated as rainfall becomes more acid. The major historical source of copper in water, however, is copper sulfate, a soluble salt that has been used as a fungicide, as a chemical intermediate and in water treatment as an algicide.

Copper-based chemicals for agriculture and industrial purposes are listed as follows.

Copper acetate, $Cu(CH_3COO)_2.H_2O$
is a soluble green pigment used in paints, lacquers, inks and linoleum. It is also a catalyst in the manuacture of phthalic anhydride and adipic acid

Copper aceto-arsenate, $(3Cu(AsO_2)_2.Cu(C_2H_3O_2)_2)$, or "Paris green"
was formerly a green pigment and later an important insecticide

Copper arsenate, $CuHAsO_3$, or "Scheele green"
formerly a green pigment, and currently a wood preservative

Copper carbonate, $CuCO_3.Cu(OH)_2$,or artificial malachite
is a green pigment (mineral green, Bremen green, mountain green); also a catalyst in the manufacture of banzoic acid

Copper chromate, $CuCrO_4.2CuO.2H_2O$
is a wood preservative, usually combined with copper arsenate

Copper hydroxide, $Cu(OH)_2$
is an intermediate and a blue pigment

Cupric chloride, CuCl)>
is used as a catalyst in the production of acetaldehyde acetone, acrylonitrile, and ethylene dichloride

Cupric oxide, CuO)
is used as a green or blue colorant for ceramics and as a catalyst in manufacturing acrolein and n-butyraldehyde

Cuprous oxide, Cu_2O)
is used as a red pigment for ceramics and glass, in electroplating and in AC rectifiers

Cuprous chloride, CuCl)
is used as a catalyst, especially in aniline, chloroprene, and methyl ethyl ketone

Copper sulfate, $CuSO_4.5H_2O$)
or "blue vitriol" or "bluestone" is the primary intermediate for manufacturing other copper compounds. It is used directly in plating baths, as an electrolyte in batteries, in dyes, as a germicide and as a fungicide (e.g. in "Bordeaux mixture")

A breakdown of fungicidal use, by crop, for the year 1944 is shown in Table 6-9.

Table 6-9: U.S. Fungicidal Use of Copper-based Chemicals by Crop for 1944$^{(a)}$

Potatoes	51.3%
Apples	22.2%
Other Deciduous Tree Fruits (Pears, Peaches, Cherries)	9.7%
Grapes (for blackrot)	5.6%
Citrus	2.7%
Tomatoes (for blight)	2.7%
Pecans & other nuts	2.0%
Other tree crops	3.2%
Miscellaneous uses	2.6%
Total	100.0%

(a) Based on 109,107,500 lb (54,554 tons) of fungicide, $CuSO_4$ equivalent, containing 21,720 tons of copper [Shepard 51]. Commercial copper fungicides are mainly based on copper sulfate (~94%) with small quantities of copper carbonate (4%) and cupric oxide (2%)

Evidently many of these crops are grown in the northeast, where copper-based fungicides could have found their way into the Hudson-Raritan Basin. For reasons that are not clear, use of copper sulfate as a fungicide, especially for potatoes, increased enormously during WWII and dropped equally sharply thereafter. Copper sulfate data is shown in Table 6-3. In recent decades, industrial uses of copper chemicals, including catalysts (especially in aniline dye manufacturing) and wood preservers, have been growing slowly. Catalyst traces may be associated with chemical products, especially dyes [Nriagu 80, NRC 77c]. (Wastewater from commercial dyeing operations typically contain 33-110 mg/l of copper). A list of chemical processes utilizing copper based catalysts is given in Table 6-10.

Another important use of copper that contributes directly to waterborne emissions is in anti-fouling paint for barnacle control. We have no data on quantities used for this purpose.

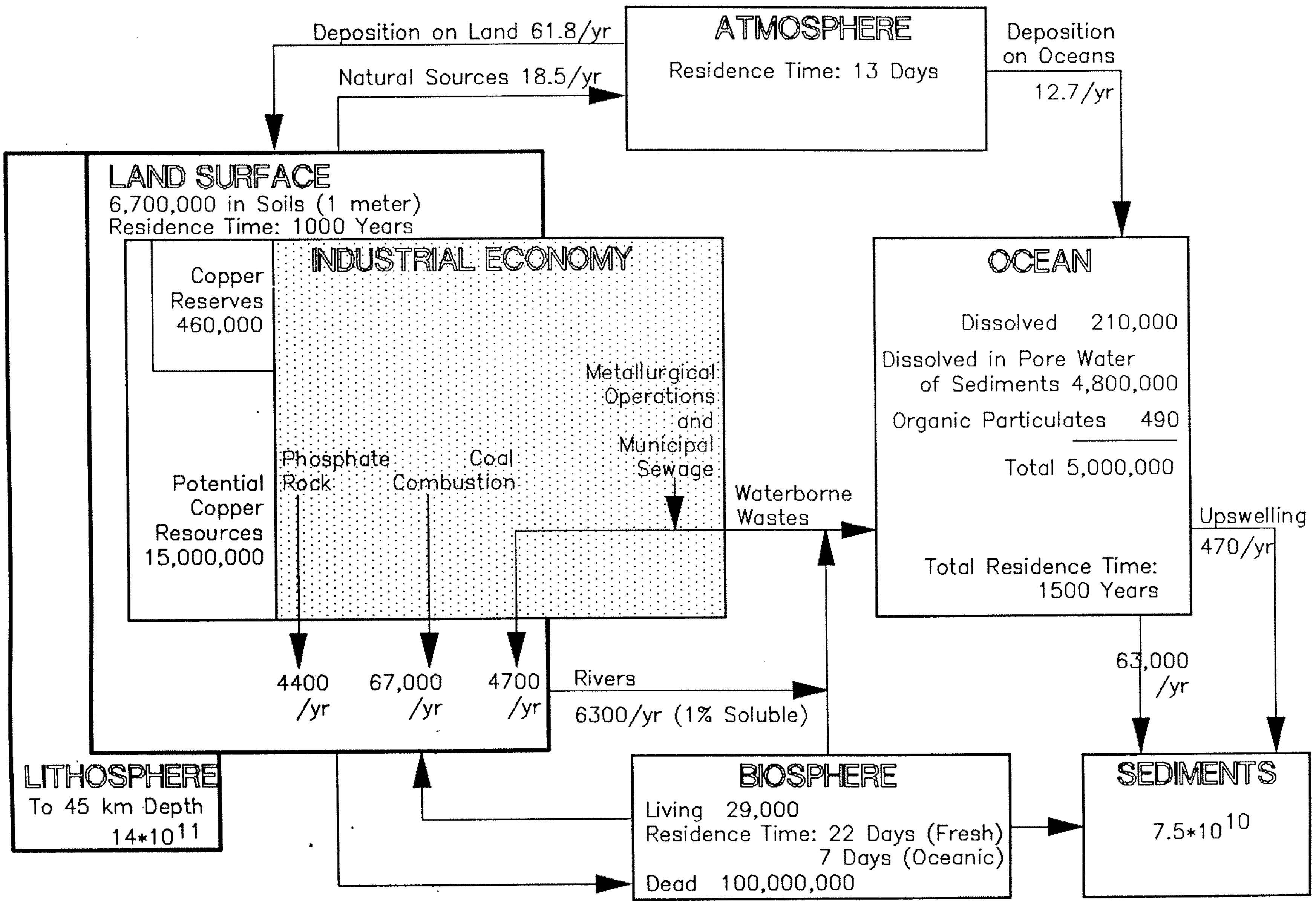
Table 6-10: Some Chemical Processes Using Copper Catalysts

acetaldehyde from ethylene	(cupric chloride)
acetaldehyde from ethanol	(copper + chromite)
acetone from isopropanol	(copper or brass)
acetic anhydride from acetaldehyde	(copper & cobalt acetates)
acetone from propylene	(copper & palladium chlorides)
acrylonitrile from acetylene + HCN	(cupric chloride)
acrolein from propylene	(copper oxide)
adipic acid from cyclohexanone	(copper acetate)
adipic acid from cyclohexanol	(copper acetate)
adiponitrile from butadiene	(cuprous salts)
aniline from nitrobenzene	(copper)
aniline from chlorobenzene	(cuprous chloride)
benzoic acid from phthalic anhydride	(copper carbonate)
butadiene from acetaldehyde	(copper + chromite)
butadiene from acetylene	(copper-bismuth)
n-butyraldehyde from n-butanol	(cupric oxide)
chlorobenzene from benzene	(copper-iron)
chloroprene from butadiene	(copper+cuprous chloride)
chloroprene from acetylene	(cuprous & ammonium chlorides)
cyclohexanone from cyclohexanol	(cupric chromite)
ethylene dichloride (EDC) by oxychlorination of ethylene	(cupric chloride)
hydrogen via water gas shift reaction	(copper-zinc-chromium)
methanol from CO by hydrogenation	(copper)
methyl ethyl ketone from butanol	(brass)
methyl ethyl ketone from n-butylenes	(cuprous chloride)
methyl isobutyl ketone from acetone	(copper)
phenol from cumene	(copper salts)
phenol from benzoic acid	(cupric benzoate)

Source: [Faith, Keyes & Clark 75]

Copper is also released into the environment by coal combustion and other industrial activities. (See the separate discussion of emissions from coal combustion) On a worldwide basis, anthropogenic copper emissions to the air appear to be substantially greater than emissions from natural sources such as vulcanism. The same is true for waterborne emissions, especially of soluble copper salts. The dominance of anthropogenic sources is even greater in a densely populated and industrial region such as the Hudson-Raritan watershed. The global copper cycle is shown in Figure 6-4.

FIGURE 6-4: Global Copper Cycle (units = 1000 metric tons)



7. Anthropogenic Mercury Sources and Flows

Mercury has long been mined from cinnabar (mercuric sulfide, HgS) deposits in many countries. The U.S. has historically imported most mercury for domestic consumption, but the new McDermitt mine in Nevada (70-90% HgS, 10-30% corderoite $Hg_3S_2Cl_2$) has sharply increased domestic production from a low in the early 1970's. California was the major mining state in earlier periods. No mercury is or has been mined in the eastern U.S. [USBM annual].

Ore is concentrated by flotation. Mercury is separated from concentrate by roasting in a furnace or kiln. The metal is vaporized and captured in a retort. Relatively low temperatures are involved, so the process is usually carried out at the mine site to save on ore transportation costs. Losses of mercury to the environment (as vapor) range from 2% to 5% at this stage [USBM 75]. An electrolytic process is also available [Vlahakis & Ouellette 76]. Mercury production (and total consumption data) are given in Table 7-1.

Mercury has been used for a wide variety of (mainly dissipative) purposes since the 19th century. Prior to 1900 its major uses were in gold and silver mining (prior to the development of the cyanide process), in mercury fulminate detonators for munitions and explosives, in the "silvering" of mirrors, in the manufacture of vermilion pigment used for cosmetics (rouge), and in the processing of felt for hats [USBM annual]. It was also used in manufacturing instruments such as thermometers and flowmeters and in electrical equipment. The use of mercury for mirrors was largely eliminated before 1910, as the silver nitrate process took over. The use of mercury in anti-fouling paint for ships bottoms began around 1910. By 1940 fulminate and vermilion each still accounted for 6% of annual consumption, while felt-making took 10%, according to the Bureau of Mines [USBM annual]. A great deal of mercury fulminate was consumed in high explosives in WWII.

Mercury is processed into a variety of chemicals as shown in Figure 7-1. A list follows:

Mercuric fulminate, $Hg(OCN)_2$

used for percussion caps and detonators since 1867. Largely displaced by lead azide after WWII.

Mercuric chloride, $HgCl_2$

"corrosive sublimate", used as an intermediate in the manufacture of yellow mercuric oxide (HgO), in zinc batteries, as a wood preservative, insecticide, antiseptic, rat poison, fungicide, in tanning, as a mordant, formerly used in anti-fouling paint for ships, and as a catalyst in the manufacture of vinyl acetate and vinyl chloride.

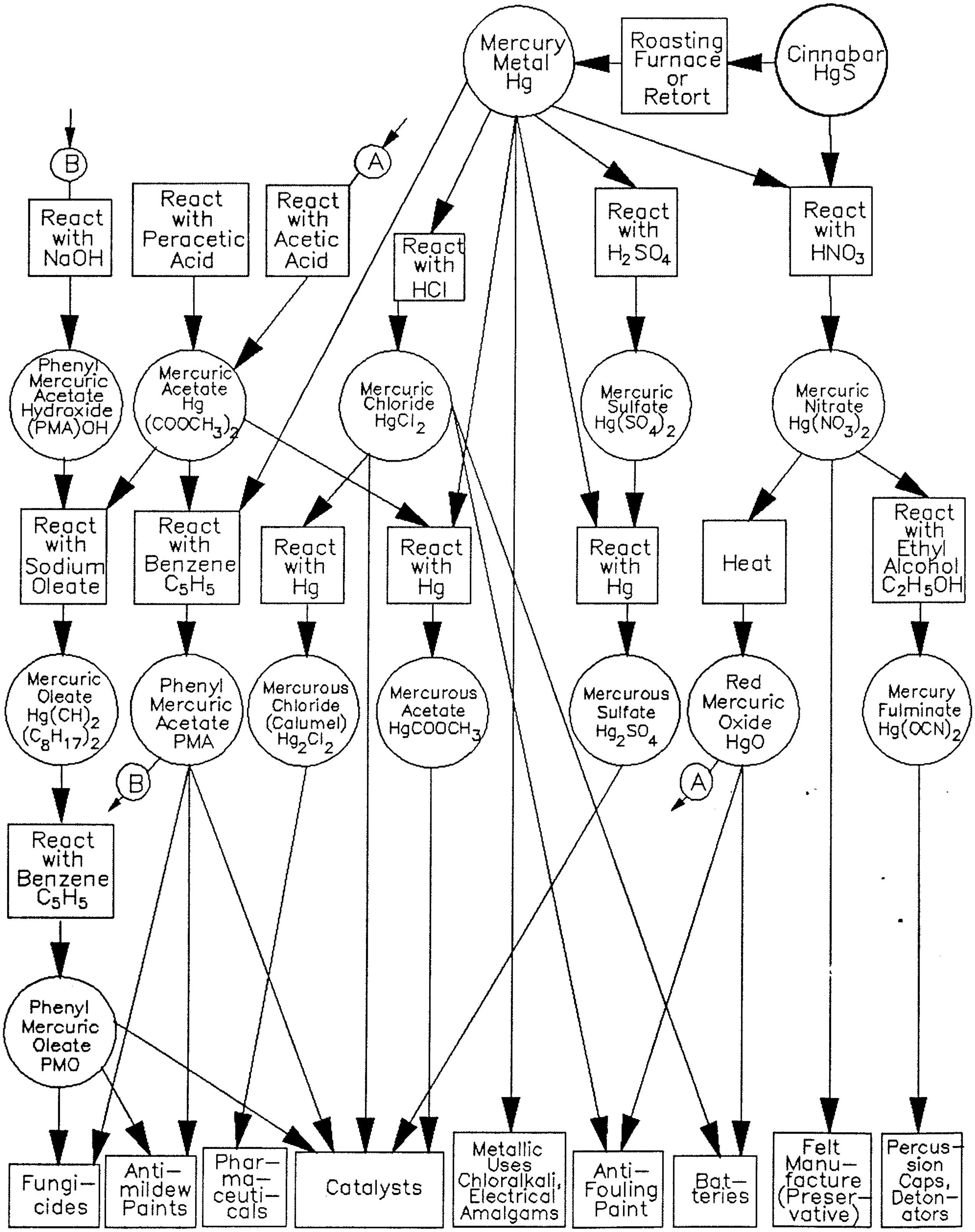
Table 7-1: U.S. Mercury Production & Consumption (1000 tonnes)

	Total Primary Production	Production From Ore	Secondary Production (inc GSA)	Imports for Consumption	Exports	Apparent Consumption Calc. as Production +Imp-Exp	Consumption (Apparent Consumption until 1909)
1880	2079.421			52.934	1291.180	841.175	841.175
1885	1211.141			271.868	442.277	1040.733	1040.733
1890	926.881			135.853	174.165	888.568	888.568
1895	1069.427			9.310	553.101	525.636	525.636
1900	1063.437			0.048	509.168	558.698	558.698
1905	1031.669			2.924	284.879	622.219	622.219
1910	738.657			53.197	83.837	708.018	708.018
1915	842.893			183.552	174.289	852.156	852.156
1920	547.059			401.728	98.262	850.525	850.525
1925	313.753	369.240		668.687	7.188	953.101	975.524
1930	694.107	602.699		259.506	89.595	634.407	915.645
1935	521.983	470.295		519.350	12.359	1195.610	1031.881
1940	1173.241	1148.117		363.435	99.786	1436.890	1114.609
1945	1164.305	1141.746		1122.972	27.330	2259.947	1564.813
1950	335.374	326.680		2143.442	15.106	2463.710	1618.363
1955	762.798	756.834	239.415	1778.980	33.687	2699.623	1787.577
1960	1106.480	1098.214	205.873	1039.637	11.031	2527.044	1928.717
1965	679.918	677.795	829.138		137.570		2577.913
1970	765.590	748.823	588.785	910.720	145.559	1795.504	2202.557
1975	435.456	426.776	252.267	1483.967	17.237	2154.453	2004.461
1980	951.476	950.076	395.557	681.745			1990.941

Source: [USBM annual]

All values are five year averages centered on year shown except 1880=actual

FIGURE 7-1: Mercury Process-Product Flows



Mercurous chloride, Hg_2Cl_2

"calomel", formerly an important pharmaceutical used as a skin ointment and as a fungicide.

Mercuric nitrate, $Hg(NO_3)_2$

intermediate in the production of fulminate (above) and red mercuric oxide (HgO). Formerly used in the treatment of felt and furs.

Mercurous sulfate, Hg_2SO_4

formerly a catalyst in the manufacture of acetic anhydride from acetylene and acetic anhydride from acetylene

Mercuric acetate, $Hg(COOH_3)_2)$

an intermediate in the production of phenyl mercuric acetate (PMA)

Mercuric Oxide, HgO (red, yellow)

a catalyst in the manufacture of sulfonated anthroquinone derivatives; used in batteries; formerly used in anti-fouling paint; formerly in pharmaceuticals

Mercuric Sulfide, HgS

a red pigment (vermilion) now used in combination with cadmium sulfide to give colors ranging from light orange to dark maroon.

Phenyl Mercuric Acetate (PMA), $Hg(COOCH_3)$

Phenyl Mercuric Oleate (PMO), $Hg(COOC_7H_{14}(CH_2)_2C_8H_{17}$

Ethyl Mercury Acetate (EMA)

Methyl Mercury Dicyandiamide (MMD)

Methyl Mercury Chloride (MMC), $4C_2H_5HgCl)$

Pyridyl Mercury Acetate

The organic mercury compounds (PMA, PMO, EMA, MMD, MMC, etc.) are currently used as fungicides; e.g. to protect seed grain, in anti-mildew paints, and as catalysts in several processes, especially the manufacture of urethane elastomers. Pyridyl mercury acetate was used as a slimicide in the paper pulp industry during the 1950's and 1960's.

The toxic and catalytic properties of mercury were the basis of many new chemical uses after 1900. Mercury salts were the preferred catalysts for a number of processes involving acetylene and its derivatives, notably

acetaldehyde from acetylene	(mercurous sulfate)
acetic anhydride from acetylene	(mercurous sulfate & mercurous acetate)
vinyl acetate from acetylene	(mercuric chloride)
vinyl chloride from acetylene[17]	(mercuric chloride)
urethane elastomers	(organic mercury, e.g. PMA, PMO)
sulfonated anthroquinone derivatives	(mercuric oxide)}

Acetylene was a major chemical feedstock from the 1930's to the 1950's but has largely been displaced in this context by ethylene. Thus the use of mercury-based catalysts grew throughout the

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[17] In this important process, about 0.148 lb of mercury was lost, primarily via waterborne wastes, on the average, for each ton of vinyl chloride monomer (VCM) produced [NMAB 69, p.15].

1920's and 1930's in proportion to the production of acetylene-based chemicals and reached a peak in WWII. Acetic acid production alone accounted for 2.5% of mercury use in 1940. Use in urethane production grew sharply in the 1960's. Catalytic applications have gradually declined since WWI *except* in the manufacture of urethanes and anthroquinone derivatives.

Applications of mercury based on its biocidal properties include familiar antiseptics, such as "mercurochrome" and "merthiolate" (classed under pharmaceuticals), industrial germicides for preventing bacterial or fungal attack on organic materials such as wood and natural fibers, agricultural fungicides -- especially for protecting cereal grains for seed, antifouling paint for ships (to retard the growth of marine organisms such as barnacles) and "anti-mildew" paints for a variety of commercial and household purposes. Mercury-based germicides and antiseptics accounted for nearly 28% of all mercury used in 1942 and over 20% in 1950.

The pattern of mercury uses has changed significantly over the decades. One of the earliest of the biocidal uses, noted above, was in the manufacture of fur and felt hats. Apparently the felt-making process involved a step (called "carotting") where the wool and/or other animal hairs from which felt is made are soaked in an acid solution of mercuric nitrate to preserve them from attack by putrefying bacteria. At the conclusion of this stage, the wool or fur contained two to three percent mercury by weight [EA 69]. About one third of this mercury was volatilized during the subsequent hat-making stage. Many hat manufacturers were located in or near Newark, NJ, or New York City [USTD 37]. For examples, one study carried out in 1878 (ibid) surveyed workers in 28 plants in Newark[18]. The remainder was lost slowly to the air over the life of the hat. As noted previously, this use of mercury was still important until WWII. A breakdown of recent uses of mercury is show in Table 7-2.

Mercury-based fungicides for agricultural purposes were also evidently quite important in the 1930's, although statistics are lacking prior to 1942. This use peaked about 1956 and has declined since then. The decline became rapid after 1968 as the dangers of mercury in the environment became apparent[19].

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[18] Mercury poisoning apparently was a serious occupational health hazard of hat-makers (hence the phrase "mad as a hatter"; and a possible inspiration for the mad hatter in *Alice in Wonderland* [Census 00, p.4-9].

[19] The dangers of mercury use were dramatized in the 1950's and 1960's by a number of cases of "Minimata Disease" in Japan, finally diagnosed as methyl mercury poisoning from eating fish. This was traced (after nearly two decades) to inorganic mercury discharges from an acetaldehyde manufacturing plant. Not until the 1960's was it discovered that inorganic mercury can be metabolized by anaerobic bacteria and converted into alkyl form that is readily taken up in the food chain. See [d'Itri 80]

Table 7-2: U.S. Mercury: Recent Categories of Use (tonnes)

	Agriculture	Catalyst	Dental Preparation	Electrical Apparatus	Electrolytic Preparation Chlorine & Caustic Soda	General Laboratory (Vacuum Pumps)	Industrial & Control Instruments	Paint-Antimildew & Antifouling	Pharmaceutical	Other Uses Known & Unknown (calculated)
1930	12.6	34.5	28.1	88.1		21.6	103.3		189.4	635.9
1935										
1940	52.8	112.1	47.5	156.9	9.5	10.1	121.7	42.1	278.8	872.4
1945	103.4	132.0	28.5	363.1	18.9	8.2	131.1	61.6	342.7	551.2
1950	205.7	82.6	41.7	304.1	47.7	17.8	197.4	65.4	117.0	538.8
1955	263.7	26.7	51.7	335.4	103.4	36.0	196.5	20.5	59.5	694.1
1960	132.9	28.8	75.0	340.1	206.5	45.6	203.8	132.5	83.8	679.7
1965	102.8	56.1	85.8	433.7	359.7	190.8	202.0	235.1	89.0	823.1
1970	77.5	61.5	115.0	593.3	529.7	56.0	212.9	307.6	21.3	227.8
1975	31.5	38.7	77.7	767.6	496.3	17.0	194.7	258.9	14.7	110.2
1980	2.0	18.3	37.4		319.6	12.4		285.4	0.0	1320.7

Source: [USBM annual]

Values shown are five year averages centered on year shown, except 1980=(1978-1980)

Fungicidal and agricultural use has been essentially banned in the U.S. since 1972. A related use, to inhibit bacterial growth in wood pulp in the paper industry, began in the late 1940's and peaked in the 1950's. It was phased out completely by 1971, partly due to EPA actions.

In 1968-69 PMA and PMO accounted for close to 60% of mercury-based fungicide sales, which amounted to about 1.3 million pounds in each of these years. Most of these compounds were apparently produced by several small firms located in northern NJ,viz.

- Cosan Chemical Corporation, Carlstadt NJ (Passaic River) Nuodex Corporation, Elizabeth NJ (Newark Bay) Troy Chemical Corporation, Newark NJ (Newark Bay) W. A. Cleary Corporation, Somerset NJ (Raritan River)

Process details are not available. However, since chemical production processes seldom have yields in excess of 96% (based on inputs) it is not unreasonable to assume that up to 4% (or more) of the mercury used in manufacturing mercury-based chemicals during the 1930's through the 1960's may have been volatilized or discharged into nearby waterways, including Newark Bay and Raritan Bay. This is apparently confirmed by core samples. Sediments taken from large areas of Newark Bay and Kill Van Kull contain more than 5 mg of mercury per kg [Suzkowski 78].

Similarly, the use of mercury for marine anti-fouling paint by the Navy was substantial during WWII (~5% of all mercury consumption) and peaked again in 1949-50 during the Korean conflict. Thereafter this use declined rapidly, being replaced primarily by zinc-based compounds. On the other hand, use of mercury compounds as a standard anti-mildew additive for house paint began in 1958 and grew fairly steadily until 1979 when it peaked at almost 10,000 flasks. It has declined sharply since then, however, as more effective means of protection have evolved.[20]

In the decades since WWII, another large consumptive use of mercury was in the manufacture of chlorine and sodium hydroxide by electrolysis of sodium chloride (brine). This technology was commercialized as early as 1894, with Hamilton Castner's "rocking cell", which was the dominant electrolytic method in the first quarter of this century. However, total chlor-alkali production in those years was not great: 19,400 tons of caustic soda were produced electrolytically in 1909, rising to 94,800 tons in 1919. (At least one small chlorine-cell plant was in Jersey City before WWII. It closed in 1953.) Most new chloralkali plants constructed in the 1920's, 1930's and 1940's utilized diaphragm cells, rather than mercury cells.

However, the economics of the mercury cell changed dramatically with the advent of the DeNora cell, developed in Italy and licensed by Monsanto shortly after WWII. See Figure 7-2. Olin Mathieson Chemical Company also developed a new mercury cell design. Chlorine production since the 1940's has risen enormously, spurred by burgeoning demand for chlorinated pesticides (like DDT, aldrin, dieldrin, endrin and chlordane), herbicides (like 2-4-D and its relatives), and plastics, notably PVC. Roughly half of the new capacity added in the 1950's and 1960's utilized mercury cells. See Figure 7-3. By 1970 there were 25 mercury cell chlor-alkali plants in the U.S., producing 2.5 million tons of chlorine per annum [EPA 71]. Two of these were located in the Hudson-Raritan basin; GAF Inc. built a plant in Linden NJ in 1956 and Maquite Inc. built one in Elizabeth NJ in 1964. A third mercury cell was built by Linden Chloride

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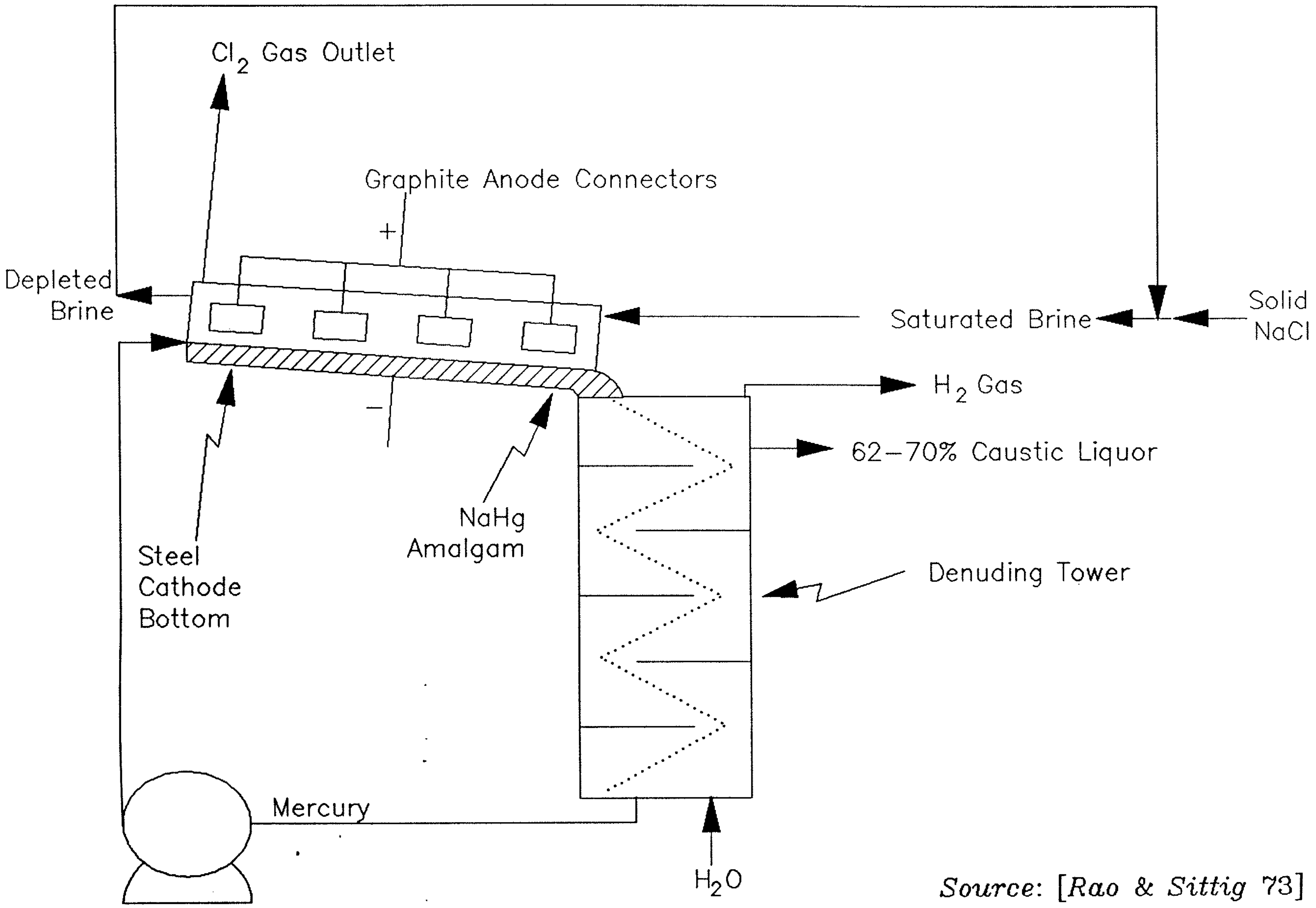
[20] The effectiveness of mercury-based fungicides in paint declines rapidly with time, due to decomposition and volatilization. Decomposition rates exceed 3.2% per month, even indoors, and experiments have shown that fungicidal effectiveness typically declines by 80% in 17 months [OECD/ED 74a, p.46]. Use of mercury-based fungicides in paint was banned in Japan in the early 1970's.

FIGURE 7-2: Schematic of DeNora Mercury Cell



Source: [*Rao & Sittig* 73]

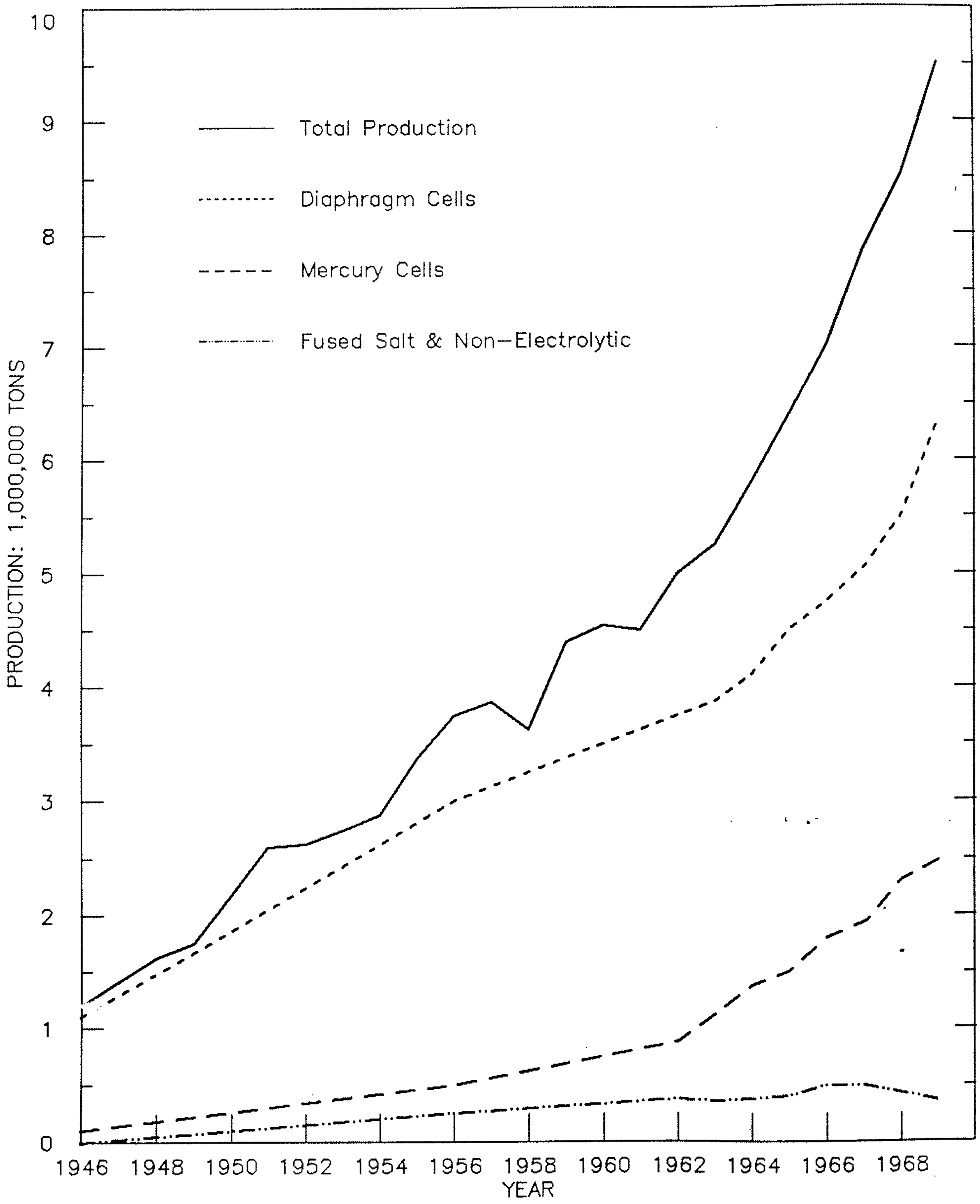
Products Co. in Linden, NJ,in 1972-74 [Rao & Sittig 73]. Before the hazardous nature of mercury emissions was fully recognized, emissions averaged 0.6 lb of mercury per ton of chlorine produced. The loss rate had declined to 0.3 lb per ton by 1971 (ibid).

The other major continuing uses of mercury have been in manufacturing instruments (e.g. thermometers), in mercury vacuum pumps used in most chemical laboratories, and for electrical apparatus. Most of the annual consumption in this category is actually replacement of losses from leakage. Mercury vapor lamps were introduced in the 1930's by Westinghouse and have been widely used since then. Mercury vapor is also used in high power rectifiers and other electron tubes. This use began declining in the 1950's when solid state transistors began replacing electron tubes. Mercury was extensively used in certain relays and switches, taking advantage of its unique property of being an electrically conductive liquid. This use is also being replaced by solid state devices. Laboratory use appears to be rather steady.

Starting in 1923 several electrical utilities installed binary-cycle mercury vapor driven turbines, which achieved higher thermal efficiencies than steam turbines. Large quantities of mercury were required, although losses were (theoretically) nil. Plants were built at Hartford, CT Kearney, NJ, and Schenectady, NY [USBM annual]. Over 150 tons of mercury was used in these plants, although most of it was recovered. Progress in steam turbine technology made mercury vapor turbines obsolete. The use of mercury vapor turbo-generators was phased out in the 1950's, primarily for economic reasons.

The largest present (and still growing) electrical use of mercury is in batteries. There are three types of primary (i.e. non-rechargeable) cells that utilize mercury. The oldest is the so-called number 6 (6 inch) "dry-cell", consisting of an exterior zinc can (anode), a pasty electrolyte consisting mainly of ammonium chloride thickened by starch, and a central carbon electrode. The electrolyte and zinc anode were separated by a wet paper liner containing a small amount of mercuric chloride ($HgCl_2$) to amalgamate the zinc. These cells were manufactured at least as early as 1886 [EB 55, *Battery*]. U.S. annual production of dry cells reached 2 million by 1899 and 34 million by 1909. They were used to power telephones, doorbells, ignition for auxiliary engines, "A" filament circuits for radio receivers and a host of other purposes. Miniature versions ("flashlight" cells) were also introduced soon after 1900. They were also used as "B" (plate) circuit batteries for radios and later as "A" batteries for portable radios. Flat type "B"

FIGURE 7-3: Chlorine Production in the U.S. by Cell Type



Total only for 1947–1955 and 1957–1961
(Specific cell types interpolated)

Source: [*EPA* 71]

dry batteries for radios also utilized mercury salts for the same purpose. Production of primary cells of all kinds in the U.S. reached an annual level of 10^9 units by 1940. This was sharply boosted by wartime requirements to an annual rate of $3*10^9$ units by the beginning of 1945. Dry cells were used in radios, 'walkie-talkie" units, bazookas, mine detectors, etc. Postwar production dropped by about one third but demand for portable radios and flashlights has continued to grow.

The second type of battery that utilizes mercury is the so-called Edison-Lalande alkaline cell, with an amalgamated zinc anode, copper oxide (CuO) cathode and caustic alkali electrolyte. Mercury serves the same function as in the "dry" cell, namely to reduce anode corrosion. These cells (in large sizes, up to 500 amp/hr) were widely used for such purposes as providing intermittant power for railway signals. These cells were manufactured initially at Silverlake NJ.

The third important use of mercury in primary batteries is in the specialized "mercury cell", a miniature cell used mainly for hearing aids, consisting of a zinc anode, an electrolyte of 30-40% potassium hydroxide containing dissolved zinc and a cathode mix of 92% red mercuric oxide and 8% micronized graphite. These cells were introduced commercially after WWII and this use continues to grow.

Secondary mercury is derived largely from mercury cell batteries and spent mercury catalysts. The occasional closure of a mercury-cell chlor-alkali plant also releases secondary mercury. Electrical apparatus containing small amounts of mercury is generally discarded in landfills. At one time it was assumed than inorganic mercury was environmentally harmless, but it is now known that anaerobic bacteria can metabolize inorganic mercury to highly toxic methyl-mercury compounds which are transmitted (and concentrated) by the food-chain. This is known to occur in water, e.g. [d'Itri 80], and may occur in soils [OECD/ED 74a, p.37]. Thus mercury in landfills is a potential future risk. On the other hand, this mechanism probably prevents large toxic buildups in soils or sediments.

In addition to process losses and dissipative consumptive losses, mercury can get into the environment in other ways [d'Itri, op cit]. The most important of these is via combustion of fossil fuels. Mercury is a trace element in both coal and oil. Flux estimates vary widely [NRC 81, Table 4.3] but it is clear that both sources of emissions may be significant, even locally dominant in certain localities, due to the enormous quantities of fossil fuels that are burned. (See separate discussion on coal combustion in Chapter 10).

8. Anthropogenic Lead Sources and Flows

Lead is mined in the U.S. mainly in Missouri, Colorado, Idaho and Arizona.[21] There are no lead mines in the Hudson-Raritan basin, but a small amount of lead was mined in the northeast states during the early years of this century. However, refining and desilverizing lead from imported ore or bullion (from Mexico) were very important in the region. Two lead refineries, Balbach Metals in Newark, NJ (1883) and American Smelting and Refining Co. (ASARCO) built in 1898 at Perth Amboy, NJ, accounted for 32.5% of the total of 222,000 tonnes of refined lead in the U.S. in 1899, almost all from imported ore [Navin 78]. These refineries incidentally yielded 22,400,000 fine oz. of silver (as dore metal). The U.S. Metals Refining Co. copper refinery at Carteret (1902) also included a lead refinery. The original Balbach refinery was expanded in 1981. It closed in 1919 but reopened in 1927 at Carteret, NJ and operated until 1945. The ASARCO refinery at Perth Amboy, NJ, was operated until 1961.

Refinery output in New Jersey evidently peaked sometime before statistics were kept regularly by the U.S. Bureau of Mines (starting in 1913). For the period 1799-1912, it is known that 18% of domestic (cumulative) lead refinery output was from imported ores or bullion [USBM annual. 1924 ed.]. Since over 80% of this production occurred after 1880, it is reasonable to assume that the 18% figure holds on the average for 1880-1912. However, since imported ore and bullion accounted for only 12% of U.S. output by 1913 and less, on the average, thereafter (except for 1918). This strongly suggests an import fraction of 30% or more during the earlier part of the period (say 1880-1900) We can probably equate New Jersey lead refinery output largely with processing imported base bullion, since the region did very little primary smelting: 0.35% of U.S. lead smelter output in 1899 [Census 00].

National Lead Company had a large lead pigment manufacturing plant in Perth Amboy, and another in Brooklyn, NY. Secondary recovery of lead from batteries and cable sheathing is growing in importance, with over 100 smelters in the U.S. as of 1975. They are predominantly located near large industrial cities in the north and east and north central regions. Several secondary smelters are located in or near Perth Amboy, NJ [Watson & Brooks 79].

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[21] There are only two significant eastern lead mines: a lead-zinc mine at Balmat (St. Lawrence County, NY and Wythe County, VA)

Aggregate consumption of primary lead in the U.S. was about 95,000 tonnes in 1880, rising to 255,000 tonnes in 1900 and 350,000 tonnes in 1935 (when the use of tetraethyl lead began to increase sharply). In recent years, aggregate U.S. lead consumption of primary and secondary lead has hovered in the region of 1.3 million tonnes (See Tables 8-1 and 8-2).

Table 8-1: U.S. Lead Production (1000 tonnes)

	US Mine Production (Pb Content)	Primary Smelter Production Total	Antimonial Lead Production (Primary Pb Content)	Refined Lead Produced From Foreign Base Bullion	Secondary Lead Production (inc Bull.) (Pb Content)	Lead Primary+ Secondary Production (Pb Content)
1880		102.814				105.233
1885		125.483				124.889
1890		163.076				
1895		220.164				
1900		309.693				
1905	165.432	357.219			23.131	
1910	356.842	413.970			43.018	
1915	500.736	496.509		27.536	100.581	
1920	431.988	477.782		49.486	159.653	
1925	576.449	666.101	15.865	64.028	277.973	779.930
1930	459.226	530.420	15.969	40.267	277.659	719.504
1935	295.548	320.408	4.946	4.688	218.838	489.616
1940	398.937	460.612	15.841	21.424	283.993	739.022
1945	359.372	391.390	17.060	0.092	352.316	760.674
1950	364.604	414.201	20.161	2.660	435.193	866.895
1955	307.922	455.334	14.825	0.093	447.462	917.580
1960	230.154	366.349	15.165	0.703	403.506	784.316
1965	269.402	377.940	8.117		496.680	882.737
1970	478.522	489.834	10.873		538.066	1034.424
1975	560.712	588.106	6.015		648.294	1242.414
1980	512.711	539.171	2.798		691.713	1233.682
		(c)	(d)	(e)	(f)	(g)

All data are five year averages centered on year shown and include from 1-5 years of raw data.
Source: [USBM annual], except where noted
(c) [Census 75] thru 1970, then summed
(d) Before 1930 includes production from scrap
(e) 1925-28 & 1936-37 estimated
(f) From 1913-1958 includes refined lead produced from foreign base bullion
(g) Before 1930 includes 1/3 of antimonal lead only. 1880-1885, [Potter & Christy 62, Table MO14a]

Table 8-2: U.S. Lead Consumption (tonnes)

	Con sump tion (Use Sum) TOTAL	Imports Refined Lead (Pigs, Bars, Old Lead) (Pb Content)	Exports Refined Lead (Pigs & Bars) (Pb Content)	Primary+ Secondary Lead Consumption	Apparent Primary Consumption =Production+ Net Imports	Primary Consumption (Preferred Series)
1880		2.589			105.536	113.096
1885		3.472			125.736	136.078
1890		2.688			154.403	157.850
1895		16.264	3.898		191.053	197.222
1900		2.133	1.228		225.526	253.467
1905		7.007	0.051		309.169	331.304
1910		2.860			342.553	351.625
1915		1.301	70.282		416.035	433.271
1920	619.743	13.678	43.114		446.879	468.833
1925	758.198	10.891	78.661	882.388	600.375	612.712
1930	663.225	3.803	51.348	723.933	473.187	485.888
1935	507.143	1.094	13.450	601.826	307.173	376.663
1940	619.563	137.411	29.087	756.048	575.336	685.832
1945	678.279	173.728	3.820	981.951	557.556	672.405
1950	1024.236	297.788	1.297	1024.236	732.461	665.583
1955	1062.667	272.390	1.954	1062.667	745.161	690.005
1960	949.924	241.861	1.873	949.924	606.337	614.799
1965	1123.343	236.663	5.633	1123.343	608.971	682.430
1970	1269.236	237.451	6.400	1269.236	720.885	863.322
1975	1362.617	148.931	30.040	1362.618	705.041	828.758
1980	1194.182	167.347	61.110	1329.018	596.997	
		(a)	(b)			(c)

All data are 5 year averages centered on year shown and include 1-5 years of raw data.
Source: [USBM annual], except where noted
(a) [Census 75] thru 1970. From 1977 = grand total minus lead
(b) [Census 75] thru 1970. From 1971 = unwrought + wrought lead
(c) [Potter & Christy 62, Table mc24h]

Since lead has relatively low melting and boiling points, metallurgical processes involving lead do create some lead-containing fumes and atmospheric aerosols. Uses that depend on the low melting point (e.g. solder and type metal) also generate aerosols. Production-related emissions in the Hudson Raritan basin in recent decades can be assumed to be associated mainly with secondary smelters, however.

Particulate emissions from a primary lead blast furnace range from 125 to 180 kg/Mg [EPA 84]. The dust -- similar in composition to the furnace charge -- is mostly recovered by means of baghouses, with an efficiency of 95 to 99.9% (ibid p.39). Recovery in the early 20th century was much lower: we assume(?)% kg/Mg of dust was generated. Input material averages 28-50% lead, 0.3-4.5% Cu, 4-1.25%(?) zinc and 0.03-0.07% silver (ibid, Table 11, p.24). The copper and residual sulfur form a matte (44-62% Cu; 10-20% Pb and up to 13% S), which is separated and sent to a copper refinery (ibid p.35).

Arsenic, if present, forms iron arsenide and separates into a so-called speiss layer below the matte. The bottom layer of (bullion) is 94-98% pure lead, with a variety of contaminants including As, Ag (0.13-0.31%), (~0.7-1.1%), Cu (1.0-2.5%), and traces of other metals (ibid p.35). Most of the zinc remains in the slag where it is essentially immobilized.

Slag piles may well be a major source of water pollution from lead smelters. Hot slag is normally cooled (and granulated) by quenching in a holding pond. Over time such ponds may be significant sources of lead, copper and zinc pollutants to groundwater or via runoff nearby surface waters.[22]

Secondary smelters may have reverberatory furnaces, or blast furnaces, or both, depending on the source of recycled material and the product. Storage batteries for automobiles are predominantly made from recycled lead. In a typical operation (prior to pollution controls), about 7% of the input materials would be lost as smoke or fumes, and about 23% of the particulates are lead, by weight. This amounts to 28 kg of lead emissions per metric ton of product for reverberatory furnaces and 26.5 kg per metric ton of product for blast furnaces [Watson & Brooks 79]. Emission control standards were not promulgated until 1973-74 and were (presumably) implemented during the following several years. Assuming annual secondary lead throughput rates of 20,000 metric t.p.y. would imply gross pre-control emissions of 5.5×10^5kg/yr from secondary smelters. Perth Amboy NJ is one of the three largest concentrations of secondary lead recovery in the U.S. (others being Baltimore and Chicago) (ibid).

Lead is used both in metallic and non-metallic forms. The latter are derived initially from the metal by a sequence of process steps illustrated graphically in Figure 8-1. Historically one of the major uses of lead has been for pigments, which is an inherently dissipative use. Major pigment products are as follows:

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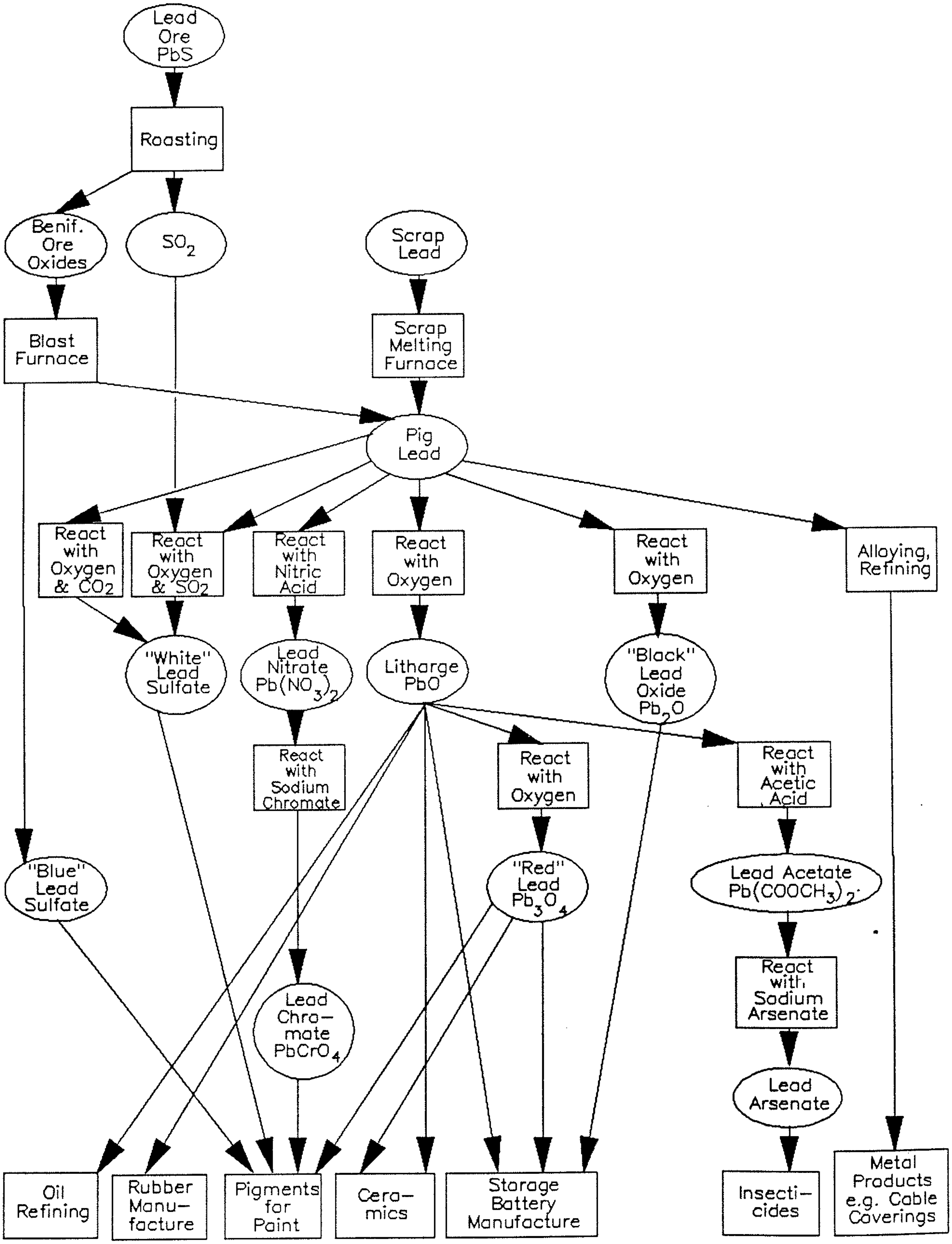
[22] It is known that the ASARCO lead and copper smelter/refinery at Perth Amboy, NJ, was built on land that was originally marsh. Much of the fill was probably slag from the plant itself [Marcosson 49].

FIGURE 8-1: Lead Process–Product Flows



"White Lead", $2PbCO_3.Pb(OH)_2$

is the oldest pigment used for manufacturing white oil paint. It was the predominant white pigment early in the century but was gradually displaced in the 1920's,1930's and 1940's by zinc oxide and then later by lithopone (a mixture of barium sulfate and zinc sulfide).[23] Almost all white lead manufactured was used in paint (~93%), the remainder having been used in ceramics (4%) and miscellaneous. It was made entirely from pig lead. White lead is 80% lead by weight.

Litharge, PbO

is primarily an intermediate material. It was used primarily to manufacture positive plates for lead-acid storage batteries, lead arsenate insecticide, and for a variety of other dissipative purposes including rubber manufacturing, oil refining (to remove sulfur from gasoline), ceramics, lead chromate pigment, varnish and linoleum. Red lead (below) is made from litharge by further heating in air (hence it is seldom pure). Litharge itself is made from pig lead by air oxidation. The use of commercial litharge and red lead in storage batteries has largely been replaced by so-called "black oxide" or suboxide, made by the battery manufacturers themselves. Litharge is 93% lead by weight.

"Red Lead", Pb_3O_4

is the pigment used in oil-based paints to protect exposed iron and steel surfaces (such as bridges). It is still used for this purpose. It was also formerly used in the manufacture of lead-acid storage batteries (with litharge). Red lead is 91% lead by weight.

Basic Lead Sulfate, $PbSO_4$

has two forms ("white" and "blue"). The white version is made directly from pig lead by reaction with oxygen and sulfur dioxide. It was used in prepared paints. The blue variety was mainly a by-product of lead smelting furnaces, the color being due to small quantities of carbon and lead sulfide. It was mainly used in protective paints for metal surfaces and in rubber. Lead Sulfate is 68% lead by weight.

Lead Chromate, $PbCrO_4$

is the major ingredient in so-called "chrome" pigments used for green, yellow and red paints with a high degree of color retention under exposed conditions. Used for protecting heavy equipment (e.g. bulldozers), marking roads, etc. Lead chromate is 64% lead and 16% Chromium by weight.

Leaded Zinc Oxide,

is essentially zinc oxide with an admixture of lead sulfate, produced by reducing zinc-lead ore (ZnS) with anthracite coal to produce SO_2 and zinc vapor which then reacts with oxygen to form the zinc oxide. The lead sulfide in the ore is also reduced and it, in turn, reacts with SO_2 and oxygen (as in the direct process to manufacture lead sulfate). The ratio of zinc to lead varies, but is usually about 2. Thus lead zinc oxide is about 25% lead and 50% zinc, by weight.

OTHER IMPORTANT LEAD CHEMICALS:

Lead Acetate, $Pb(COOCH_3)_2$ ("sugared lead")

is an intermediate in the production of lead arsenate.

Lead Arsenates, (See Arsenic)

Quantities were significant in the 1930's and 1940's.

Lead Azide, $Pb(N_3)_2$

is an explosive used for detonators and percussion caps (a more stable substitute for mercury fulminate)

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[23] The major disadvantage of white lead (apart from cost) was its tendency to blacken in the presence of sulfur compounds. The increasing combustion of coal, resulting in emissions of sulfur dioxide (SO_2) was thus an important factor in the replacement of white lead.

Lead Molybdate, $PbMbO_4$
is a component of molybdate chrome orange pigment used in chrome yellow pigments.

Lead Nitrate, $Pb(NO_3)_2$

Lead Suboxide, Pb_2O, ("black oxide")
has replaced litharge and red lead in storage batteries. It is made directly from pig lead. Black oxide is 96.5% Pb by weight.

Tetraethyl lead(TEL), $Pb(C_2H_5)_4$ & Tetramethyl lead(TML), $Pb(CH_3)_4$
are gasoline additives to increase the octane number. 'Leaded' gasoline contains about 0.6 gm of lead per liter.

Lead Stearate, $2PbO.Pb(C_{18}H_{35}O_2)_3$
is used in greases, cutting oils and as a stabilizer in vinyl plastics.

Until the 1950's, pigments were by far the major dissipative use of lead (see Table 8-3), with lead arsenate and tetraethyl lead (TEL) interchanging second and third spots in volume in the late 1930's. However, lead-based pigments are highly insoluble in water and weather slowly. Volatilization is insignificant, in normal circumstances. Lead from pigments will find its way to waterways via urban runoff primarily by way of dust from weathering processes. Residual lead from lead arsenate insecticides tends to be bound quite strongly to soil particles in insoluble form. It reaches waterways only when the soil particles themselves are blown or carried away by runoff. For the northeastern U.S. this process is probably insignificant.

On the other hand, the lead allyls, tetraethyl lead (TEL) and tetramethyl lead (TML) are manufactured and used exclusively as anti-knock additives for gasoline.[24] Production of TEL began in the early 1920's[25] at Dupont's Deepwater NJ plant (located on the Delaware River south of Camden) under exclusive contract to Ethyl Corporation which was then jointly owned by GM and Standard Oil (NJ). (Dupont then owned 25% of GM.) Production at Deepwater reached maximum capacity of 65,000,000 lb. in 1937. The following year (1938) Dupont built a similar plant for Ethyl Corp. at Baton Rouge, LA. After the original anti-knock patents expired Dupont terminated its contract with Ethyl Corp. and became an independent competitive producer in the 1940's. Other companies also now produce TEL and TML.

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[24] The discovery of TEL (1921) by Kettering, Midgely and Boyd at Dayton Engineering Laboratories (later DELCO division of GM) enabled refineries to increase gasoline octane numbers very significantly at moderate cost. This, in turn, enabled auto manufacturers to increase engine compression ratios, resulting in significantly higher engine power output per cubic inch of displacement. It also resulted in substantially increased fuel efficiency. The average auto engine compression ratio in 1927 was 4.55, generating .256 hp per cubic inch displacement. By 1965 – the peak year – average compression ratios were up to 9.73 and engines were generating .832 hp/cubic inch. Both figures have dropped significantly since 1970 when nearly all new cars had to be built to utilize unleaded gasoline.

[25] ESSO(EXXON) also briefly produced TEL at its Bayonne NJ refinery in the early 1920's but the attempt ended in tragedy, with several deaths, and ESSO discontinued production.

Table 8-3: Detail Breakdown of U.S. Lead Uses (1000 tonnes of lead content)

	Metal except Batteries	Storage Batteries	White Lead Pigment	Red Lead & Litharge	Colors & Paint	Other Pigment	Pigment Total	TEL &	Other Chemicals	Chemical Sub Total	Lead Arsenate	Not Accounted For (Dif)	Consumption (Use Sum) TOTAL
1922	303.6	117.9	141.5	27.2			168.7				3.6	29.5	619.7
1925	411.5	155.7	119.2	35.6			154.8				5.7	34.0	758.2
1930	361.7	161.1	83.2	23.0			106.2	3.4		3.4		31.4	663.2
1935	206.5	157.5	68.1	37.3			105.3	25.1		25.1	19.5	8.8	507.1
1940	275.9	131.0	63.7	73.2			137.0	40.0	6.9	42.8	19.3	13.6	619.6
1945	235.5	57.6	38.6	128.7			167.3	61.7	8.1	69.8	19.6	29.5	678.3
1950	439.1	325.3	24.3	75.8	10.6	12.2	123.0	104.9	6.7	111.6	7.3	18.0	1024.2
1955	431.1	330.5	15.2	75.7	11.7	9.4	111.1	154.0	4.8	158.7	3.9	26.0	1062.7
1960	346.3	332.3	11.2	64.1			90.2	147.7	2.7	150.4	2.7	27.6	949.9
1965	323.6	398.3	8.0	64.1			89.9	207.7	0.6	175.5	1.5	66.7	1123.3
1970	319.3	604.7	4.1	63.2	13.5	0.7	81.4	248.3	0.6	248.9	1.6	38.6	1269.2
1975	260.4	741.9	2.9	75.2	13.8	0.5	92.5	218.8	0.4	219.2	1.2	48.4	1362.6
1980	219.0	729.8					84.6	157.4				23.4	1194.2
	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)	(s)	(t)		

All data are five year averages centered on year shown and include from 1-5 years of raw data, except 1922= actual.

Source: [USBM annual], except where noted

(j-w) Prior to 1946 follows ABMS classification

(l-p) Classification change in 1980; Pigment total remains same

(n-r) Prior to 1946 included in Miscellaneous

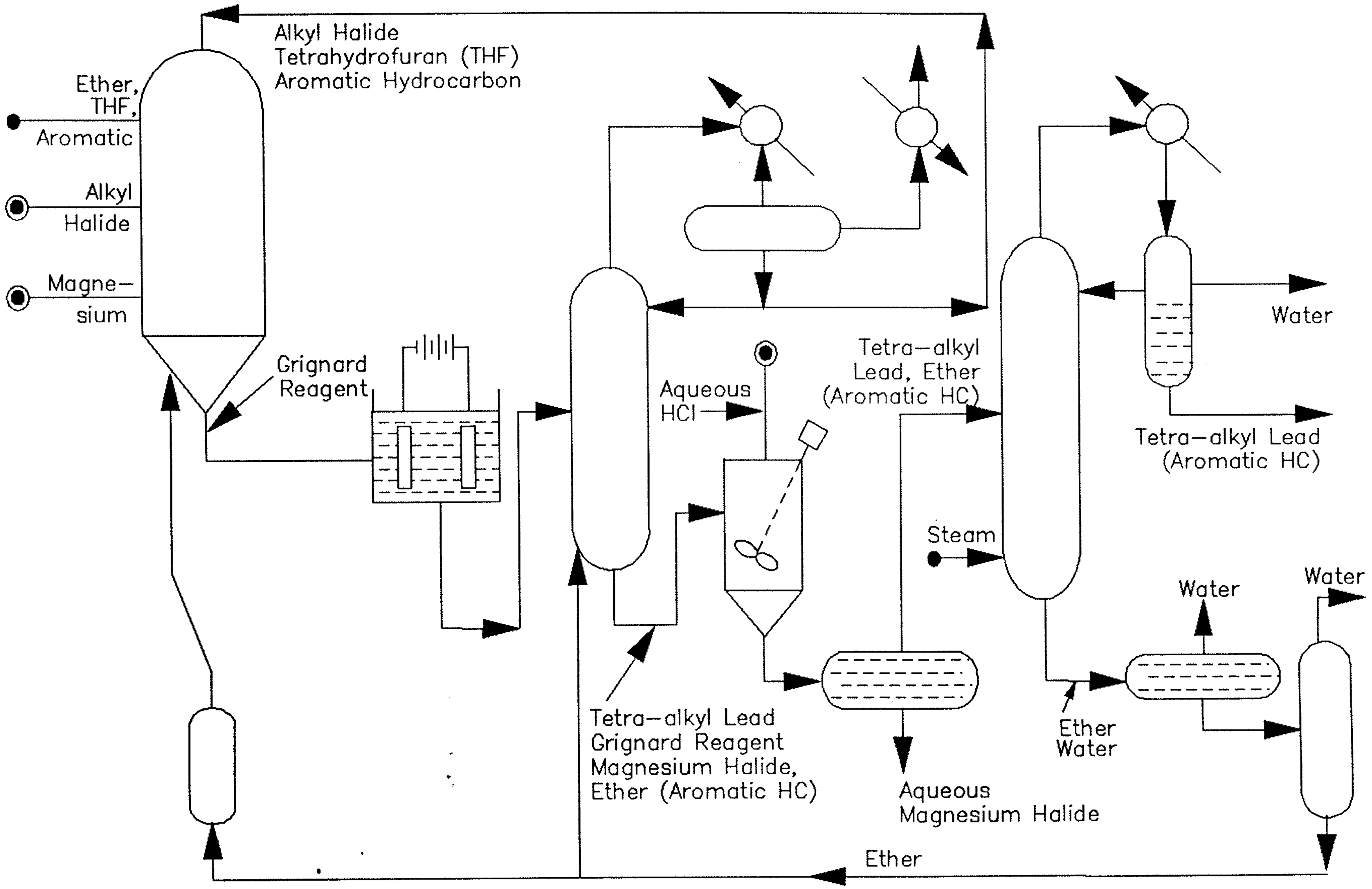
(q) Author's calculation prior to 1930

(t) Apparent supply- see Appendix M-3 (Arsenic)

However, only the original Dupont plant is located in the eastern part of the U.S. A flow chart for the standard TEL production process is shown in Figure 8-2.

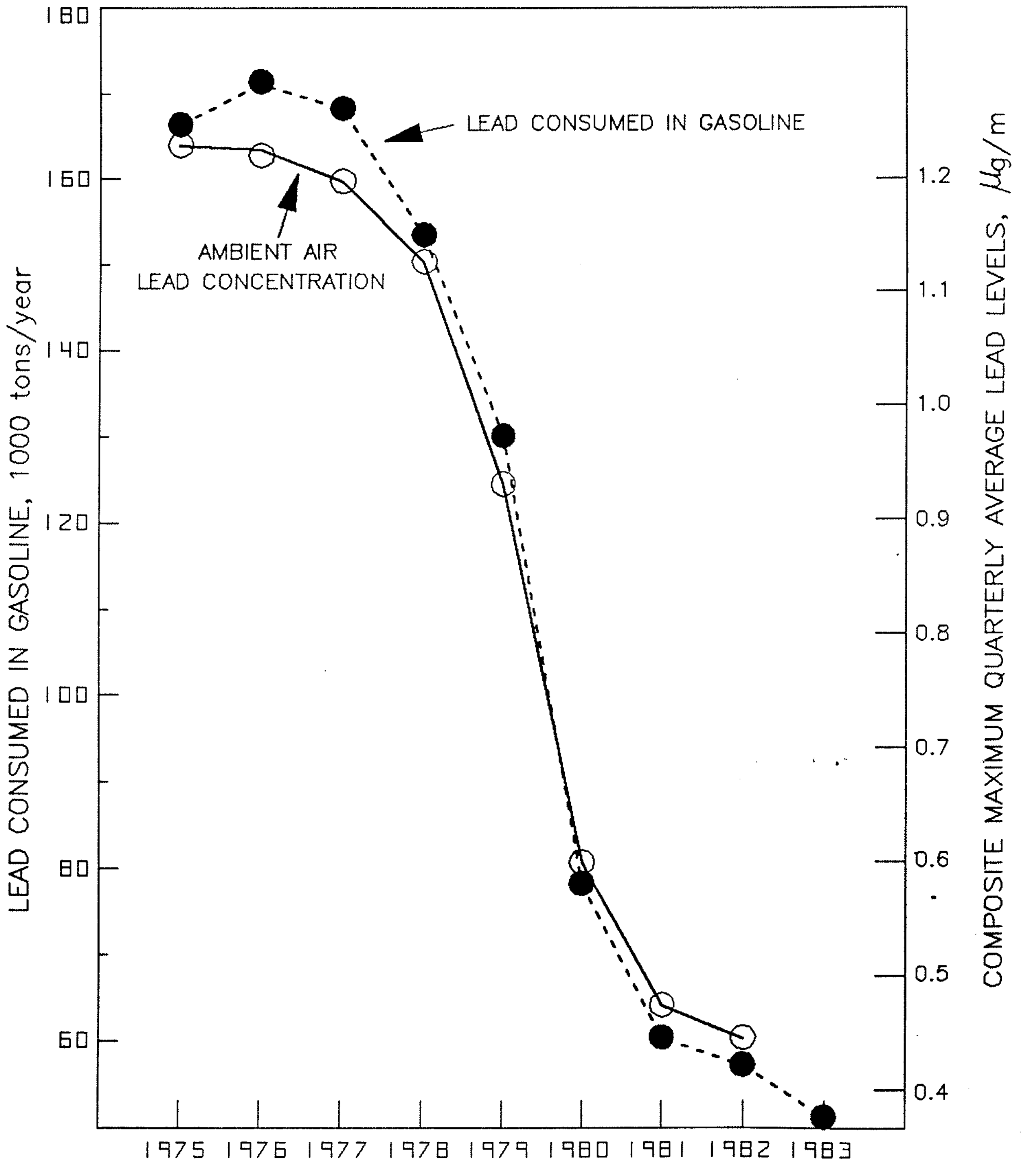
Consumption of leaded gasoline by automobiles and trucks has become the dominant source of atmospheric lead since the 1930's, if not earlier, except in the immediate vicinity of lead smelters and secondary recovery activities. TEL and TML are blended into gasoline by refineries at the rate of 100 to 120 tons (Pb content) per million bbl. of (leaded) fuel. After combustion, some of this (of the order of 25%) is retained in the car, mainly in the oil filter and exhaust system. The remainder is vented directly into the air [Nriagu 80a]. Emission control regulations on new automobiles have sharply reduced usage of leaded fuel since 1970. The decline in atmospheric lead concentrations has followed rather precisely (Figure

FIGURE 8-2: TEL Recovery from an Alkyl Grignard-containing Electrolyte



Source: [*Rao & Sittig* 73]

FIGURE 8-3: U.S. Lead Consumed in Gasoline & Ambient Lead Concentrations 1975-1983



Source:[*EPA* 84, *Figure* 1-8]

8-3). Consumption of alkyl lead by a region can be assumed to be roughly in proportion to the gasoline consumption of the region. For purposes of estimating gross magnitudes, the 1970 population of the Hudson-Raritan watershed area was 8.3% of the U.S., while gasoline consumption in that year was 6.65% of the U.S. total, due to the high degree of urbanization of the area. On this basis, it can be assumed that close to 6.65% of the 246,000 tonnes of lead consumed in gasoline 1970, or 16,400 tonnes was consumed in the Hudson-Raritan river basin. Of that amount, close to 12,000 tonnes of lead must have been emitted directly to the air of the basin, the rest being retained in auto exhaust systems, oil filters and waste motor oil. Some of the latter must certainly find its way eventually into incinerators and thence also into the air. (On the order of 10-15% of the motor oil consumed is dumped or lost by leakage onto city streets from whence it is washed into the sewers. See Oil and Grease. Some waste motor oil is commingled with refuse and is ultimately incinerated. This may account for the high lead content in some incinerator emissions).

The fate of lead from airborne auto exhaust emissions has been studied in Los Angeles. Based on a mass-balance for lead in the Los Angeles basin (2500 square miles) carried out by Huntzicker [Huntzicker & Friedlander 75] in dry weather about 33% of the atmospheric emissions consist of submicron particulates that are carried beyond the area by winds, mainly inland. In the case of New York City where prevailing winds are from the west, the fraction carried out of the area by wind is probably higher. The remainder is divided between "near" and "far" deposition, the former being defined as an area within a hundred meters or so of a freeway. They estimated the division for LA as follows:

"near" component	55% (+ or - 12%)
"far" component	12% (+ or - 6%)
removed by wind	33% (+ or - 20%)

where the figures in parentheses represent uncertainties in the estimates. About one fifth of the near component (or 11% of the total) was deposited directly on streets and other paved areas. The remainder was deposited on soil. Most of the lead deposition on soil has apparently been immobilized (although this appears to be a function of acidity). The increasing acidity of rain in the northeastern U.S. may solubilize some formerly insoluble trace metals.

In the case of New York, the fraction of "near deposition" that lands on streets, alleys and rooftops is certainly much higher than in LA, simply because the area is much more densely built-up. In the case of the Hudson-Raritan basin, the fate of lead-containing aerosols can be crudely estimated as follows:

"near"	55%	(of which 2/5 comes down on paved surfaces or roofs & is subject to surface runoff & 3/5 lands on soil)
"far"	10%	(on soil)
removed by wind	35%	(out to sea)

The fate of lead aerosols dry-deposited on streets and paved areas depends on the frequency of street sweeping and the fate of the sweepings. In the LA case, where rainfall is infrequent, Hunzicker et al concluded that most (~3/4) of the deposition on roadway surfaces is removed by weekly street sweeping, and that each sweeping is about 50% efficient. The remainder is washed into the rivers by storms. In the New York area the frequency of rainfall is much higher and sweeping is probably not the major means of street dirt removal. In addition, the percentage of the land surface that is occupied by streets, alleys and buildings themselves is much higher than in LA, whence it can be assumed that a much higher percentage of the "near" deposition lands on roofs or paved areas and is washed into the drains and/or sewers.

Metallic uses of lead are much less important sources of atmospheric and water pollution than chemical uses. The major current ones are ammunition, solder and lead-acid battery anodes. Other major former uses include cable coverings, foil, bearing metal and type metal. Metallic lead is still used for sound-proofing in buildings and radiation shielding. Lead was used extensively for interior plumbing purposes in the 19th and early 20th century. Many older buildings, especially tenements, still have some lead pipes -- which constitute an environmental health hazard. However volatilization is not a problem except where lead-containing materials are incinerated accidentally or deliberately.

One other source of lead emissions may have been locally significant in the past, if not currently. That is coal combustion. As far as we can determine eastern bituminous coals average about 7.9 ppm. (by weight) lead. Of this amount somewhere between 35% and 65% is retained in the fly ash and most of the remainder is apparently discharged as vapor. (Very little remains in the bottom ash). The vaporized fraction eventually condenses on dust or soot particles which fall (or are washed out by rain) downwind of the source. The partition into "near", "far" and "remote" fractions depends on smokestack height, combustion temperature and atmospheric conditions. In the days before smoke controls, most fly ash would have fallen fairly nearby. Since the 1960's fly ash has been largely captured from utility and large boiler stacks by electrostatic precipitators. However in the earlier decades of this century (when coal was the predominant heating fuel, as well as the major fuel for electric power plants) most of the ash and soot escaped into the air. In the heyday of coal, as much as 25 million tons annually were burned in the New York metropolitan area alone, resulting in a discharge of up to 200 tons of lead to the air. This would not, however, be significant in comparison with automotive emissions or smelter emissions (except in the immediate neighborhood of the smelter).

It is interesting to note that anthropogenic sources of lead emissions greatly outweigh non-anthropogenic sources, even on a global scale. Gasoline combustion is the largest anthropogenic source, followed by the metallurical industries. A summary of U.S. emissions in 1981 is given in Table 8-4,

Table 8-4: Estimated Atmospheric Lead Emissions For the U.S. (1981) & the World (1979)

Source Category	Annual U.S. Emissions (t/yr)	Percent of U.S. Total Emissions	Annual Global Emissions (t/yr)
Gasoline combustion	61,000	91.4%	273,000
Waste oil combustion	830	1.2%	8,900
Solid waste disposal	319	0.5%	
Coal combustion	950	1.4%	14,000
Oil combustion	226	0.3%	4,500
Wood combustion	--	--	4,500
Gray iron production	295	0.44%	50,000
Iron & steel production	533	0.80%	
Secondary lead smelting	631	0.95%	770
Primary copper smelting	30	0.04%	27,000
Ore crushing & grinding	326	0.49%	8,200
Primary lead smelting	921	1.38%	31,000
Other metallurgical	54	0.08%	
Lead alkyl manufacture	245	0.37%	
Type metal	85	0.13%	7,400
Portland cement manufacture	71	0.11%	
Miscellaneous	233	0.35%	5,900
Total	66,749	100%	435,170

Total does not include emissions from exhausting workroom air, burning of lead- painted surfaces, welding of lead-painted steel structures, or weathering of painted surfaces

Source: For U.S. emissions, [EPA 84, Table 1.1]
For global emissions, [Nriagu 78]

along with a (rather untrustworthy) estimate of global emissions. Table 8-5 indicates current estimates of the distribution of global emissions among various sinks.

Table 8-5: Estimated Global Deposition of Atmospheric Lead

		Mass of Water 10^{17}kg/yr	Lead Concentration 10^{-6}g/kg		Lead Deposition 10^{6}kg/yr
Wet	To oceans	4.1	0.4		164
	To continents	1.1	0.4		44
		Area 10^{12}m^{2}	Deposition Rate 10^{-3}g/m^{2}yr		
Dry	Oceans, ice caps, deserts	405	0.2		89
	Grass, agriculture, tundra	46	0.71		33
	Forests	59	1.5		80
				Total Dry	202
				Total Wet	208
				Global	410

Source: [Battelle 77, Table 1-3]

9. Anthropogenic Zinc Sources and Flows

Zinc is mined primarily from sulfide ores (sphalerite, ZnS), often associated with ores of copper and/or lead. Zinc was mined in a few Eastern States (NJ, NY, PA), but only two mines (belonging to the NJ Zinc Co.) are located in the river basins of concern. Ore from Sussex Country, NJ, and Lehigh County, PA, was refined pyrolytically until 1980 at Palmerston in Lehigh County, (this operation generated effluents to the Delaware River, not the Hudson).[26] Waterborne effluents from The NJ mining and milling operations eventually reached the Hudson River at Kingston, NY. Mines in Ogdensburg (Sussex County), NJ, yielded about 29,000 tonnes of recoverable zinc in 1980, while mines in Lehigh County, PA, yielded 22,556 tonnes. These production levels have been relatively constant in recent years. Both of these mines are quite old, going back to the 19th century. One plant manufactured zinc oxide at East Rutherford, NJ (Royce Chemical Co.). There was a secondary zinc recovery unit (Prolerized Shiabo-Neu Co.) in Jersey City, NJ which opened in the early 1970's and closed around 1980. No secondary zinc plant currently operates in the NJ-NY area.

Major zinc chemicals are as follows:

Zinc acetate, $Zn(C_2H_3O_2)_2$
is a mordant, wood preservative, mild antiseptic and

Zinc arsenate, $ZnHAsO_4$
is an insecticide formerly used as a substitute for lead arsenate on some crops.

Zinc bichromate, $ZnCr_2O_7$
is an orange-yellow pigment.

Zinc chloride, $ZnCl_2$
is a major intermediate: formerly used as a wood preservative ("Burnettizing"); also for vulcanizing rubber, in dry batteries as a mordant, for mercerizing cotton, and as a disinfectant.

Zinc chromate, $4ZnO.4CrO_3.K_2O.3H_2O$, "zinc yellow"
is a widely used pigment.

Zinc dithiophosphates, ZnPSO
are anti-oxidants and anti-corrosion additives for motor oils used by automobiles and trucks.

Zinc oxide, ZnO), "Zinc white" is a white insoluble powder widely used as a pigment for paints.
Also used as an accelerator activator for rubber products (e.g. tires).

Zinc peroxide, ZnO_2
is an oxident, used in dental pastes and cosmetics and as a mild antiseptic.

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[26] St. Joe Minerals Co. operates several zinc mines in St. Lawrence County, NY, and in Virginia. It has a smelter at Monaca, in Beaver County, western Pennsylvania. None of these operations affects the Hudson or Delaware watersheds.

Zinc stearate, $Zn(C_{18}H_{35}O_2)_2$
is a zinc soap used in paints and rubber (as an anti-tack agent).

Zinc sulfate, $ZnSO_4$, "white vitriol"
is used to manufacture lithopone, in the manufacture of "zineb" and in galvanizing by the electrolytic method. Also a component of fertilizers and fungicides. It was used in the 1950's to harden rayon filaments prior to spinning.

Zinc sulfide, $ZnS.H_2O$
is used as a pigment (in lithopone), for whitening rubber, for paper coating, and as the major component of phosphors.

Copperized CZC
is copperized chromated zinc chloride, used as a wood preservative in the 1960's.

Zinc emissions from mining and milling operations have been estimated at 0.1 kg per metric ton (Mg) of zinc mined [MRI 80]. 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 arsenic, cadmium, copper and lead are also significant.

Total recoverable zinc content of U.S. mine output rose from around 30,000 tonnes in 1880 to 150,000 tonnes in 1900, and peaked at 700,000 tonnes in 1926. (See Tables 9-1 and 9-2.) Domestic mine and smelter output have trended gradually down since the 1920's to about 300,000 tonnes in recent years. Imports of refined zinc (mostly slabs) make up the balance. Zinc currently has four major metallurgical uses and a number of chemical uses. The metallurgical uses are (1) galvanizing (coating) of sheet iron and steel to provide enhanced corrosion resistance, (2) thin-walled (hollow) die castings for a variety of purposes, especially in the auto industry, (3) brass and bronze products (4) rolled zinc for dry cells, weather stripping and lithographic plates. Metallurgical operations generate some effluents, both to air and to water, but metallic zinc is not extensively utilized in the mid-Atlantic area except in small plants involved in die-casting, electroplating and battery manufacturing.

Slab zinc (from refineries) is the starting point of all metallurgical uses. Galvanizing iron and steel by the hot dip process has consistently been a major use of slab zinc, ranging from 40% in 1919 to a low of 31% in 1963 back up to 48% in 1982 [USBM annual]. Brass was the second major user before WWII but has declined in importance to ~11% at present, while special zinc alloys for die-casting accounted for 42% of slab zinc by 1968. This use has since declined to 28% in 1982 [USBM annual]. A small amount of slab zinc is used in the manufacture of zinc chemicals, notably zinc oxide (by the French process).[27] Zinc

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[27] The American process, by contrast, produces zinc oxide directly from ore. Most zinc oxide is made directly from ore, or from scrap by the French process [USBM annual].

Table 9-1: U.S. Zinc Production (1000 tonnes)

	Mine Production Recoverable Zinc Content	Primary Smelter Production of Slab Zinc from Ores Total	Slab Zinc Production From Scrap (Redistilled Slab Zinc)	Slab Zinc Production Total	Secondary Production excluding Redistilled Slab Zinc	Secondary Production All Forms Total
1880	29.756	22.770		22.770		
1885	51.220	37.936		37.936		
1890	82.191	62.882		62.882		
1895	97.831	77.170		77.170		
1900	159.628	120.852		120.852		
1905	222.854	185.864		185.864	7.862	23.162
1910	286.311	246.881		246.881	39.456	56.121
1915	514.262	458.520		458.520	67.775	98.725
1920	453.798	363.205		363.205	95.649	120.166
1925	626.432	510.138	35.867	546.006	111.695	147.563
1930	491.807	403.737	30.337	434.074	89.030	119.367
1935	461.366	388.355	27.360	410.243	87.172	121.744
1940	595.608	606.497	44.208	650.705	163.564	207.772
1945	596.862	745.149	45.459	790.608	260.421	305.880
1950	579.463	767.864	52.272	820.136	222.293	274.565
1955	473.486	843.943	60.153	904.096	196.886	257.039
1960	406.893	744.911	52.122	797.032	178.737	230.859
1965	514.779	871.798	67.546	939.345	223.774	291.320
1970	471.295	807.447	69.348	876.795	261.509	330.857
1975	432.221	458.258	62.555	520.813	254.520	317.074
1980	299.966	358.875	48.372	407.248	279.434	327.807
	(a)	(b)			(c)	(d)

Values are 5 year averages centered on year shown except 1880=actual

Source: [Census 75 through 1970, then USBM annual] except

(a) [Potter & Christy 62] through 1905

(b) Calculated as sum of ores from 1971 on

(c) Assumed zero until 1907. Calculated as secondary minus 6.7% slab production 1908 - 1922.
Calculated as secondary minus redistilled 1923 - 1962.

(d) Calculated as redistilled plus nonredistilled from 1963 on.

chloride is made from metal (either slab or secondary) and zinc sulfate is made either from ore or from secondary zinc.

A significant amount of zinc is consumed in non-metallic form. Processing stages are shown in Figure 9-1. Zinc chemicals and their uses are summarized in Tables 9-3 through 9-7. The single most important zinc chemical is zinc oxide (ZnO). Roughly, 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

Table 9-2: U.S. Zinc Consumption (1000 tonnes)

	Refined Imports (=Blocks, Pigs or Slabs	Exports Refined	Consumption Total	Consumption Slab Zinc (Industrial Uses)	Consumption Recoverable Zinc Content Ores	Consumption Recoverable Zinc Content Secondary
1880	3.670	0.621	34.110			
1885	3.551	0.194	55.701			
1890	0.815	1.907	79.651			
1895	0.499	5.703	92.624			
1900	0.781	8.399	124.284			
1905	0.671	4.067	193.412			
1910	4.033	4.119	278.687			
1915	0.991	108.823	437.263			
1920	1.277	62.399	395.714	346.681		
1925	0.009	52.029	528.889	510.110		58.681
1930	0.198	9.334	476.453	424.689		56.064
1935	10.329	1.479	470.103	430.949		
1940	22.675	69.593	690.730	602.662		
1945	71.245	50.928	901.923	752.113		
1950	104.233	41.982	869.990	777.179		
1955	198.928	14.629	1161.811	895.291	100.035	184.790
1960	132.859	31.752	1110.436	846.479	88.925	175.032
1965	167.415	15.335	1472.888	1150.457	94.987	185.427
1970	318.925	10.935	1565.045	1196.648	109.570	255.407
1975	500.722	8.033	1429.955	1080.070	134.671	215.214
1980	518.920	0.394	(a)			

All values are five year averages centered on year shown except 1880=actual

Source: [Census 75 until 1970], [USBM annual] 1971 on, except
(a) [Potter & Christy 62, Table MC-26f] 1880-1957, then [USBM annual].

FIGURE 9-1: Zinc Process–Product Flows

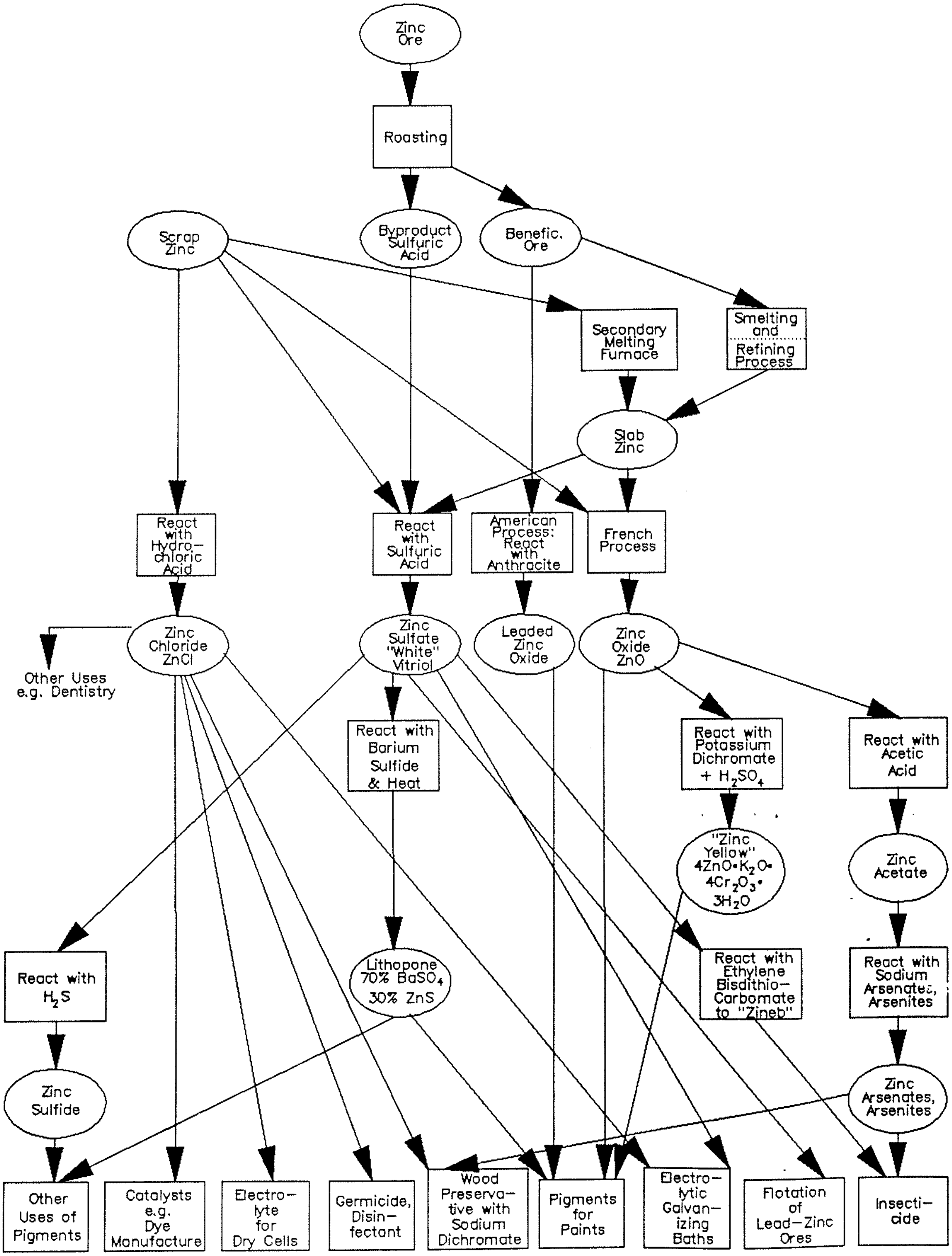

Table 9-3: U.S. Zinc Oxide Usage (tonnes)

	Shipments by Industry							
	Rubber	Paints	Ceramics	Floor Cov/Textls	Photo-Copying	Other	Total	Apparent Supply
1910							62.387	
1915							86.309	
1920							94.377	87.733
1925							128.454	114.870
1930	50.942	33.827	3.704	3.059		10.005	110.424	
1935	54.738	25.289	4.393	5.258		5.898	95.577	
1940	59.979	22.664	5.327	4.652		8.149	100.771	
1945	64.752	27.309	5.869	9.993		24.643	132.568	123.860
1950	66.881	28.493	9.085	9.308		15.388	129.155	124.443
1955	72.280	29.411	8.544	8.586		19.738	138.559	138.766
1960	67.963	29.110	9.175	2.231		24.888	133.367	141.001
1965	75.093	31.191	8.510			32.416	147.210	157.184
1970	110.393	22.416	8.418		31.009	35.404	207.640	207.640
1975	100.054	15.379	8.472		26.530	42.340	192.775	216.970
1980	84.287	12.635	8.061		14.949	45.734	165.666	186.150

Source: [USBM annual]. All values are 5 year averages centered on year shown, except 1910=(1910-1912) and 1980=(1978-1980)

Table 9-4: U.S. Zinc Oxide, Leaded Zinc Oxide & Zinc Chloride Usage (tonnes)

	ZINC OXIDE		LEADED ZINC OXIDE SHIPMENTS			ZINC CHLORIDE		
			Industry Distribution					
	Net Imports	Apparent Supply	Paints	Other	Total	Total Shpmnts	Net Imports	Apparent Supply
1910					7.559			
1915					15.594			
1920	-3.662	87.733			21.860	51.995		
1925	-2.364	114.870			23.933	41.103		
1930			17.251	0.283	18.422	31.989		
1935			27.621	0.357	27.978	23.497		
1940			43.133	1.012	44.145	47.513		
1945	-11.183	123.860	55.554	2.552	58.105	52.675	0.001	54.150
1950	-4.712	124.443	44.477	0.949	45.426	56.204	0.221	56.212
1955	0.207	138.766	28.134	0.481	28.615	48.576	0.394	49.028
1960	9.079	141.001	16.851	1.092	17.943	52.707	0.702	53.409
1965	9.974	157.184	13.434	0.602	14.037	46.196	0.849	47.045
1970		207.640						
1975	14.440	216.970				21.117	1.708	22.591
1980	28.378	186.150				19.202	1.105	20.306

about 30% of the weight of a finished tire [Shreve 56, chapter 36] and zinc is dispersed to the environment by tire wear at the rate of 25 kg per million vehicle miles [Huntzicker & Friedlander 75]. The other major historical use of zinc oxide -- both lead-free and leaded -- is as a white pigment for oil-based

Table 9-5: U.S. Lithopone Usage (tonnes)

	Shipments by Industry					Net Imports	Apparent Supply
	Paint, Etc.	Floor Covring/	Rubber	Other	Total		
1910					16.251		
1915					40.642		
1920					66.863	4.720	73.590
1925					125.121	6.741	100.938
1930	114.289	24.487	5.418	9.005	153.199		
1935	107.312	17.418	4.246	8.729	137.706		
1940	104.308	16.049	2.598	10.268	133.224		
1945	105.264	14.369	1.356	10.883	131.871	-10.547	124.982
1950	65.434	11.834	2.966	8.432	88.666	-13.294	75.372
1955	33.976	7.603	1.563	4.430	47.572	-1.975	44.037
1960						-0.364	
1965						-0.617	
1970							
1975						-0.674	
1980						0.679	

Source: [USBM annual]. All values are 5 year averages centered on year shown, except 1910=(1910-1912) and 1980=(1978-1980)

Table 9-6: U.S. Zinc Sulfate Usage (tonnes)

	Shipments by Industry						Net Imports	Apparent Supply
	Agriculture	Rayon	Chemicals	Paint Etc.	Other	Total		
1920						3.222		
1925						5.202		
1930						5.076		
1935						7.477		
1940	3.740	2.857	2.354	1.739	2.311	11.500		
1945	6.095	5.999	1.831	0.833	3.410	18.169	0.342	20.703
1950	4.750	9.065	1.698	0.214	3.978	19.704	0.132	19.836
1955	7.057	12.218	2.303	0.096	4.001	23.756	0.476	24.232
1960	6.409	16.753			9.822	29.633	0.634	30.103
1965	9.784				26.604	36.388	0.803	37.191
1970	13.298				29.934	43.232		43.232
1975	11.026				19.742	30.767	5.316	38.447
1980	19.686				8.112	27.798	5.360	36.146

paints. Zinc oxide gradually replaced white lead in this application, but is itself gradually being replaced by lithopone (a mixture of 70% barium sulfate and 30% zinc sulfide) and finally by titanium dioxide. Another major use in the late 1960's was for photocopying paper. This use has probably been largely displaced by xerography, which does not require treated paper. Zinc oxide uses are detailed in Table 9-3; lithopone

Table 9-7: U.S. Zinc Pigments (tonnes)

	Imports for Consumption Pgmnts/Cmpnds	------------ZINC CONTENT OF ZINC PIGMENT PRODUCTION------------					
		Lithopone	Zinc Oxide	Leaded Zinc Oxide	Zinc Sulfate	Zinc Chloride	Total Zinc in Pigment
1930		30.595	82.219	9.747	1.425	6.348	130.334
1935		27.393	67.709	10.267	1.658	4.997	112.024
1940		23.912	71.431	18.772	2.583		116.697
1945		24.047	105.779	28.555	5.246	11.370	174.996
1950	0.010	16.692	95.289	21.345	5.745	11.649	150.720
1955	0.229	9.535	111.823	16.402	8.826	12.481	154.301
1960	0.344		105.564	10.285	10.338	10.621	136.808
1965	0.384		113.904	8.393	12.131	10.097	144.525
1970							
1975	1.965		167.242		12.260	9.413	184.209
1980	2.329		125.878		12.549	7.299	145.725

Source: [USBM annual]. All values are 5 year averages centered on year shown, except 1910=(1910-1912) and 1980=(1978-1980)

uses are broken out in Table 9-5. Other major tonnage zinc chemicals include zinc sulfate, and zinc chloride. Zinc chloride has many uses, including batteries (dry cells). The zinc sulfate was primarily consumed by the rayon industry[28] during the 1950's, and as a mineral supplement to fertilizers and animal feeds. It is also used in the electrolytic galvanizing process. Zinc dithiophosphates are common additives to automotive motor oils. A typical zinc content for motor oil is 0.1% by weight [Huntzicker & Friedlander 75], which implies that as much as $3.8\text{x}10^3(.001\text{x}.45\text{x}8.44\text{x}10^6)$ tonnes of zinc is dispersed into the environment annually by this route alone.

It is important to emphasize that most uses of zinc are essentially dissipative (the major exception being brass/bronze). As in the case of cadmium, most zinc-containing products end in land-fills, from which an unknown 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 [Nriagu 80z, Chapter 4]. Other sources include tire dust, weathered paint, and auto exhaust (from burning of lube oil detergents) and incinerators. A still smaller fraction of zinc wastes is discharged directly to water courses. In several cases, zinc and cadmium waste flows are proportional to one another. This is notably true for zinc refinery waste streams. See Tables 9-8 and 9-9.

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[28] Specifically, zinc sulfate was a constituent of the acid bath (consisting also of sulfuric acid, sodium sulfate and glucose) which solidifies jets of molten viscose rayon into filaments that can be spun into yarn [Moncrieff 59, p.130].

Table 9-8: Global Emissions of Zinc from Natural Sources

Source	Global Production of Particulates (10^9 kg/year)	Emission Function (mcg/g)	Global Emission (10^9 g/year)
Windblown Dusts	500	50	25
Forest Fires	36	58	2.1
Volcanogenic particles	10	700	7.0
Vegetation	75	125	9.4
Seasalt Spray	1000	0.21	0.21
Total			43.7

Source: [Nriagu 80z, Chapter 4, page 114]

Table 9-9: Worldwide Anthropogenic Emissions of Zinc in 1975

Source	Global Production or Consumption (10^9 kg/year)	Emission Factor (mcg/g)	Zinc Emissions (10^9 g/year)
Mining(Zn+Cu+Pb)	16	100	1.6
Primary Metal Production			
Zinc	5.6	17600	
Lead	7.0	110	98.6
Copper	7.9	845	6.6
Nickel	0.8	845	0.68
Aluminum	12.3	11	0.14
Secondary Metal Production			
Zinc	0.9	9000	8.1
Copper	2.1	500	1.1
Lead	1.0	300	0.3
Iron & Steel	1300	27	35.1
Ferroalloys & Iron Foundries	83	54	4.5
End Uses of Zinc Products	-	-	26
Inadvertent Sources			
Coal Combustion	3100	4.8	14.9
Oil Combustion	2800	0.025	0.07
Wood Combustion	640	58	37.2
Waste Incineration	150	500	75.0
Rubber Tire Wear	5 x 10^8 tires	4.5 g/tire	2.2
Phosphate Fertilizers	118	15	1.8
Grain Handling	356	0.5	0.18
Total			315

Source: [Nriagu 80z, Chapter 4, p.115]

Environmental reservoirs (soil, sediment, oceans) contain large quantities of zinc. Since zinc and cadmium are chemically similar and closely associated in ores, it is not surprising that the natural zinc cycle somewhat resembles the natural cadmium cycle (Figure 4-1), but on a much larger scale, of course.

Unlike the case of cadmium, the anthropogenic environmental flows of zinc overwhelm the anthropogenic flows on a global scale by a factor of ten. This is even more true in heavily industrialized and densely populated areas. Apart from a few point sources of waterborne effluents associated with zinc alloying, scrap-processing, or galvanizing operations, the single most important source of zinc in the Hudson-Raritan and Delaware estuaries is undoubtedly urban runoff carrying suspended particulates deposited from the air. Most of the airborne zinc, in turn, originates from manufacturing or consumption related activities (e.g. waste incineration) within the same region.

10. Trace Metals as By-Products of Combustion & Other Processes

There is evidence that minor trace metals may be mobilized by coal combustion to an extent comparable with natural processes or mining. This is because around 600 million tons of coal are burned annually in the U.S. at present and most trace elements are present in quantities of the order of a few to several hundred ppm. Unfortunately, quantitative estimates vary by more than an order of magnitude for some metals. This is partly because coals can differ rather widely in trace element composition, depending on rank and regional origin, and partly because a variety of different measurement techniques with differing sensitivities have been used in different studies [Torrey 78, Chapter 2].[29]

For instance, zinc is relatively scarce in Appalachian coals (average 7.6 ppm for 73 samples), as compared to 44 ppm for the eastern interior region (53 samples), 59 ppm for the northern great plains basin coals (51 samples), and 108 ppm for the western and southwestern interior coals (48 samples). [See Torrey 78, Table 7.5 and text.] A separate study of 82 Illinois basin coals indicated an average of 313 ppm for zinc.

Trace element compositions for other metals vary almost as widely from region to region. Thus, we must limit consideration largely to the Pennsylvania (and some West Virginia) coals that have been predominantly burned in the New York area.[30] Because of these regional differences, national averages that have appeared in various publications are essentially useless for our purposes. Emissions coefficients used in this study are shown in Table 10-1.

The partitioning of trace metals between ash fractions and gaseous emissions is fairly complex. Most trace metals are associated (by definition) with "ash", but some of these ash particulates are extremely small, <0.1 microns in diameter. In the stack, some of the smaller particles tend to agglomerate, shifting the size distribution toward larger sizes. Nevertheless, there is a clearly marked bimodal distribution, with a "small" peak around 0.08 microns and a "large" peak around 1.0 microns [See Torrey 78, Chapter 1, Figure 1.3 and text].

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[29] Methods used include instrumental neutron activation analysis (NAA); spark source mass spectroscopy (SSMS); optical emission spectrometry (OES); direct reading emission spectrometry (DRES); and atomic absorption spectrometry (AAS). Recently NBS undertook to compare these methods for applicability to trace element analysis of coal and coal ash [Torrey 78, p.46]. For the metals in our list, SSMS is the preferred technique for Cd, Cr, Hg, Pb, and Zn, while INAA is preferred for As and Cr. Nevertheless, SSMS is only plus or minus 50% accurate unless the more difficult isotope dilution variation is utilized.

[30] Bituminous coal has been mostly used by industry and electric utilities. Anthracite coal was widely used for home heating until as recently as the 1950's, when it was generally replaced by oil or gas.

Table 10-1: Trace Element Emissions from Coal Combustion

(# Samples Shown in Parentheses, units=ppm)

	Earth's Crust	Appal-achian (73 Smples)	Pitts-burgh Coals	Pre-ferred Estimate NYC Coal	Fraction Retained by Fly Ash (* = Preferred)		W. Va Coal Refuse	Anthra-cite Coal Ash
Arsenic (As)	2	NA	8.3 (8)	8.30	0.35-0.50	0.91*	NA	NA
Cadmium (Cd)	0.12	NA	0.14 (9)	0.14	0.38	0.55*	0.25-1	NA
Chromium (Cr)	170	13 17[EPA 71n]	NA	17.00	70 - 95*	NA	3 - 25	304(5)
Copper (Cu)	58	15	NA	15.00	70 - 95*	NA	15 - 50	405(5)
Lead (Pb)	12	NA	7.9 (9)	7.90	0.37	+0.63*	20 -150	81(5)
Mercury (Hg)	0.05	NA	0.15(18)	0.15	0 - 0.10	0.03*	NA	NA
Silver (Hg)	0.20	NA	NA	0.20	70 - 95*	NA	3 - 25	NA
Zinc (Zn)	70	7.6	NA	7.60	70 - 95*	NA	30 - 85	155-350
Sources:	Chap.3	Table7.5	Table6.1		Table 5.7	Table6.5	Table7.3	Table1.1
	[USGS 73]	(all other cols [Torrey 78])						

Average fly ash content 6.5% (1970)
Average control level 82% (1970)

The trace elements are partitioned quite differently between these distributions. The more volatile elements like arsenic (57% plus or minus 7%) and mercury (40% plus or minus 9%) are predominantly found -- to the extent they are found in solid form at all -- in the small peak mode; while less volatile elements like zinc and chromium are predominantly found in the larger particulates. These facts are consistent with the volatilization- condensation theory of Davidson, et al [Davidson et al 74] which holds that the more volatile elements or their compounds (with low boiling points) vaporize in the fire box and subsequently recondense. Recondensation tends to occur on existing nuclei, in proportion to surface area. Since small ash particles have proportionally more surface area available for recondensation, they are relatively more "enriched" by this mechanism. However, not all of the material is recondensed. In the case of mercury, more than 95% probably escapes in vapor form from modern utility-type furnaces.[31] The retention fraction might well have been much greater in the fireplaces and coal stoves of the 19th century, where temperatures were relatively low and the mercury vapor would have been largely condensed and absorbed onto soot particles or chimney walls. According to our preferred source, about 40% of the

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[31] Mercury retention by ash is known to be a function of carbon-content of the ash, ash loading in the filter, and baghouse temperature. Extrapolating to utility operating conditions mercury retention in ash would be of the order of 2.5% [Torrey 78, Table 6.2 and text].

cadmium, 35% of the lead and 8% of the arsenic also escapes in vapor form, based on experiments with Pittsburgh seam bituminous coal [Torrey 78 Table 6.5 and text]. These figures may also be somewhat uncertain, however. Other sources give widely divergent figures for As, Cd, and Pb [See Torrey 78, Table 5.7 and Table 6.6 for a summary of the literature]. Variance in the results can be attributed to differences in experimental technique as well as operating conditions and coal source. However, it seems to be generally agreed that for Ag, Cr, Cu, and Zn, the fly ash retention fractions are all generally in the 90-95% range (the remainder going to bottom ash or slag).

The quantities of trace metals actually released to the environment depend on the fraction that escapes as vapor and the fraction that condenses on very small particulates (<0.1 microns in diameter) that are *not* efficiently captured by electrostatic precipitators. Almost all of the larger ash particles are now captured and disposed of in landfills. Of course this was not completely true in the past. Smoke control by means of filters, cyclone collectors and electrostatic precipitators, has a fairly long history, however (see Chapter 12).

11. Fossil Fuels Production and Consumption

This chapter consists entirely of tables summarizing available fossil fuel production and consumption data 1880-1980 by decades. Detailed annualized backup data is also given in appendices M-10 and M-11.

Table 11-1: U.S. Bituminous Coal Consumption (million tonnes)

	Total Consumption	Electric Utilities	by Class I Railroads	in Coke Production	in Other Industry	Residential /Commercial
1880	49.260					
1885	67.567					
1890	100.171					
1895	120.111					
1900	189.057					
1905	288.122					
1910	350.536					
1915	418.649	30.391	121.037	75.979	147.522	98.348
1920	424.492	31.296	110.748	57.757	130.681	87.121
1925	459.865	36.277	109.798	69.162	143.868	95.912
1930	390.481	35.963	85.801	57.027	125.314	83.542
1935	336.909	30.287	72.605	50.263	109.082	72.161
1940	394.708	45.582	81.813	69.946	119.150	75.568
1945	506.071	68.410	110.117	89.121	134.661	101.037
1950	418.631	85.221	57.315	93.159	108.266	72.728
1955	373.723	123.459	14.748	94.270	94.691	45.209
1960	340.297	156.591	1.529	69.839	84.142	27.412
1965	411.170	219.681	0.000	81.526	91.387	18.012
1970	460.210	290.036	0.000	81.602	76.772	11.260
1975	523.743	381.771	0.000	77.718	57.066	6.939
1980	616.846	501.249	0.000	57.393	57.839	5.807
					(a)	(b)

All values are five year averages centered on year shown except 1880=(1880-1882)

Source: [Census 75] prior to 1939, [BEA biennial] (1939-1983)

(a) sum or difference of other categories when not given explicitly in source

(b) Allocated between industrial and residential in ratio of 60-40 (1917-1932) which is ratio maintained in first ten years for which separate data given

Table 11-2: U.S. Anthracite Coal Consumption (million tonnes)

	Anthracite Production	Anthracite Net Exports	Anthracite Apparent Consumption (Prod-Exp)
1880	28.936	0.477	28.460
1885	35.393	0.637	34.756
1890	43.867	0.739	43.128
1895	49.141	1.317	47.824
1900	50.806	1.512	49.294
1905	69.365	2.247	67.118
1910	76.866	3.216	73.650
1915	83.195	4.271	78.923
1920	76.507	4.042	72.464
1925	73.957	3.249	70.707
1930	59.523	1.739	57.784
1935	48.136	0.910	47.225
1940	46.406	2.536	43.870
1945	53.882	4.869	49.014
1950	41.217	4.714	36.503
1955	25.487	3.314	22.173
1960	17.232	1.599	15.634
1965	13.701	1.295	12.406
1970	8.618	0.607	8.010
1975	5.759	0.605	5.154
1980	4.706	1.292	3.414

All values are 5 year averages centered on year shown except 1880=(1880-1882)

Source: [Census 75] (1918-1939),
[BEA biennial] (1939-1983)
[Potter & Christy 62] prior to 1917

Table 11-3: U.S. Selected Petroleum Products as % of Runs to Stills (million tonnes)

	Runs to Stills	Lubricants Production as % of runs	Kerosene Production	Kerosene Production as % of runs	Residual Fuels Production as % of runs	Distillates Production as % of runs
1880	2.78	3.65%	1.85	66.53%	1.74%	
1885	3.45	4.44%	2.34	67.84%	3.19%	
1890	5.00	6.12%	3.23	64.68%	5.16%	
1895	6.99	7.12%	4.25	60.82%	9.29%	
1900	8.05	8.85%	4.44	55.34%	13.42%	
1905	11.51	11.17%	4.96	43.92%	21.41%	
1910	19.68	9.49%	5.99	30.84%	37.55%	
1915	33.42	6.32%	7.01	21.54%	47.53%	
1920	60.48	5.24%	7.69	13.02%	50.25%	
1925	106.66	4.08%	8.52	8.13%	47.07%	
1930	137.31	3.20%	7.28	5.30%	34.45%	8.54%
1935	149.01	2.80%	8.13	5.48%	25.94%	10.53%
1940	193.47	2.71%	10.08	5.22%	24.29%	13.23%
1945	253.65	2.52%	12.96	5.09%	25.62%	14.83%
1950	329.77	2.34%	17.73	5.38%	19.82%	18.53%
1955	414.02	1.94%	17.28	4.19%	15.00%	21.04%
1960	450.75	1.85%	19.06	4.21%	10.70%	21.86%
1965	517.20	1.80%	16.19	3.16%	7.61%	21.71%
1970	620.71	1.54%	13.58	2.20%	6.40%	20.87%
1975	721.23	1.30%	9.06	1.26%	9.36%	21.17%
1980	757.15	1.31%	7.51	1.26%	11.53%	22.40%

All values are 5 year averages centered on year shown except 1880=(1880-1882)

Source: Gutmanis

Table 11-4: U.S. Domestic Production & Consumption of Petroleum Products - Summary
(million tonnes)

	Total Petroleum Production	Total Refined Imports	Total Refined Exports	Total Petroleum Demand	consumpt. Preferred series	Petroleum Runs to Stills
1880	2.78		1.43	2.51	2.51	2.78
1885	3.45		1.70	1.70	1.70	3.45
1890	5.00		1.99	3.87	3.87	5.00
1895	6.99		2.70	4.80	4.80	6.99
1900	8.05		3.06	6.20	6.20	8.05
1905	11.51		3.53	14.61	14.61	11.51
1910	19.68		5.10	23.82	23.82	19.68
1915	33.42	0.13	7.70	36.09	36.09	33.42
1920	60.48	0.50	9.16	61.64	61.64	60.48
1925	104.64	2.47	15.28	101.61	101.61	106.66
1930	134.17	4.46	16.80	122.62	122.62	137.31
1935	147.71	3.00	11.46	140.02	140.02	149.01
1940	192.02	4.79	13.67	183.77	183.77	193.47
1945	246.43	7.25	19.18	242.50	242.50	253.65
1950	301.16	15.72	14.94	328.03	328.03	329.77
1955	359.73	24.41	18.90	419.75	419.75	414.02
1960	374.42	44.40	10.50	516.73		450.75
1965	424.79	64.02	10.75	614.12		517.20
1970	497.26	102.61	12.14	782.98		620.71
1975	453.08	121.49	11.12	913.69		721.23
1980	456.72	88.24	17.41	909.37		757.15
	(e)	(h)	(h)	(f)	(g)	

All values are 5 year averages centered on year shown except 1880=(1880-1882)

Source: Unless otherwise noted, [Census 75] through 1938 and [BEA biennial] from 1939 on

(e) Gutmanis "Runs to Stills" (1880-1922), "Refinery Output" (1923-1938), [BEA biennial] "Crude Petroleum Production"(1939-1983)

(f) [Potter & Christy 62] "Preferred Consumption (Petroleum Only)" 1880-1957, then [BEA biennial] "Demand"

(g) [Potter & Christy 62, Table MC-9] column i minus cols b&c

(h) [Potter & Christy 62,Tables MC-7,8] from 1880-1918

Table 11-5: U.S. Domestic Production & Consumption of Residual Oils & Lubricants
(million tonnes)

	Residual Oil Production	Residual Oil Imports	Residual Oil Total Demand	Lubricants Production	Lubricants Exports	Lubricants Total Demand
1880	0.05		0.05	0.10		0.10
1885	0.11		0.11	0.15		0.15
1890	0.27		0.27	0.31		0.31
1895	0.65		0.65	0.50		0.50
1900	1.08		1.08	0.72		0.72
1905	2.57		2.57	1.28		1.28
1910	7.51		7.51	1.83		1.83
1915	15.99		15.99	2.08		2.08
1920	30.39	0.43	30.48	3.17	1.19	2.02
1925	50.26	1.74	52.00	4.32	1.35	2.91
1930	47.77	2.91	50.68	4.42	1.36	3.05
1935	38.84	2.41	41.24	4.19	1.28	2.93
1940	46.98	3.54	51.35	5.25	1.45	3.75
1945	64.67	5.64	72.61	6.36	1.45	4.95
1950	65.42	14.40	77.51	7.71	2.14	5.47
1955	61.82	21.74	79.88	8.02	2.03	6.00
1960	48.04	33.25	79.80	8.35	2.25	6.10
1965	39.23	48.96	85.90	9.29	2.58	6.66
1970	38.67	69.16	114.91	9.53	2.44	7.23
1975			146.27			8.13
1980			128.94			8.52
			(c)			(d)

All values are 5 year averages centered on year shown except 1880=(1880-1882)

Source: Unless otherwise noted, [Census 75] through 1938, [BEA biennial] from 1939 on

(c) =Apparent consumption (Production + Imp-Exp) thru 1938

(d) =Apparent consumption (Production + Imp-Exp) thru 1917, then [BEA biennial]

Table 11-6: U.S. Domestic Production & Consumption of Motor Fuels & Distillate Oils (million tonnes)

	Motor Fuel Production	Motor Fuel Exports	Consumption Motor Fuels	Distillates Production	Distillates Imports	Distillates Total Demand
1880	0.29		0.24			
1885	0.40		0.33			
1890	0.63		0.52			
1895	0.89		0.73			
1900	0.98		0.80			
1905	1.21		0.99	3.32		2.82
1910	2.60		2.13	7.50		6.37
1915	7.07		5.80	15.99		13.59
1920	16.46	2.10	12.56	30.39	0.43	25.92
1925	37.25	4.95	31.63	50.26	1.74	44.46
1930	60.05	7.57	52.64	32.24	2.91	30.32
1935	67.95	4.01	62.94	15.87	2.21	15.70
1940	87.33	5.29	81.69	25.63	1.02	23.21
1945	106.05	9.67	84.29	37.74	1.06	34.39
1950	147.59	5.16	138.48	61.34	0.33	57.82
1955	191.92	5.25	182.36	87.31	0.72	82.09
1960	218.13	2.12	218.93	98.51	2.16	99.45
1965	250.53	0.93	262.72	112.09	1.92	112.91
1970	307.63	0.29	338.76	124.93	7.40	137.60
1975	355.10		384.69			163.02
1980	354.51		363.87			160.19
			(a)			(b)

All values are 5 year averages centered on year shown except 1880=(1880-1882)

Source: Unless otherwise noted, [Census 75] through 1938, and [BEA biennial] from 1939 on

(a) =80% of [Census 75] "Production" (1880-1918), [USDOT 77] (1919-1975), [BEA biennial] (1976-1983)

(b) =Apparent consumption (85% Production + Imp-Exp) thru 1938

Table 11-7: Details of U.S. Motor Fuel Use (million tonnes)

	NJ Consumption MotorFuel	NY Consumption MotorFuel	NJ+NY Consumption MotorFuel	Gasoline Used on Highways	Special Fuels on Highways	Total Hwy Use Motor Fuel	Non-Hwy Uses Motor Fuel	Total Motor Fuel Burned	Loss Allowances
1925	0.33	0.88	1.22			30.22	1.41	31.63	
1930	0.53	1.33	1.85			49.11	3.40	52.51	0.31
1935	0.63	1.50	2.14			57.83	4.40	62.23	0.71
1940	0.82	1.71	2.53			73.59	7.01	80.60	1.09
1945	0.73	1.48	2.21			72.89	10.43	83.32	0.97
1950	1.17	2.44	3.61	124.71	2.17	122.56	14.41	136.97	1.51
1955	1.61	3.27	4.88	159.46	4.31	163.78	16.77	180.55	1.82
1960	1.92	3.97	5.89	191.10	8.42	199.52	17.64	217.16	1.77
1965	2.27	4.39	6.67	231.69	14.34	246.03	14.62	260.64	2.07
1970	2.82	5.37	8.19	298.06	24.09	322.15	13.86	336.01	2.75
1975	3.23	5.64	8.88	341.59	33.71	375.30	12.86	388.16	3.19

All values are 5 year averages centered on year shown except 1880=(1880-1882)
Source: Highway Statistics

Table 11-8: Petroleum Products Refined & Comsumed - Hudson Raritan Basin (million tonnes)

	Total Petroleum Consumed (a)	Residual Fuel Oil Consumed (b)	Distillate Fuel Oil Consumed (b)	Gasoline Consumed (c)	Lubricants Consumed (c)	Total Petroleum Refined (d)	Residual Fuel Oil Refined (e)	Distillate Fuel Oil Refined (e)
1980	51.88	14.15	9.75	16.37	0.393	20.37	2.35	4.56
1970	48.27	20.58	15.30	17.62	0.379	20.09	1.29	4.44
1960	40.50	9.84	12.79	14.23	0.404	19.52	2.09	4.27
1950	30.80	7.08	3.11	8.59	0.351	17.52	3.47	3.25
1940	18.70	3.35	1.47	6.78	0.299	15.10	3.67	2.00
1930	12.33	1.86	0.75	5.05	0.299	12.40	4.27	1.06
1920	5.62	2.60			0.190	5.27	2.60	
1900	0.68	0.26			0.032	0.85	0.26	
1880	0.19	0.007			0.013	0.57	0.007	

(a) Based on population share

(b) Allocated to H-R from consumption data by state (NJ,NY) based on population

(c) Computed from Table 11-6 in this Volume and Table 3-9 in Volume I.

(d) Based on H-R share of refinery capacity

(e) Computed from total refined petroleum by using Table 11-3

12. History of Particulate Emissions Control

Public concern with smoke in the U.S. was intense as early as the mid 19th century, when St. Louis passed an ordinance regulating chimney height [EB 55, *Smoke*]. A St. Louis court also awarded the first recorded damage ($50) for "smoke nuisance". The award was upheld by the Missouri Supreme Court. The first smoke ordinance in the U.S. was adopted by Chicago (May 1, 1881), specifying a range of fines from $5 to $50 for emission of dense smoke [EB 55, *Smoke*]. Cincinnati, Pittsburgh, Cleveland, St. Louis and St. Paul all adopted such ordinances within a few years [EB 55, *Smoke*]. Such ordinances were not rigorously enforced, at first. However, in 1915 the city of DesMoines prosecuted a laundry plant for smoke nuisance. The laundry sued in U.S. district court to enjoin enforcement. The case was appealed all the way to the U.S. supreme court, which upheld the city's position [EB 55, *Smoke*]. By 1924 the U.S. Bureau of Mines, in cooperation with national engineering societies, had drawn up the first model smoke ordinance as a guide to local governments.

From 1880 to 1920 the chief strategy for "black" smoke control was to increase the efficiency of combustion and -- where possible -- to burn "smokeless" fuels, e.g. anthracite coal or coke. Chicago established criteria for coal-burning furnace design as early as 1907, and required city permits prior to construction. This approach was soon adopted by most other cities. The first anti-smoke ordinances were initiated in the midwest because midwestern cities utilized bituminous coal, in contrast to the "clean" cities of the eastern seaboard, which burned Pennsylvania anthracite coal.

Damages from coal smoke were first evaluated comprehensively in a study carried out by the Mellon Institute of Pittsburgh shortly afer 1900 [MI 12]. The damages mainly identified at the time were from soot (causing damage to merchandise, extra cleaning costs, etc.) and corrosion due to the sulfuric acid created by SO_2 emissions. Damages were estimated by the Mellon Institute at $15 to $20 per capita per annum (c. 1905).

In stoker-fired boilers a large percentage of the ash (up to 80%) remains in the furnace as "clinker" and is removed in solid form. The fly ash that goes up the stack is sooty and coarse. Much of it can be removed easily by mechanical means, e.g. dust baffles, although electrostatic precipitators do not operate efficiently to remove large particles [Carlton-Jones 74].

Mechanical collectors were first utilized by NY Edison Co. at its Sherman Creek station in 1915 for this purpose, achieving a collection efficiency better than 70% [ConEd 84]. Cyclone collectors were installed by NY Edison in the stoker-fired boilers at the Hudson Avenue station, in the mid 1920's achieving 90% fly-ash collection efficiency [ConEd 84].

The situation began to change after the first successful introduction of equipment for burning pulverized coal, by Milwaukee Street Railway and Electric Light Co. (1919) [Carlton-Jones 74]. The second successful use of pulverized coal and the first to be based on original equipment design, was the Lakeside power plant completed by the same utility in 1921.

Pulverized coal burns much more efficiently than lump coal; in fact in the initial Milwaukee installation, the fuel consumption per unit of electricity generation dropped from over 4 lbs/hr to less than 2 lbs/hr when the mechanical stoker was replaced by pulverized coal-feed equipment [Carlton-Jones 74]. However, the burning of pulverized coal also sharply increased the amount of ash emitted to the air, from 20-40% to 70-85% at the Lakeside plant. Despite the success of the Milwaukee installations and the obvious economic gains to be made, electric utilities were not quick to adopt the new technology, because of a host of technical difficulties, primarily due to the ash problem.

The first successful use of an electrostatic precipitator (ESP) for fly-ash control was in 1924 at the Trenton Channel plant of Detroit Edison Co. [Carlton-Jones 74], probably the second major application of pulverized coal. Other units came on-stream slowly, at first. In 1928-29 NY Edison ordered ESP's for 3 boilers at the 14th Street (East River) station, with others soon to follow. By 1934 more than 50% of all power plants using pulverized coal had installed ESP's, with an average collection efficiency of 90% [Carlton-Jones 74]. The 95% efficiency milestone for ESP's was first reached in 1933 (Potomac Electric Co.), with further improvements following rapidly.

The installation of pulverized coal-fired boilers with ESP's, accelerated sharply after WWII. By 1947 an efficiency of 97.5% could be guaranteed for the first time [Carlton-Jones 74]. Average efficiencies for new units ordered reached 95% in 1951 and 98% in 1960. The 99% milestone was achieved for the first time in 1958 (by Consolidated Edison Co. of NY) and this standard became the average for newly ordered units by 1970 [Carlton-Jones 74]. As of 1957, there were 730 ESP's in service at electric power generating plants in the U.S. [Carlton-Jones 74]. Consolidated Edison Co. decided in the mid '50's to try to reach the 99% level of control and began to install a series of new more efficient units. They had 25 operating ESP's in service by 1961, averaging about 97% collection efficiency [ConEd 84]. In 1966 the city of New York mandated that the 99% level be achieved by 1969. Consolidated Edison announce it had met this standard by June 1967 [ConEd 84].

In summary, there are three distinct phases in the history of coal ash control. In the first phase (before 1920), a large fraction of the ash was collected, removed in solid form, although there were no means of recovering fly-ash. An estimate of the fraction captured as bottom ash can be arrived at from data on refuse collection in New York City during the period 1910-1917 [Hering & Greeley 21, p.13]. Approximately 1400 lb of ashes were collected per capita each year. During that period, we can also estimate that around 14 tons of coal per capita (~ 60% anthracite, 40% bituminous) were burned for residential and commercial heating purposes. Thus bottom ash collected accounts for (at least) 50% of the total weight of coal burned. The total ash content of the coal used in the New York metropolitan area is approximately 11% for anthracite and 9% for bituminous, or a bit over 10% on average.[32] Assuming the ash-content of coals burned in 1910-17 was similar, it appears that very close to half of the ash was retained in the furnace and removed in solid form as refuse. We therefore assume a 50% minimum control level for all stoker-fired coal combustion.

The introduction of mechanical baffles, filters and cyclones by utilities beginning in 1915 may have raised this level in some facilities, but the introduction of pulverized coal to increase combustion efficiency had the opposite effect as far as fly ash emissions were concerned, as noted above. Absent more detailed information, it is difficult to estimate the net impact of the two developments. Only after 1929, when ESP's were introduced by NY Edison Co. and other utilities, did significant improvements over the 50% level occur. However, non-utility coal use, without fly-ash control, was still important until at least 1950. Averaging over all users, therefore, we estimate 50% control for 1930, 60% for 1940, 70% for 1950, 90% for 1960 and 97% by 1970.

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[32] Based on data from [Roark 38], assuming 90% of the ash is emitted as fly ash when burned by utilities.

The motivation for particulate emissions control for copper and lead smelters was perceived earlier, because environmental damage associated with copper smelting was severe. Damages to many species of plants and animals occurred near early smelters in the Ducktown and Copper Hill areas of Tennessee, Clifton (Arizona), Anaconda (Montana), and Sudbury (Ontario). In the Ducktown, Tennessee case, 17,000 acres were literally devastated and the area was still barren in 1965, 50 years after the smelter closed in 1915, primarily because of excessive arsenic, copper, and lead burdens in the soil [Hutchinson 78].

Early complaints were mainly focussed on the effects of sulfur dioxide emissions, but in 1902 Anaconda's new Washoe smelter was implicated in the deaths of thousands of animals (horses, cows and sheep) over a wide area. Two chemistry professors, Harkins and Swain, were hired by local farmers and ranchers to investigate. Most of the animal deaths were attributed to arsenic poisoning. Anaconda offered cash compensation and tried to mitigate the problem with a taller (300') smokestack. This did not satisfy the farmers, who sued. They won a minimal damage award ($350) from the Federal Circuit Court, [Hutchinson 78] but under the threat of numerous lawsuits (strongly aided and abetted by the U.S. Forest Service), copper companies began searching actively for more effective means of particulate emissions control.

The first approach to dust control, beginning in the 1890's, was mechanical, e.g. baffles, expansion chambers, balloon flues and boiler settings. These were often supplemented in lead and zinc smelters by the use of cotton or woolen cloth filters in "bag houses", especially in lead and zinc smelters. A typical bag was 18" in diameter and 30' long, suspended over the gas outlet. However bags could not be used effectively on hot gases (over 270°F at maximum) and, in the case of copper smelters there was a further problem that sulfuric acid in the smoke would attack and destroy the bags. Baghouses also resist the flow of the gas and consequently require auxiliary "booster" fans, which consumed power.

The effective solution was the development of electrostatic precipitators by F.G. Cottrell of the University of California at Berkeley. Improving on prior work in Europe by O. Lodge, A.O. Walker, K. Moeller, and others [White 57]. The first commercial ESP unit was installed by Cottrell in 1907 at a sulfuric acid plant in Pinole, California. It processed about 5000 cubic feet per minute (open) of gas. It was followed by a similar unit at a copper-zinc-lead smelter at Selby, California [White 57]. A much larger unit (250,000 cfm) was installed in 1910 to collect lead and zinc oxide fume at the Balaklala smelter in northern California [White 57]. A recovery efficiency of 80-90% was achieved, after some difficulty. The Balbach lead smelter in Newark NJ also installed an ESP about that time, claiming 90% particulate recovery efficiency. Work began in 1910 on the Garfield Utah copper smelter (50,000 cfm). This was extended in 1913. Work also began at this time on a unit for the giant Anaconda smelters (700,000 cfm), which began operation in 1916. A central gas cleaning plant for the entire plant was operating by 1919 (2.25 million cfm). Many other smelters also installed ESP's before 1920, including the copper smelter at Trail, B.C. (1914), and a unit on the electric furnace recovering gold and silver from electrolytic anode slime at Anaconda's Raritan Works (1913). The United States Assay Office in New York City also installed a unit to recover gold from furnace operations (early 1920's). By the end of the 1920's most copper smelters had "Cottrell Treaters", usually operating at 90% efficiency or better [Welch 33]. By 1957 there were 200 ESP's in operation on copper, lead and zinc smelters in the U.S., with a total capacity of 15 million cfm.

Averaging over all non-ferrous smelters and related activities in the Hudson-Raritan basin, we estimate roughly 50% dust recovery by 1900 (entirely mechanical) 80% by 1920 (mostly mechanical) and 90% by 1930. Thereafter, we estimate 93% by 1940, 95% by 1950, 97% by 1960 and 98% by 1970.

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1 Notes on Appendix Source Abbreviations

In the metals worksheets in the appendices which follow, sundry inconsistent abbreviations were used for data sources for individual columns. For clarity, these are listed below:

Abbrev.	Citation Code	Reference
ABM	ABMS annual	American Bureau of Metal Statistics, various years, "Non Ferrous Metal Data"
Bus BusStat	BEA biennial	U.S. Department of Commerce, Bureau of Economic Analysis, 1975, 1979, 1982, "Business Statistics", USGPO, Washington, DC
FKC	Faith, Keyes & Clark 75	Lowenheim, F.A. & Moran, M.K. (eds), 1975, "Faith, Keyes and Clark's Industrial Chemicals", (4th Edition), John Wiley & Sons, NY
FTC	USTC annual	U.S. Tariff Commission, Annual, "Synthetic Organic Chemicals", USGPO, Washington, DC
Gutm.	Gutmanis 85	Gutmanis, Ivars, Special compilation for this study
Hist HistStat HISTSTATS Hstat	Census 75	U.S. Department of Commerce, Bureau of the Census, 1975, "Historical Statistics of the United States: Colonial Times to 1970", USGPO, Washington, DC
HWY STATS	USDOT annual	U.S. Department of Transportation, Annual, "Highway Statistics", USGPO, Washington, DC
Min F&P	USBM quinquennial	U.S. Bureau of Mines, 1970, 75, 80, "Mineral Facts & Problems", USGPO, Washington, DC
Min YB MINYB MYB BuMine	USBM annual	U.S. Bureau of Mines, Annual, "Minerals Yearbook", USGPO, Washington, DC
RFF	Potter & Christy 62	Potter, N. & Christy, F.T. Jr., 1962, "Trends in Natural Resource Commodities", published for Resources for the Future, Inc. by the Johns Hopkins University Press
USDA	USDA annual	U.S. Department of Agriculture, Annual, "Agricultural Statistics", USGPO, Washington, DC

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Mine Pro duc tion Hstat 2-1	Refinery Produc- tion from Domestic Ores MIN YB 2-1	Imports Except Coinage MIN YB 2-1	Second- ary Produc- tion MIN F&P 2-1	Total U.S. Supply MIN F&P 2-1	Exports Except Coinage MIN YB 2-1	Total U.S. Demand MIN F&P 2-1	Net Consump tion Industry & Arts MIN YB 2-1	Silver- ware (Electro- plate & Sterling) MIN F&P 2-3	Jewelry & Arts MIN F&P 2-3	Photo- graphy MIN F&P 2-3
1982	40.2	43.8	117.5			25.5		118.8			
1981	40.7	44.5	94.1	39.1	300.2	27.9	116.8	116.7	8.3	5.4	51.0
1980	32.3	36.2	78.8	53.1	306.7	80.9	124.8	124.7	13.5	5.9	49.8
1979	37.9	39.0	92.4	39.7	316.0	35.6	157.4	157.3	21.2	5.4	66.0
1978	39.4	44.0	75.6	37.1	318.4	22.4	160.2	160.2	25.2	6.8	64.3
1977	38.2	36.7	79.1	47.9	309.0	22.4	153.7	153.6	23.5	8.1	53.7
1976	34.3	34.4	72.7	50.2	331.9	14.6	171.9	170.6	29.3	11.0	55.5
1975	34.9	33.1	66.5	51.1	312.4	32.6	160.4	157.7	32.4	12.7	46.1
1974	33.8	32.4	94.5	56.1	340.6	18.4	177.0	176.0	35.3	5.1	49.6
1973	37.5	36.5	96.4	34.6	344.2	11.2	197.3	196.4	43.9	5.8	52.0
1972	37.2	38.4	65.4	31.1	322.1	29.7	153.9	151.7	39.2	4.9	38.3
1971	41.6	37.2	58.0	30.1	322.3	12.2	131.6	129.1	33.6	3.4	36.1
1970	45.0	49.5	62.3	56.0	399.3	27.6	129.1	128.4	30.6	5.1	38.0
1969	41.9	51.7	71.9	79.8	445.9	88.9	161.0	141.5	33.0	3.0	41.4
1968	32.7	34.1	70.7	64.2	449.3	125.8	182.1	145.3	43.6	4.5	41.6
1967	32.3	30.3	55.5	33.5	407.7	70.8	214.9	171.0	48.2	5.8	50.3
1966	43.7	48.4	63.0	36.8	341.7	85.5	237.6	183.7	52.4	6.3	48.4
1965	39.8	39.0	54.7	33.5	530.5	39.7	490.8	137.0	48.2	5.8	47.4
1964	36.3	37.0	51.7			109.4		123.0			
1963	35.2	35.0	59.1			31.5		110.0			
1962	36.8							110.4			
1961	34.8							105.5			
1960	30.8							102.0			
1959	31.2							101.0			
1958	34.1	36.8	166.0			2.7		85.5			
1957	38.2	38.7	206.1			10.3		95.4			
1956	38.7	38.7	162.8			5.5		100.0			
1955	37.2	36.5	84.5			4.9		101.4			
1954	36.9	35.6	90.9			0.7		86.0			
1953	37.6	37.7						106.0			
1952	39.5	39.8						96.5			
1951	39.8	39.9						105.0			
1950	42.5	42.3						110.0			
1949	34.7	34.9						88.0			
1948	38.1	39.2						105.3			
1947	35.8	38.6						98.5			
1946	22.9	21.1						87.0			
1945	29.0	29.0						126.3			
1944	34.5	35.7						120.1			
1943	41.5							118.0			
1942	54.1							101.4	34.0	16.5	19.6
1941	67.0							72.4			
1940	70.4							44.5			
1939	64.4							44.6			
1938	61.7							20.2			
1937	71.4							27.7			
1936	61.2							19.1			
1935	48.5							5.3			
1934	32.8							11.5			
1933	23.1							10.8			
1932	22.8							9.3			
1931	29.9							12.2			
			(d)						(j)		

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Mine Production Hstat 2-1	Refinery Production from Domestic Ores MIN YB 2-1	Imports Except Coinage MIN YB 2-1	Secondary Production MIN F&P 2-1	Total U.S. Supply MIN F&P 2-1	Exports Except Coinage MIN YB 2-1	Total U.S. Demand MIN F&P 2-1	Net Consumption Industry & Arts MIN YB 2-1	Silverware (Electroplate & Sterling) MIN F&P 2-3	Jewelry & Arts MIN F&P 2-3	Photography MIN F&P 2-3
1930	47.7							19.6			
1929	60.9										
1928	57.9										
1927	59.6										
1926	62.5										
1925	66.7										
1924	64.1										
1923	70.4										
1922	61.2										
1921	46.2										
1920	56.5										
1919	51.9										
1918	68.1										
1917	70.7										
1916	78.9										
1915	72.4										
1914	69.6										
1913	71.2										
1912	66.0										
1911	61.1										
1910	57.6										
1909	57.3										
1908	50.9										
1907	52.5										
1906	57.4										
1905	56.3										
1904	56.0										
1903	54.3										
1902	55.5										
1901	55.2										
1900	57.6										
1899	54.8										
1898	54.4										
1897	53.9										
1896	58.8										
1895	55.7										
1894	49.5										
1893	60.0										
1892	63.5										
1891	58.3										
1890	54.5										
1889	50.1										
1888	45.8										
1887	41.7										
1886	39.7										
1885	39.9										
1884	37.7										
1883	35.7										
1882	36.2										
1881	33.3										
1880	30.3										
			(d)						(j)		

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Refrig. & Appliance (Brazing Alloys& Solders) MIN F&P 2-3	Batteries MIN F&P 2-3	Elec.Equip.& Components (Contacts & Conductors) MIN F&P 2-3	Coins, Medallions, etc. MIN F&P 2-3	Catalysts MIN F&P 2-3	Other MIN F&P 2-3	Gross Consumption Industry & Arts MINYB/sum 2-1	Gross Consumption Coinage MIN YB 2-1	Gross Consumption sum 2-1	Secondary Returned from Industrial Use MIN YB 2-1
1982							118.8	1.8	120.7	
1981	7.7	3.8	26.4	2.6	3.8	7.6	116.6	0.2	116.8	39.1
1980	8.5	6.0	27.8	4.7	3.0	5.5	124.7	0.1	124.8	53.1
1979	10.9	4.6	33.5	4.7	5.6	5.3	157.2	0.2	157.4	39.7
1978	11.0	6.0	30.8	2.7	8.2	5.2	160.2	0.0	160.2	37.1
1977	12.4	5.8	31.3	4.3	8.9	5.6	153.6	0.1	153.7	47.9
1976	11.2	3.5	32.3	8.2	1.3	7.3	159.6	1.3	160.9	50.2
1975	13.6	4.3	27.2	7.2	8.8	5.4	157.7	2.7	160.4	51.1
1974	14.5	4.2	31.3	21.4	7.3	7.3	176.0	1.0	177.0	56.1
1973	17.7	4.2	40.2	20.1	6.0	6.5	196.4	0.9	197.3	34.6
1972	12.2	6.0	36.4	7.1	3.4	4.1	151.6	2.3	153.9	31.1
1971	12.1	5.6	28.0		1.7	8.6	129.1	2.2	131.3	30.1
1970	18.0	6.3	21.3			9.1	128.4	0.7	129.1	56.0
1969	21.2	3.8	28.3			10.9	141.6	19.4	161.0	79.8
1968	17.5	5.8	23.0			9.3	145.3	36.8	182.1	64.2
1967	19.5	11.4	26.5			9.3	171.0	43.9	214.9	33.5
1966	21.6	12.5	32.5			10.0	183.7	53.9	237.6	36.8
1965	19.7	11.4	28.5			9.5	170.5	320.3	490.8	33.5
1964								203.0		
1963							204.5	111.5	316.0	94.5
1962							180.8	77.4	258.2	70.4
1961							155.8	55.9	211.7	50.3
1960							151.0	46.0	197.0	49.0
1959							143.0	41.4	184.4	42.0
1958							121.5	38.1	159.6	36.0
1957							133.7	52.1	185.8	38.3
1956							130.0	31.4	161.4	30.0
1955							123.5	8.2	131.7	22.1
1954							104.6	53.2	157.8	18.6
1953							125.4	42.8	168.2	19.4
1952							121.5			25.0
1951							151.7			46.7
1950							155.3			45.3
1949							110.7			22.7
1948							129.2			23.9
1947							126.4			27.9
1946							123.6			36.6
1945							184.7			58.4
1944							176.3			56.2
1943							162.1			44.1
1942	10.6		9.3	7.0		34.4	131.4			30.0
1941							92.8			20.4
1940							67.1			22.6
1939							69.6			25.0
1938							38.6			18.4
1937							51.3			23.6
1936							35.8			16.7
1935							41.2			35.9
1934							39.7			28.2
1933							29.3			18.6
1932										
1931							33.7			
	(m)		(o)	(p)	(q)			(t)		

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Refrig. & Appliance (Brazing Alloys& Solders) MIN F&P 2-3	Batteries MIN F&P 2-3	Elec.Equip.& Components (Contacts & Conduc-tors) MIN F&P 2-3	Coins, Medal-lions, etc. MIN F&P 2-3	Cata-lysts MIN F&P 2-3	Other MIN F&P 2-3	Gross Consump-tion Industry & Arts MINYB/sum 2-1	Gross Consump-tion Coinage MIN YB 2-1	Gross Consump-tion sum 2-1	Secondary Returned from Industrial Use MIN YB 2-1
1930							36.4			
1929										
1928										
1927										
1926										
1925							39.8			
1924										
1923										
1922										
1921										
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1884										
1883										
1882										
1881										
1880										
	(m)		(o)	(p)	(q)			(t)		

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Production BuMint	Production BusStat	Production OTHER	Refinery Production MIN F&P	Refined Imports MIN F&P	Exports MIN F&P	Treasury Stock BuMine	Industrial Stock BuMine	D.O.D. Stock BuMine	Exports Hstat	Imports Hstat
1982				43.8			36.8	126.8	1.8		
1981				47.0	75.9	27.9	38.7	117.4	3.8		
1980				39.4	64.9	80.9	38.9	138.1	4.5		
1979				50.8	78.4	35.6	39.0	149.1	5.7		
1978				54.4	61.4	22.4	39.2	146.9	6.5		
1977				45.0	69.4	22.4	39.0	165.3			
1976				54.4	67.2	14.6	40.0	146.4			
1975				60.1	61.6	32.6	41.0	158.3			
1974		52.6		63.3	90.0	18.4	44.0	136.5			
1973		43.6		75.4	81.2	11.2	45.0	130.1			
1972		43.6		77.5	25.7	29.7	46.0	152.3			
1971		41.0		68.7	22.4	12.2	48.0	185.3			
1970		47.5		81.4	32.6	27.6	25.0	210.2		-9	-9
1969		41.6		83.5	39.5	88.9	104.0	198.8		-9	-9
1968		29.2		66.9	41.9	125.7	256.0	166.4		-9	-9
1967		30.4		54.0	29.9	70.8	351.0	83.4		101	80
1966		45.0		79.4	27.0	85.6	594.0	57.2		114	78
1965		44.4		86.8	6.9	39.6	804.0			54	65
1964		45.9					1218.0			144	66
1963		46.1					1583.0			42	71
1962		45.2					1766.6			15	75
1961		42.3					1862.3			38	45
1960		40.1					1992.2			26	57
1959		23.2					2059.9			10	63
1958		35.7					2106.0			4	132
1957		36.3	38.2				2014.0			11	158
1956		38.2	38.7				1981.0			7	129
1955		33.1	37.2				1930.0			8	73
1954		38.1	36.9				1935.0			5	80
1953		34.7	37.6				1926.0			9	95
1952		40.2	39.4				1938.0			5	67
1951		40.0	39.8				1965.0			9	103
1950		42.1	42.5				1983.0			7	110
1949		34.6	34.7				1978.0			24	74
1948		36.1	38.1				1952.0			13	71
1947		36.1	35.8				1953.0			31	68
1946		21.4	22.9				1951.0			36	58
1945		29.3	29.0				2005.0			91	27
1944		37.4	34.5				2999.0			127	23
1943		44.8	41.5				3254.0			31	28
1942		54.5	54.1				3334.0			2	41
1941		69.1	67.3				3280.0			6	47
1940		67.0	70.6				3135.0			4	58
1939		57.8	64.4				2927.0			15	85
1938		58.7	61.7							7	231
1937		69.3	71.4							12	92
1936		62.8	61.2							12	183
1935		38.3	48.5							19	355
1934		26.4	32.8							17	103
1933		21.0	23.1							19	60
1932		24.8	22.8							14	20
1931		31.6	29.9							26	29

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Production BuMint	Production BusStat	Production OTHER	Refinery Production MIN F&P	Refined Imports MIN F&P	Exports MIN F&P	Treasury Stock BuMine	Industrial Stock BuMine	D.O.D. Stock BuMine	Exports Hstat	Imports Hstat
1930		50.2	47.7							54	43
1929		60.2	60.9							83	64
1928			57.9							87	68
1927			59.6							76	55
1926			62.5							92	70
1925			66.7							99	65
1924			64.1							110	74
1923			70.4							72	74
1922			61.2							63	71
1921			46.2							52	63
1920			56.5							114	88
1919			51.9							239	89
1918			68.1							253	71
1917			70.7							84	53
1916			78.9							71	32
1915			72.4							51	29
1914			69.6							55	30
1913			71.2							72	41
1912			66.0							65	47
1911			61.1							65	46
1910			57.6							55	45
1909			57.3							56	44
1908			50.9							58	45
1907			52.5							57	43
1906			57.4							66	44
1905			56.3							49	27
1904			56.0							49	28
1903			54.3							44	24
1902			55.5							50	28
1901			55.2							64	36
1900			57.6							57	35
1899			54.8							56	31
1898			54.4							55	31
1897	53.9		53.9							62	31
1896	58.8		58.8							61	29
1895	55.7		55.7							47	20
1894	49.5		49.5							50	13
1893	60.0		60.0							41	23
1892	63.5		63.5							33	20
1891	58.3		58.3							23	18
1890	54.5		54.5							35	21
1889	50.0		50.1							37	19
1888	45.8		45.8							28	15
1887	41.2		41.7							26	17
1886	39.4		39.7							30	18
1885	39.9		39.9							34	17
1884	37.8		37.7							26	15
1883	35.7		35.7							20	11
1882	36.2		36.2							17	8
1881	33.3		33.3							17	11
1880	30.3		30.3							14	12

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Avg NY Price (cents/ fine oz) Hstat	Coin & Bullion Exports BuMint	Coin & Bullion Imports BuMint	Exports BusStat	Imports BusStat	Imports BuMine	Exports BuMine
1982	795						
1981	1052						
1980	2063						
1979	1109						
1978	540						
1977	462						
1976	435						
1975	442						
1974	471			81.7	501.5		
1973	256			27.6	268.6		
1972	169			31.6	59.4		
1971	155			19.5	49.5		
1970	177			27.6	65.0		
1969	179			156.7	80.1		
1968	214			252.1	145.2		
1967	155			100.7	80.2		
1966	129			114.3	78.4		
1965	129			54.1	64.8		
1964	128			144.1	66.3		
1963	108			41.8	70.9	70.9	41.8
1962	92			15.1	74.5	74.5	15.1
1961	92			37.9	45.4	45.4	37.9
1960	91			25.8	57.4	57.4	25.8
1959	91			9.9	62.7	62.7	9.9
1958	89			3.7	132.0		
1957	91			11.2	158.4	114.4	7.0
1956	91			7.0	129.1		
1955	89			8.3	72.9		
1954	85			4.5	79.7		
1953	85			8.7	95.1		
1952	85			5.2	67.3	67.3	4.9
1951	89			8.6	103.5	103.5	8.6
1950	74			6.2	110.0	110.0	6.2
1949	72			23.3	73.5	73.5	23.3
1948	74			12.4	70.9	70.9	12.4
1947	72			30.6	68.1		
1946	80			36.5	57.6		
1945	52			90.9	27.3		
1944	45			126.9	23.4		
1943	45			30.7	27.9		
1942	38			2.0	41.1		
1941	35			5.7	47.1		
1940	35			3.7	58.4		
1939	39			14.6	85.3		
1938	43			7.1	230.5		
1937	45			12.0	91.9		
1936	45			12.0	182.8		
1935	64			18.8	354.5		
1934	48			16.5	102.7		
1933	35			19.0	60.2		
1932	28			13.8	19.6	19.6	13.8
1931	29			26.5	28.7	28.7	26.5
				(al)	(al)		

NOTES TO SILVER WORKSHEET

(d) General imports thru 1972, then imports for consumption

(j),(m),(o) Category change (new categories in parentheses) after 1970

(p) included in other categories prior to 1970

(q) included in "Other" category prior to 1970

(t) NA prior to 1959

(al) 1929-46 calculated as monthly average times 12

APPENDIX I: Silver Worksheet (units = million troy ounces)

	Avg NY Price (cents/ fine oz) Hstat	Coin & Bullion Exports BuMint	Coin & Bullion Imports BuMint	Exports BusStat	Imports BusStat	Imports BuMine	Exports BuMine
1930	38			54.2	42.8		
1929	53			83.4	63.9		
1928	58						
1927	56						
1926	62						
1925	69						
1924	67						
1923	65						
1922	68						
1921	63						
1920	101						
1919	111						
1918	97						
1917	81						
1916	66						
1915	50						
1914	55						
1913	60						
1912	61						
1911	53						
1910	53						
1909	52						
1908	53						
1907	65						
1906	67						
1905	60						
1904	57						
1903	54						
1902	52						
1901	59						
1900	61						
1899	60						
1898	58	55.1	30.9				
1897	60	61.9	30.5				
1896	67	60.5	28.8				
1895	65	47.3	20.2				
1894	63	50.5	13.3				
1893	78	40.7	23.2				
1892	88	32.8	20.0				
1891	99	22.6	18.0				
1890	105	34.9	21.0				
1889	94	36.7	18.7				
1888	94	28.0	15.4				
1887	98	26.3	17.3				
1886	100	29.5	17.9				
1885	107	33.8	16.6				
1884	111	26.1	14.6				
1883	111	20.2	10.8				
1882	114	16.8	8.1				
1881	113	16.8	10.5				
1880	115	13.5	12.3				
				(al)	(al)		

NOTES TO SILVER WORKSHEET

(d) General imports thru 1972, then imports for consumption

(j),(m),(o) Category change (new categories in parentheses) after 1970

(p) included in other categories prior to 1970

(q) included in "Other" category prior to 1970

(t) NA prior to 1959

(al) 1929-46 calculated as monthly average times 12

APPENDIX II: Arsenic Worksheet (units = short tons)

	Total US Sales White Arsenic AS2 O3 MIN YB 3-1	Total US Production White Arsenic AS2 O3 MIN YB 3-1	Imports for Consump. White Arsenic MIN YB 3-1	Exports White Arsenic et al MIN YB 3-1	Apparent Consump. (Sales+ IMP-EXP) White Arsenic 3-1	Imports for Consump. All Forms Arsenic MIN YB 3-1	Exports Total Arsenic MIN YB or calc 3-1	Apparent Consump. (Sales+ IMP-EXP) All Forms of Arsenic 3-1	Primary Demand Total Contained Arsenic MIN F&P 3-1,2	Agri-cultural Demand 3-6
1982	na	na	16092	0	22392	17958		24308		
1981	na	na	18958	0	25258	20952		27302		
1980	na	na	12528	0	18828	13077		19427	13713	6080
1979		6350	12325	0	18675	12947		19297	16200	11300
1978		6360	10306	0	16666	11713		18073	14760	10300
1977		5330	5981	0	11311	7830		13160	13190	9200
1976		7300	4262	0	11562	4900		12200	10700	7500
1975		8100	12013	0	20113	12573		20673	17000	14000
1974		7400	13742	0	21142	14582		21982	27800	22800
1973		10200	13496	0	23696	14405		24605	24190	19700
1972		10300	13613	0	23913	14520		24820	18970	15100
1971		7500	17306	0	24806	17975		25475	19640	15600
1970		10900	18763	0	29663	19341		30241	20300	16100
1969		10300	18171	0	28471	18636		28936	20600	16300
1968		6100	25195	0	31295	25667		31767	23900	19900
1967		3200	27075	0	30275	27790		30990	26700	21800
1966		9400	18675	0	28075	19168		28568	24280	20500
1965		12300	15525	0	27825	15916		28216	24680	20500
1964		7700		0	23225			23616	24955	20800
1963				0	26900			26739	21770	
1962			14600	0	26900	14933	494	22139	20615	
1961				0	27825			15718	20965	
1960				0	22891			21366	18570	
1959				0	21892			20452	19900	
1958	10931	11508	9524	0	20455	9705	1687	18949	15500	
1957	12785	10493	10135	0	22920	10422	1998	21209	17400	
1956	18876	12201	6422	0	25298	6659	1596	23939	19200	
1955	11673	10780	7222	0	18895	7520	1483	17710	14300	
1954	11523	13167	4848	0	16371	5021	1343	15201	12400	
1953	11315	10873	4717	0	16032	4864	2097	14082		
1952	9244	15673	4483	0	13727	4795	2931	11108		
1951	14351	16190	14518	0	28869	15610	2991	26970		
1950	17330	13273	14774	0	32104	15170	2449	30051		
1949	10181	12795	4696	0	14877	4769	2454	12496		
1948	14965	18639	9336	0	24301	9417	3304	21078		
1947	18188	18755	13940	1000	31128	14073	5036	27225		
1946	12039	10211	13821	1000	24860	13912	5837	20114		
1945	24810	24349	13149	858	37101	14387	5778	33419		
1944	34472	36094	9965	2401	42036	10055	5740	38787		
1943	32423	31202	16112	1975	46560	16112	2000	46535		
1942	31038	28681	16350	391	46997	16490	2658	44870		
1941	34784	32481	10292	1728	43348	11052	9474	36362		
1940	23339	24983	9929	1639	31629	10446	5529	28256		
1939	22439	22341	14674	3178	33935	16025	7400	31064		
1938	13160	16685	14238	2267	25131	14715	5399	22476		
1937	17636	16814	19256	2200	34692	20146	5413	32369		
1936	15581	15379	17586	1000	32167	17936	4561	28956		
1935	12670	14237	15075	800	26945	15655	3431	24894		
1934	15623	13096	14110	2700	27033	14590	4703	25510		
1933	11797	10650	10583	2000	20380	11053	3592	19257		
1932	12483	12704	6882	2000	17365	7192	3862	15813		
1931	13777	17137	7791	1400	20168	8209	3367	18619		
	(b)	(c)			(f)	(g)	(h)	(f)		

APPENDIX II: Arsenic Worksheet (units = short tons)

	Total US Sales White Arsenic AS2 O3 MIN YB 3-1	Total US Production White Arsenic AS2 O3 MIN YB 3-1	Imports for Consump. White Arsenic MIN YB 3-1	Exports White Arsenic et al MIN YB 3-1	Apparent Consump. (Sales+ IMP-EXP) White Arsenic 3-1	Imports for Consump. All Forms Arsenic MIN YB 3-1	Exports Total Arsenic MIN YB or calc 3-1	Apparent Consump. (Sales+ IMP-EXP) All Forms of Arsenic 3-1	Primary Demand Total Contained Arsenic MIN F&P 3-1,2	Agri-cultural Demand 3-6
1930	17425	17057	10471	0	27896	10905		28330		
1929	14546	16605	13157		27703	13618		28164		
1928	11767	14163	11153		22920	11604		23371		
1927	11560	11730	12517		24077	12905		24465		
1926	11805	6759	7703		19508	8137		19942		
1925	12317	12119	9316		21633	9940		22257		
1924	14453	20177	8877		23330	9271		23724		
1923	14271	14902	10152		24423	11514		25785		
1922	10027	9350	1081		11108	4946		14973		
1921	4786	6158	1669		6455	5043		9829		
1920	11502	11502	3740		15242	7855	7	19351		
1919	6029	6029	4389		10418	6613		12642		
1918	6323	6323	1847		8170	6689	40	12972		
1917	6151	6151	1178		7329	3955	57	10049		
1916	5986	5986	1071		7057	2175	1	8160		
1915	5498	5498	1400		6898	3194	5	8687		
1914	4670	4670	1594		6264	3628	0	8298		
1913	2513	2513	1519		4032	4701	30	7184		
1912	3141	3141	3103	0	6244	6156	0	9297		
1911	3132	3132	1921	0	5053	4096	0	7228		
1910	1497	1497	1348	0	2845	5139	0	6636		
1909		1214		0	5250	4036	0	5250		
1908				0	4964	4964	0	4964		
1907		1751		0	6915	5164	0	6915		
1906		737		0	4724	3987	0	4724		
1905		754		0	4592	3838	0	4592		
1904		36		0	3436	3400	0	3436		
1903		611		0	4790	4179	0	4790		
1902		1353		0	5408	4055	0	5408		
1901		300		0	3795	3495	0	3795		
1900		0		0	2883	2883	0	2883		
1899		0		0	4520	4520	0	4520		
1898		0		0	4343	4343	0	4343		
1897		0		0	3621	3621	0	3621		
1896		0		0	2907	2907	0	2907		
1895		0		0	3492	3492	0	3492		
1894		0		0	3532	3532	0	3532		
1893		0		0	3046	3046	0	3046		
1892		0		0	2467	2467	0	2467		
1891		0		0	2672	2672	0	2672		
1890		0		0	4248	4248	0	4248		
1889		0		0	4352	4352	0	4352		
1888		0		0	3555	3555	0	3555		
1887		0		0	1795	1795	0	1795		
1886		0		0	2521	2521	0	2521		
1885		0		0	1684	1684	0	1684		
1884		0		0	1847	1847	0	1847		
1883		0		0	2805	2805	0	2805		
1882		0		0	1724	1724	0	1724		
1881		0		0	1113	1113	0	1113		
1880		0		0	1360	1360	0	1360		
	(b)	(c)			(f)	(g)	(h)	(f)		

APPENDIX II: Arsenic Worksheet (units = short tons)

	Industrial Chemicals Demand	Ceramics & Glass Demand	Non-ferrous Alloys & Elec-tronics Demand	Other Demand	Total US Prod. Calcium Arsenate Insect-icides	US Domestic Disap-pearance Calcium Arsenate	Total US Prod. Lead Arsenate Insect-icides	Total US Production Paris Green, etc Insect-icides	Primary (Mine) Produc-tion Arsenic Content	Refinery Produc-tion Arsenic Content	Imports for Consumption (Met+comp) Arsenic Content
	3-6	3-6	3-6	3-6	MIN YB	USDA	MIN YB	MIN YB	MIN F&P	MIN F&P	MIN F&P
1982											
1981											
1980	6080	680	410	260							
1979	3300	800	500	300					860	6350	9770
1978	3000	700	460	300					1200	6360	8200
1977	2600	700	400	290					930	5330	4900
1976	2200	500	300	200					1100	7300	3500
1975	800	1400	500	300					1600	8100	9600
1974	1400	2200	850	550					1500	7400	11300
1973	1200	2000	800	490					2100	10300	9190
1972	940	1900	550	480					1900	10300	11170
1971	970	2000	570	500					2100	7500	13840
1970	1000	2100	600	500					2300	10900	14900
1969	1000	2100	700	500					2500	10300	14400
1968	1200	2100	0	700					1400	6100	19700
1967	1900	2000	0	1000					1800	5000	21100
1966	1280	1800	0	700					2900	9400	14580
1965	1580	1900	0	700					5000	12300	12180
1964	1855	1500	0	800					2600	7700	14155
1963							2330		2500		
1962					4965		3972		3000		
1961					5223		3295		2700		
1960					5031		3212		3100		
1959					6452		6354		1200		
1958									2700		
1957					9739		5960		2400		
1956					13553		5878		2800		
1955					1885		7388		2500		
1954					1379		7810		3000		
1953					3600	8000	7000				
1952					3817	8726	7143				
1951					20450	15087	12708				
1950					23750	13745	19750				
1949					8003		8434				
1948					13618		12316				
1947					23594		15094				
1946					17696		28334				
1945					12822		35261	1950			
1944					22154		45352	2265			
1943					34932		40478	1944			
1942					38898		31789	2000			
1941					29684		36656	2746			
1940											
1939					19641		29784	1020			
1938											
1937					18501		31646	917			
1936											
1935					21648		26073	1319			
1934											
1933											
1932											
1931											

APPENDIX II: Arsenic Worksheet (units = short tons)

	Industrial Chemicals Demand 3-6	Ceramics & Glass Demand 3-6	Non-ferrous Alloys & Elec-tronics Demand 3-6	Other Demand 3-6	Total US Prod. Calcium Arsenate Insect-icides MIN YB	US Domestic Disap-pearance Calcium Arsenate USDA	Total US Prod. Lead Arsenate Insect-icides MIN YB	Total US Production Paris Green, etc Insect-icides MIN YB	Primary (Mine) Produc-tion Arsenic Content MIN F&P	Refinery Produc-tion Arsenic Content MIN F&P	Imports for Consumption (Met+comp) Arsenic Content MIN F&P
1930					0		0	0			
1929											
1928											
1927											
1926											
1925											
1924					21813		10502	3046			
1923					18241		7581	2373			
1922											
1921											
1920											
1919					1500		5750				
1918											
1917											
1916											
1915											
1914											
1913											
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1888											
1887											
1886											
1885											
1884											
1883											
1882											
1881											
1880											

APPENDIX II: Arsenic Worksheet (units = short tons)

	Apparent Supply (Prod+ Imp-Exp) Calcium Arsenate Insect. 3-2	Apparent Supply (Prod+ Imp-Exp) Lead Arsenate Insect. 3-2	Apparent Supply (Prod+ Imp-Exp) Other Arsenic Insect. 3-2	Wood Preserv. Consump. Compound Arsenic Total 3-2	Wood Preserv. Consumption N.E.C. 3-2	FCAP Fluor-Chrome Arsenate Phenol (Wolman Salts) 3-2	CCA Chrom-ated Copper Arsenate 3-2	ACA Ammoni-ated Copper Arsenate	Wood Preserv. Consump. Acid Copper Chromate	Wood Preserv. Consump. Chromated zinc Chloride	Wood Preserv. Consump. Penta-chloro-phenol
1982											
1981				23772			23193	579			
1980				18619			18082	537			
1979				17414			16882	532			
1978				12604		112	12492				
1977											
1976				9769		1223	8546				
1975				8600		600	8000				
1974				8387		758	7629				
1973	650	1973		7310	635	842	5834		818	975	19419
1972	876	2596		6331	500	957	4874		619	887	18273
1971				5745	375	1085	4286		589	668	16020
1970				4770	410	1344	3017		378	731	14231
1969				5129	525	2270	2334		436	692	12771
1968				4370	777	1986	1608		570	763	13195
1967				3836		2671	1165				
1966				4586	2256	2330					
1965				4147	2283	1864					
1964				3616	1646	1970					
1963		2330		2802	1278	1524					
1962	4872	3571		3126	1768	1358					
1961	5223	3295		2673	1329	1344					
1960	5031	3212		2425	1150	1275					
1959	6452	6354		2631	1274	1357					
1958	7459	5107		1820	779	1082					
1957	8349	5352		1820	779	1068					
1956	13239	4596		1820	779	1005					
1955	972	6848		1820	779	1067					
1954	391	7455		1820	779	983					
1953	1676	6848		950		950					
1952	1110	7096		829		829					
1951	18549	12402		772		772					
1950	21935	19230		599		599					
1949	5979	8004		502		502					
1948	11333	11297		643		643					
1947	21110	13602		578		578					
1946	14257	26936		835		835					
1945	11072	32091	3162	375	9	366					
1944	20948	43219	2345	397	6	391					
1943	33344	40478	1944	411	27	385					
1942	36927	31493	2136	774	120	654					
1941	27351	31859	2890	828		828					
1940	22439	31770	2177								
1939	17089	28934	1532								
1938	16649	30204	1238								
1937	16207	31125	1334								
1936			809								
1935			962								
1934			941								
1933			918								
1932			787								
1931			886								

(aa)

APPENDIX II: Arsenic Worksheet (units = short tons)

	Apparent Supply (Prod+ Imp-Exp) Calcium Arsenate Insect. 3-2	Apparent Supply (Prod+ Imp-Exp) Lead Arsenate Insect. 3-2	Apparent Supply (Prod+ Imp-Exp) Other Arsenic Insect. 3-2	Wood Preserv. Consump. Compound Arsenic Total 3-2	Wood Preserv. Consumption N.E.C. 3-2	FCAP Fluor-Chrome Arsenate Phenol (Wolman Salts) 3-2	CCA Chromated Copper Arsenate 3-2	ACA Ammoniated Copper Arsenate	Wood Preserv. Consump. Acid Copper Chromate	Wood Preserv. Consump. Chromated zinc Chloride	Wood Preserv. Consump. Pentachlorophenol
1930			878								
1929			2325								
1928			2365								
1927			2271								
1926			2355								
1925			2552								
1924	21814	10504	3376								
1923	18241	7581	3647								
1922			3854								
1921			3374								
1920			4115								
1919	1500	5750	2224								
1918			4842								
1917			2777								
1916			1104								
1915			1794								
1914			8								
1913			3232								
1912			81								
1911			63								
1910			91								
1909			92								
1908			98								
1907			67								
1906			156								
1905			22								
1904			14								
1903											
1902											
1901											
1900											
1899											
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1897											
1896											
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1891											
1890											
1889											
1888											
1887											
1886											
1885											
1884											
1883											
1882											
1881											
1880											

(aa)

APPENDIX II: Arsenic Worksheet (units = short tons)

	US Sales Crude White Arsenic AS2 O3 MIN YB	US Prod Crude White Arsenic AS2 O3 MIN YB	US Sales Refined White Arsenic AS2 O3 MIN YB	US Prod Refined White Arsenic AS2 O3 MIN YB	Imports for Consump- tion Sulfide MIN YB	Imports for Consump- tion Sheep Dip MIN YB	Imports for Consumption Paris Green & London Purple MIN YB	Imports for Consump. Arsenic Acid MIN YB	Imports for Consump- tion Calcium Arsenate MIN YB	Imports for Consump- tion Lead Arsenate MIN YB	Imports for Consump- tion Metallic Arsenate MIN YB
1982					20			771			150
1981					0			1666			323
1980					11			271			266
1979					39			176			405
1978					0			565			369
1977					0			383			357
1976					275			20			283
1975					0			0			483
1974					0						707
1973					3						643
1972					1						666
1971					9						536
1970					9						456
1969					10	35				15	346
1968					25						410
1967					289	5					295
1966					30				100		181
1965					46	10					181
1964											
1963											
1962					18	10					169
1961											
1960											
1959											
1958	10544	11121	387	387	63	0	0	0	0	0	31
1957	11980	9814	805	679	21	34	0	0	0	0	68
1956	18048	11423	828	778	42	35	0	0	0	0	44
1955	10986	9968	687	812	47	20	0	0	30	0	114
1954	10921	12630	602	537	0	28	0	0	0	0	59
1953	10816	10345	499	528	10	26	0	0	21	0	71
1952	8719	15046	525	627		51	21		96	81	30
1951	13656	15485	695	705	74	31		3	777	7	110
1950	15778	11903	1552	1370	74	39	44	1	114		69
1949	9597	12289	584	506	22	28					23
1948	13749	17213	1216	1426	44	19					18
1947	17119	17636	1069	1119	22	42				60	9
1946	10448	8981	1591	1230	44	1					46
1945	22180	21358	2630	2991	1113	99					26
1944	29159	31182	5313	4912		80					10
1943	27588	26269	4835	4933							
1942	27981	25658	3057	3023		136			0		3
1941	28661	26845	6123	5638	6	132	6		615		1
1940	16688	18241	6651	6742	110	171	13		216		7
1939	17070	17499	5369	4842	328	153	23	0	814	6	20
1938	9428	12619	3732	4066	121	84	52	0	200		8
1937	10903	9936	6733	6878	251	104	54	0	398	0	75
1936	8755	9937	6826	5442	178	112	17	0	1		41
1935	6985	7583	5685	6654	355	82	19	0	91		32
1934	9030		6593		314	119	4	0	12		31
1933	3029		8768		337	53	23	0	6	1	50
1932	1975		10508		251	31	1	1	2		23
1931	1795		11982		299	77	1	6	20		14

APPENDIX II: Arsenic Worksheet (units = short tons)

	US Sales Crude White Arsenic AS2 O3 MIN YB	US Prod Crude White Arsenic AS2 O3 MIN YB	US Sales Refined White Arsenic AS2 O3 MIN YB	US Prod Refined White Arsenic AS2 O3 MIN YB	Imports for Consump-tion Sulfide MIN YB	Imports for Consump-tion Sheep Dip MIN YB	Imports for Consumption Paris Green & London Purple MIN YB	Imports for Consump. Arsenic Acid MIN YB	Imports for Consump-tion Calcium Arsenate MIN YB	Imports for Consump-tion Lead Arsenate MIN YB	Imports for Consump-tion Metallic Arsenate MIN YB
1930	2771		14654		277	87	10	0	3	0	57
1929	4723		9823		212	104	1	0		0	144
1928	3652		8115		263	88	7	0	1		93
1927	1540		10020		206	51		6	2		123
1926	828		10977		283	60	2	1	1		87
1925	1077		11240		476	37	1	30	1	5	75
1924	2183		12270		234	57	38	0	2	2	61
1923	1914		12357		1097	44	50	83		0	87
1922	1122		8905		3815	35	2	2			11
1921	1359		3427		3343	31	0				
1920	560		10942		4080	35	0				
1919	0		6029		2151	73	0				
1918					4842						
1917					2777		0				
1916					1092		12				
1915					1783		11				
1914							8				
1913					3182		50				
1912							81				
1911							63				
1910							91				
1909							92				
1908							98				
1907							67				
1906							156				
1905							22				
1904							14				
1903											
1902											
1901											
1900											
1899											
1898											
1897											
1896											
1895											
1894											
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1890											
1889											
1888											
1887											
1886											
1885											
1884											
1883											
1882											
1881											
1880											

APPENDIX II: Arsenic Worksheet (units = short tons)

	Imports for Consumption N.E.C.	Exports Calcium Arsenate	Exports Lead Arsenate
	MIN YB	MIN YB	MIN YB
1982	925		
1981	5		
1980	1		
1979	2		
1978	473		
1977	1110		
1976	60		
1975	76		
1974	133		
1973	263		
1972	240		
1971	125		
1970	114		
1969	60		
1968	38		
1967	127		
1966	182		
1965	155		
1964			
1963			
1962	136	93	401
1961			
1960			
1959			
1958	87	637	1050
1957	164	1390	608
1956	115	314	1282
1955	86	943	540
1954	87	988	355
1953	40	1945	152
1952	33	2803	128
1951	90	2678	313
1950	55	1929	520
1949		2024	430
1948		2285	1019
1947		2484	1552
1946		3439	1398
1945		1750	3170
1944		1206	2133
1943			
1942		1971	296
1941		2949	4797
1940		2440	1450
1939	7	3366	856
1938	12	2621	511
1937	7	2692	521
1936	2	3147	414
1935	6	2052	578
1934		1678	325
1933		1293	299
1932		1267	595
1931		1073	894
		(at)	(at)

NOTES TO ARSENIC WORKSHEET

(b) Includes processed output of imported AsO3 ore

(c) MINYB crude + refined sum through 1953
MIN F&P mines+ores=Total refinery from 1954

(f) Production used 1880-1909 and 1965-1979. General imports used before 1910. Estimated 1959-1964 and 1980-1982.

(g) MIN YB thru 1912, then sum

(h) Sum from 1928 on, estimate for 1943

(aa) zinc meta-arsenate in 1942-1946

(at) From 1940, USDA as reported in MIN F&P

APPENDIX II: Arsenic Worksheet (units = short tons)

	Imports for Consumption N.E.C.	Exports Calcium Arsenate	Exports Lead Arsenate
	MIN YB	MIN YB	MIN YB
1930	67	1589	1135
1929		1570	782
1928		589	547
1927			
1926			
1925			
1924			
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1919			
1918			
1917			
1916			
1915			
1914			
1913			
1912		0	0
1911		0	0
1910		0	0
1909		0	0
1908		0	0
1907		0	0
1906		0	0
1905		0	0
1904		0	0
1903		0	0
1902		0	0
1901		0	0
1900		0	0
1899		0	0
1898		0	0
1897		0	0
1896		0	0
1895		0	0
1894		0	0
1893		0	0
1892		0	0
1891		0	0
1890		0	0
1889		0	0
1888		0	0
1887		0	0
1886		0	0
1885		0	0
1884		0	0
1883		0	0
1882		0	0
1881		0	0
1880		0	0
		(at)	(at)

NOTES TO ARSENIC WORKSHEET

(b) Includes processed output of imported AsO3 ore

(c) MINYB crude + refined sum through 1953
MIN F&P mines+ores=Total refinery from 1954

(f) Production used 1880-1909 and 1965-1979. General imports used before 1910. Estimated 1959-1964 and 1980-1982.

(g) MIN YB thru 1912, then sum

(h) Sum from 1928 on, estimate for 1943

(aa) zinc meta-arsenate in 1942-1946

(at) From 1940, USDA as reported in MIN F&P

APPENDIX III: Cadmium Worksheet (units = short tons)

	Primary Production of Cadmium Sulfide (Cd Content) MIN YB	Primary Production of Cadmium Oxide (Cd Content) MIN YB	Primary Production of Compounds Other Than Sulfide (Cd Content) MIN YB	Primary Production of Metallic Cadmium MIN YB 4-1	Primary Production of Compounds Total MIN YB or Sum 4-1	Primary Production Total MIN YB or Sum 4-1	Secondary Production MIN YB & MIN F&P 4-1
1982	412		1070				
1981	581		976				
1980	883		911				
1979	1647		1005				
1978	769		780				
1977	704		766				
1976	804		1091				
1975	987						
1974	1085		86				
1973	1412						
1972	1357						
1971	1118						
1970	1068						
1969	1220						
1968	1228						
1967	768						
1966	1133						
1965	787						
1964	765						
1963	771						
1962	660	740					
1961	558	537					
1960	542	562					
1959	621						
1958	521			4836		4836	
1957	629			5275		5275	
1956	674			5307		5307	
1955	523			4877		4877	143
1954	565	419		4777	68	4776	69
1953	615	478		4841	42	4884	35
1952	449	266		4194	90	4284	40
1951	478	264		4057	99	4156	84
1950	785	253		4433	170	4595	214
1949	500	249		4012	101	4113	192
1948	1048	146		3791	96	3888	61
1947	654	196		4004	250	4254	52
1946	613	159		3100	135	3236	178
1945	319	192		3966	226	4192	36
1944	233	250		4227	163	4390	53
1943	114	235		4198	35	4233	81
1942	150	277		3662	24	3685	158
1941				3469	148	3617	190
1940				2961	422	3182	114
1939				2206	339	2545	
1938				2039	215	2254	
1937				2134	414	2548	
1936				1817	313	2130	
1935				1738	254	1992	
1934				1389	283	1672	
1933				1138	201	1339	
1932				400	130	530	
1931				525	169	694	
1930				1389	158	1547	
1929				1241	216	1458	
1928				938	120	1058	
1927				244	114	652	
1926				184	84	489	
1925				251	56	308	
1924				65		65	
1923				92		92	
1922	67			66		66	
1921	10			34		34	
1920	5			65		65	
1919	4.7			50		50	
1918	7.8			64		64	
1917	7.5			104		104	
1916	3.3			68		68	
1915	1.6			46		46	
1914	3.4			46		46	
1913	2.6			27		27	
1912	1.3			26		26	
1911	0.4			13		13	
1910	0			2		2	
1909	0			2.6		2.6	
1908	0			4.0		4.0	
1907	0			7.0		7.0	
1906	0			0.2		0.2	
1905				0		0	
1904				0		0	
1903				0		0	
	(a)	(b)	(c)	(d)	(c)	(e)	(e)

APPENDIX III: Cadmium Worksheet (units = short tons)

	Primary + Secondary Production MIN F&P or sum 4-1	Apparent Primary Consumption MIN YB= MIN F+P 4-1	Total Producers Shipments (Primary+ Secondary Inc compnds) MIN YB or sum 4-1	Total Us Primary Demand =sum uses MIN F&P 4-1	Imports for Consumption (Metallic Cadmium) MIN YB	Imports for Consumption (Flue Dust and Other Cd Content) MIN YB	Total Imports for Consumption MIN YB Or Sum
1982	1110	4086	2019		2541		
1981	1767	4826	1523		3406		
1980	1739	3896	1401		2885		
1979	2010	5621	2721	5429	2835		
1978	1822	4971	2157	4971	3176		
1977	2204	4209	2025	4209	2570	14	2584
1976	2256	5932	2984	5932	3411	246	3657
1975	2193	3368	818	3368	2618		
1974	3333	6050	3250	6049	1985	166	2151
1973	3751	6267	4304	6267	1948	174	2122
1972	4145	6313	5240	6313	1211		
1971	3965	5436	3887	5437	1749		
1970	4732	4531	3424	4531	1246	555	1802
1969	6323	7531	6489	7531	539	558	1097
1968	5326	6664	5622	6665	963		
1967	4349	5789	4803	5545	794		
1966	5230	7390	5896	7212	1679		
1965	4835	5215	4064	5164	1061		
1964	5229	4682	4845	4334	552		
1963	4995	5741	5062	5666	496		
1962	5569	6289	6028	5962	558		
1961	5233	5320	5111	4933	539		
1960	5223	5168	5991	4885	471		
1959	4355	5795	5506	5581	819		
1958	4836	4089	3961	3973	501	609	1110
1957	5275	5500	5046		793	700	1493
1956	5307	6355	5468		1558		
1955	5020	5342	5721		464		
1954	4845	3750	4104		201		
1953	4919	4814	4111		778	932	1709
1952	4324	4521	4024		739	996	1735
1951	4240	3586	4026		45	803	848
1950	4809	4772	4810		315	801	
1949	4306	3743	4227		79	895	973
1948	3948	3899	3976		5	914	919
1947	4306	3863	4244		10	1178	1188
1946	3413	3492	3406		9	826	835
1945	4228	4322	4229		14	1096	1111
1944	4443	4432	4472		33	845	878
1943	4315	3690	4326		24	822	
1942	3844	3829	3808		27	862	
1941	3807	3883	3843		74	1161	
1940	3296	3089	3450		14	852	
1939	2546	2950			155	945	
1938	2254	2050			11	738	
1937	2547	2826			414	683	
1936	2130	2418			288	600	
1935	1992	2085			93		
1934	1672	1735			63		
1933	1339	1394			54		
1932	530	530			0		
1931	694	694			0		
1930	1547	1567			20		
1929	1458	1565			107		
1928	1058				117		
1927	652				11		
1926	489				0.0		
1925	308				0.0		
1924	65				0.6		
1923	92				0.0		
1922	66				1.1		
1921	34				0.1		
1920	65				0		
1919	50				0		
1918	64				0		
1917	104				0		
1916	68				0		
1915	46				0.1		
1914	46				0.2		
1913	27				0.8		
1912	26				2.6		
1911	13				2.7		
1910	2				2.0		
1909	2.6				4.4		
1908	4.0				1.8		
1907	7.0				1.0		
1906	0.2				6.9		
1905	0				3.7		
1904	0				3.5		
1903	0				3.9		
	(f)	(g)	(h)				

APPENDIX III: Cadmium Worksheet (units = short tons)

	Exports (metallic Cadmium) MIN YB	Exports Other (Gross Wgt) MIN YB	Total Exports (Gross Wgt) MIN YB or Sum	Producers Secondary Shipments MIN YB= MIN F+P	Total U.S. Distribution= App.Prim.Cons +Second.Ships -metal exports MIN F+P	-- Cadmium Use Data -- Plating-Transportation Related MIN F&P	Other Coating & Plating MIN F&P
1982			12				
1981			263				
1980			260				
1979			233			926	1841
1978			359			849	1687
1977			118			717	1433
1976			252			1003	1995
1975			198			595	904
1974			31			1102	1797
1973			153			1246	1742
1972			509			1246	1896
1971			33			1058	1653
1970			187			882	1378
1969			542			1102	3263
1968			265			992	2921
1967			346			849	2447
1966			189			915	3153
1965			36				
1964			719				
1963			656				
1962			359				
1961			351				
1960			1224				
1959			450				
1958			290				
1957			346				
1956			642				
1955			697	143			
1954			499	74			
1953			33	30	4877		
1952			150	61	4733		
1951	303	103	406	44	3933		
1950	176	5	181	214	5161		
1949	283	2	285	192	4219		
1948	478	47	525	61	4437		
1947	152	9	161	67	4081		
1946	70	230	300	180	3741		
1945	51	1172	1223	34	4406		
1944	274	1355	1629		4706		
1943	79				3769		
1942	142				3971		
1941	86				3969		
1940	194				3282		
1939	0				2950		
1938	229				2279		
1937	0				2826		
1936	0				2418		
1935	0				2085		
1934	0				1738		
1933	0				1394		
1932	0				530		
1931	0				694		
1930	0				1567		
1929	0				1565		
1928	0						
1927	0						
1926	0						
1925	0						
1924							
1923							
1922							
1921							
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1904							
1903							
	(p)		(r)	(s)	(t)	(u)	(u)

APPENDIX III: Cadmium Worksheet (units = short tons)

	U.S. Demand Pattern				
	Total Plating	Batteries	Pigments	Plastics& Synthetics	Other
	Sum	MIN F&P	MIN F&P	MIN F&P	MIN F&P
1982					
1981					
1980	33%	20%	10%	10%	27%
1979	2767	1190	705	595	171
1978	2535	1091	650	551	143
1977	2150	926	551	463	119
1976	2998	1301	739	661	233
1975	1499	452	595	551	270
1974	2899	595	1102	992	461
1973	2987	617	1124	992	546
1972	3142	452	948	1246	526
1971	2712	176	772	1422	355
1970	2260	154	650	1190	276
1969	4365	254	728	1356	829
1968	3913	198	672	1268	613
1967	3296	198	551	1102	386
1966	4068	198	1003	1190	753
1965	2697	308	1279	424	456
1964					
1963	3263	419	849	992	143
1962					
1961					
1960	3417				
1959					
1958					
1957					
1956					
1955					
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1904					
1903					
	(u)	(u)	(u)	(u)	(u)

NOTES TO CADMIUM WORKSHEET

(a) From 1976 includes Cadmium Lithopone & Cadmium Sulfoselenide. 1906-1925 content estimated as .3 * gross.

(b) No data available 1955-1959

(c) Excludes compounds made of metal No data 1954-1974, 1974 estimated from text. 1976 includes oxide

(d) No production prior to 190

(e) 1940-1954 from Minerals Yearbooks

(f) 1955 on from Minerals Yearbooks

(g) 1940-1944 is Primary plus Metal

(h) No data prior to 1940

(p) Lumped into total after 1952

(r) 1952 on from Mineral Yearbook

(s) Not available thru 1939. Included with primary production 1940-1944

(t) from 1952 on, exports are total not metallic

(u) 1960 & 1963 calculated from estimates of percent of total demand

APPENDIX IV: Chromium Worksheet (units = 1000 short tons except where noted)

	Chromium Metal & Ferroalloys Production (Cr Content) MIN YB	Crude Chromite (~42% CR2 O3) Domestic Mine Sales (Gross Weight) MIN YB	Crude Chromite (~42% CR2 O3) Imports for Consumption (Gross Weight) MIN YB	Crude Chromite (~42% CR2 O3) Apparent Supply (Gross Weight) (Mine+Imports) MIN YB or sum	Apparent Supply Cr Content .29*Gross (.42*.684)	Total Chromite Consump-tion MIN YB	Chromite Consump-tion Average Cr2 O3 Percent MIN YB
	5-1	5-1	5-1	5-1	5-1	5-1	5-1
1982		0	507		162	545	38.8%
1981		0	898		287	889	37.9%
1980	142.315	0	982		314	977	38.4%
1979	177.032	0	1024		328	1214	39.2%
1978		0	1013		324	1010	39.9%
1977	158.093	0	1293		414	1000	40.9%
1976	157.608	0	1275		408	1006	42.0%
1975		0	1352		433	881	42.5%
1974	257.619	0	1102		353	1450	44.2%
1973	260.043	0	931		298	1387	45.2%
1972		0	1056		338	1140	45.2%
1971		0	1299		416	1093	45.4%
1970	241.451	0	1405		450	1403	45.2%
1969		0				1411	45.5%
1968		0				1316	45.4%
1967	268.983	0				1355	45.5%
1966		0				1461	44.5%
1965		0				1584	44.8%
1964		0				1451	44.0%
1963	180.432	0				1187	43.8%
1962		0				1131	42.7%
1961		62				1200	42.6%
1960		107				1220	42.6%
1959		105				1337	43.2%
1958		143.795	1263	1406.8	408.0	1221	43.8%
1957		166.157	2283	2449.2	710.3	1760	43.9%
1956		207.662	2176.056	2382.7	691.0	1847	43.5%
1955		153.253	1833.999	1987.3	576.3	1584	43.0%
1954		163.365	1471.037	1634.4	474.0	914	42.4%
1953		58.817	2226.631	2285.427	662.8	1335.755	42.7%
1952		21.304	1708.969	1730.273	501.8	1185.460	42.9%
1951		7.056	1429.020	1436.076	416.5	1212.480	42.6%
1950		0.404	1303.713	1304.117	378.2	980.369	42.4%
1949		0.433	1203.852	1204.650	349.3	672.773	41.3%
1948		3.619	1542.125	1545.744	448.3	875.033	42.7%
1947		0.948	1106.180	1107.128	321.1	833.357	41.1%
1946		4.107	757.391	761.498	220.8	734.759	43.2%
1945		13.973	914.765	928.738	269.3	808.120	43.8%
1944		45.629	848.390	894.019	259.3	848.449	44.1%
1943		160.120	928.576	1088.696	315.7	964.600	43.8%
1942		112.876	981.607	1094.483	317.4	891.952	43.2%
1941		14.259	1115.292	1129.551	327.6	800.290	44.3%
1940		2.982	736.612	739.593	214.5	562.915	45.0%
1939		4.048	355.612	359.660	104.3		42.0%
1938		0.909	394.335	395.245	114.6		
1937		2.600	620.386	622.985	180.7		
1936		0.301	363.169	363.470	105.4		
1935		0.577	290.151	290.727	84.3		45.0%
1934		0.413	215.373	215.786	62.6		43.0%
1933		0.944	130.492	131.436	38.1		
1932		0.174	99.840	100.014	29.0		49.1%
1931		0.200	238.031	238.332	69.1		
							(h)

APPENDIX IV: Chromium Worksheet (units = 1000 short tons except where noted)

	Chromium Metal & Ferroalloys Production (Cr Content) MIN YB 5-1	Crude Chromite (~42% CR2 03) Domestic Mine Sales (Gross Weight) MIN YB 5-1	Crude Chromite (~42% CR2 03) Imports for Consumption (Gross Weight) MIN YB 5-1	Crude Chromite (~42% CR2 03) Apparent Supply (Gross Weight) (Mine+Imports) MIN YB or sum 5-1	Apparent Supply Cr Content .29*Gross (.42*.684) 5-1	Total Chromite Consumption MIN YB 5-1	Chromite Consumption Average Cr2 03 Percent MIN YB 5-1
1930		0.090	365.811	365.901	106.1		
1929		0.301	355.746	356.047	103.3		
1928		0.739	242.583	243.322	70.6		
1927		0.225	249.043	249.268	72.3		
1926		0.158	241.320	241.478	70.0		
1925		0.121	167.708	167.829	48.7		
1924		0.323	132.544	132.867	38.5		
1923		0.254	145.256	145.589	42.2		
1922		0.398	100.891	101.288	29.4		
1921		0.316	91.656	91.972	26.7		
1920		2.802	168.308	171.110	49.6		
1919		5.688	68.772	74.461	21.6		
1918		92.322	112.159	204.481	59.3		
1917		48.972	80.722	129.694	37.6		
1916		52.679	129.858	182.537	52.9		
1915		3.675	85.630	89.305	25.9		
1914		0.662	83.648	84.310	24.4		
1913		0.286	73.002	73.288	21.3		
1912		0.225	60.400	60.625	17.6		
1911		0.134	42.045	42.179	12.2		
1910		0.230	43.208	43.438	12.6		
1909		0.670	44.379	45.049	13.1		
1908		0.402	31.221	31.623	9.2		
1907		0.325	47.028	47.353	13.7		
1906		0.120	48.654	48.774	14.1		
1905		0.025	60.966	60.991	17.7		
1904		0.138	27.134	27.272	7.9		
1903		0.168	25.684	25.852	7.5		
1902		0.353	44.318	44.671	13.0		
1901		0.412	22.525	22.937	6.7		
1900		0.157	19.647	19.804	5.7		
1899		0	17.688	17.688	5.1		
1898		0	18.260	18.260	5.3		
1897		0	12.958	12.958	3.8		
1896		0.880	9.709	10.589	3.1		
1895		1.949	5.858	7.807	2.3		
1894		4.122	3.886	8.008	2.3		
1893		1.624	7.116	8.740	2.5		
1892		1.680	5.522	7.202	2.1		
1891		1.537	4.994	6.531	1.9		
1890		4.031	4.875	8.906	2.6		
1889		2.240	6.131	8.371	2.4		
1888		1.680	1.572	3.252	0.9		
1887		3.360	3.759	7.119	2.1		
1886		2.240	0.013	2.253	0.7		
1885		3.024	2.998	6.022	1.7		
1884		2.240	0	2.240	0.6		
1883		3.360	0	3.360	1.0		
1882		2.800	0	2.800	0.8		
1881		2.240	0	2.240	0.6		
1880		2.563	0	2.563	0.7		

(h)

APPENDIX IV: Chromium Worksheet (units = 1000 short tons except where noted)

	Chromium Consumption (Cr Content) (.68* % *Gross Chromite) 5-1,3	Chromite Consumption by Chemical Industry MIN YB	Chromite Consum.by Chemical Industry Average Cr2 O3 MIN YB Percent	Chromite Consum.by Chemical Industry (Cr Content) (.68* % *Gross Chromite) 5-2	Chromic Acid Consumption (=Production) FKC graph (MIN YB)	Chromic Acid Consumption (Cr Content) .52*amount 5-3	Sodium Dichromate & Chromate Production (Cr Cont.) 104/298.05 *amount 5-3	Sodium Dichromate & Chromate Production FKC graph	Crude Chromite (~42% CR2 O3) Exports & Re-Exports (Gross Weight) MIN YB
1982		195	44.9%	60					65
1981		238	42.6%	69					138
1980	257	240	45.8%	75					50
1979	326	242	44.9%	74					55
1978	276	239	44.9%	73					52
1977	280	214	44.7%	65					248
1976	289	207	44.8%	63					209
1975	256	166	44.9%	51					184
1974	439	251	44.8%	77					117
1973	429	206	45.3%	64			53.387	153.0	55
1972	353	189	45.7%	59	27.0	14.040	51.293	147.0	77
1971	340	180	45.6%	56	21.5	11.180	48.153	138.0	180
1970	434	213	45.3%	66	22.5	11.700	53.736	154.0	114
1969	439	211	45.1%	65	24.8	12.870	53.038	152.0	
1968	409	202	45.1%	62	24.0	12.480	50.596	145.0	
1967	422	179	45.2%	55	22.0	11.440	47.106	135.0	
1966	445	194	44.9%	60	24.5	12.740	49.200	141.0	
1965	486	217	45.0%	67	24.3	12.610	48.851	140.0	
1964	437	189	45.1%	58	20.0	10.400	47.804	137.0	
1963	356	187	45.1%	58	19.5	10.140	46.408	133.0	
1962	330	176	45.3%	55	17.5	9.100	43.617	125.0	
1961	350	163	45.2%	50	16.5	8.580	41.872	120.0	
1960	356	164	45.3%	51	16.0	8.320	42.221	121.0	
1959	395	162	45.4%	50	17.5	9.100	41.872	120.0	
1958	366	131	45.6%	41	13.5	7.020	34.021	97.5	0.7
1957	529	148	45.0%	46	15.0	7.800	36.638	105.0	0.8
1956	550	160	45.4%	50	17.0	8.840	41.872	120.0	1.7
1955	466	159	44.8%	49	15.5	8.060	41.000	117.5	1.3
1954	265	134	44.6%	41	15.0	7.800	34.893	100.0	0.9
1953	390	151.800	44.5%	46	15.5	8.060	38.383	110.0	1.166
1952	348	121.750	44.4%	37	10.0	5.200	31.404	90.0	1.531
1951	353	198.630	44.3%	60	17.0	8.840	45.362	130.0	2.030
1950	284	135.040	44.6%	41	10.0	5.200	31.404	90.0	2.044
1949	190	115.330	44.1%	35	9.9	5.148	26.868	77.0	2.382
1948	256	151.821	45.5%	47	9.8	5.096	33.498	96.0	2.894
1947	234	136.356	44.7%	42	9.7	5.044	31.404	90.0	3.435
1946	217	129.270	44.9%	40	9.6	4.992	29.659	85.0	2.158
1945	242	126.069	45.0%	39	9.5	4.940	27.915	80.0	12.366
1944	256	128.225	45.7%	40			28.613	82.0	1.019
1943	289	127.163	44.7%	39			29.311	84.0	26.259
1942	264	118.245	44.8%	36					4.743
1941	243	127.135	46.3%	40					1.906
1940	173		47.2%						
1939	103.3								
1938	114.6								
1937	180.7								
1936	105.4								
1935	89.5								
1934	63.5								
1933	38.1								
1932	33.6	152.000							
1931	69.1								
	(i)								(q)

APPENDIX IV: Chromium Worksheet (units = 1000 short tons except where noted)

	Chromium Consumption (Cr Content) (.68* % *Gross Chromite) 5-1,3	Chromite Consumption by Chemical Industry MIN YB	Chromite Consum.by Chemical Industry Average Cr_2O_3 MIN YB Percent	Chromite Consum.by Chemical Industry (Cr Content) (.68* % *Gross Chromite) 5-2	Chromic Acid Consumption (=Production) FKC graph (MIN YB)	Chromic Acid Consumption (Cr Content) .52*amount 5-3	Sodium Dichromate & Chromate Production (Cr Cont.) 104/298.05 *amount 5-3	Sodium Dichromate & Chromate Production FKC graph	Crude Chromite (~42% Cr_2O_3) Exports & Re-Exports (Gross Weight) MIN YB
1930	106.1								
1929	103.3				1.8	0.939			
1928	70.6								
1927	72.3				0.4	0.234			
1926	70.0								
1925	48.7								
1924	38.5								
1923	42.2								
1922	29.4								
1921	26.7								
1920	49.6								
1919	21.6								
1918	59.3								
1917	37.6								
1916	52.9								
1915	25.9								
1914	24.4								
1913	21.3								
1912	17.6								
1911	12.2								
1910	12.6								
1909	13.1								
1908	9.2								
1907	13.7								
1906	14.1								
1905	17.7								
1904	7.9								
1903	7.5								
1902	13.0								
1901	6.7								
1900	5.7								
1899	5.1								
1898	5.3								
1897	3.8								
1896	3.1								
1895	2.3								
1894	2.3								
1893	2.5								
1892	2.1								
1891	1.9								
1890	2.6								
1889	2.4								
1888	0.9								
1887	2.1								
1886	0.7								
1885	1.7								
1884	0.6								
1883	1.0								
1882	0.8								
1881	0.6								
1880	0.7								
	(i)								(q)

APPENDIX IV: Chromium Worksheet (units = 1000 short tons except where noted)

	Imports for Consumption Chromic Acid Short Tons MIN YB	Imports for Consumption Chromate & Dichromate of Potash Short Tons MIN YB	Imports for Consumption Chromate & Dichromate of Soda Short Tons MIN YB	Imports for Consumption Chromium Chloride & Sulfide Short Tons MIN YB	Miscellaneous Production Data Min YB
1982					
1981					
1980					
1979					
1978					
1977					
1976					
1975					
1974					
1973					
1972					
1971					
1970					
1969					
1968					
1967					
1966					
1965					
1964					
1963					
1962					
1961					
1960					
1959					
1958					
1957					
1956					
1955					
1954					
1953					
1952					
1951					
1950					
1949					
1948					
1947					
1946					
1945					
1944					
1943					
1942					
1941					
1940	0	0	0		
1939	1.155	0	0		
1938	0.263	0.276	0		
1937	1.155	0.336	0		
1936	1.343	1.327	0.455		
1935	2.141	0	0	0	
1934	1.075	0.011	0.055	0	
1933	1.020	0.946	0	0	
1932	1.010	0.393	0.123	0	
1931	0.763	2.407	0.032	0.050	

NOTES TO CHROMIUM WORKSHEET

(h) Before 1940 import % is used

(i) Until 1940 this = supply value, including Cr203 % where available

(q) Not available or zero until 1940

APPENDIX IV: Chromium Worksheet (units = 1000 short tons except where noted)

	Imports for Consumption Chromic Acid Short Tons MIN YB	Imports for Consumption Chromate & Dichromate of Potash Short Tons MIN YB	Imports for Consumption Chromate & Dichromate of Soda Short Tons MIN YB	Imports for Consumption Chromium Chloride & Sulfide Short Tons MIN YB	Miscellaneous Production Data Min YB
1930	88.570	0.522	0.151	0	Chrome
1929	231.243	4.440	0.175	1.912	Orange
1928	49.809	3.433	0.876	0.055	1927=
1927	7.810	2.504	0.165	20.325	2.326
1926	3.610	4.089	0.110	0.655	
1925	2.782	2.190	0.111	1.760	1929=
1924	16.247	5.243	0	4.548	4.977
1923	2.316	2.782	0.123	1.386	
1922	2.332	4.292	11.366	0	
1921	0.985	36.506	32.118		Chrome
					Yellow
1920	0.550	2.207			1927=
1919		7.725			7.167
1918	4.756	0.010	2.551		
1917		1.201	11.013		1929=
1916		0.230	3.077		8.200
1915	1.786	16.471			
1914	4.582	15.929	5.528		
1913	2.781	9.315			Chrome
1912	4.364	16.457			Green
1911	3.395	11.204			1927=
					7.057
1910	4.925	203.395			
1909	3.780	268.509			1929=
1908	1.903	108.041			8.176
1907	0.917	9.086			
1906	0.654	15.049			
1905					
1904					
1903					
1902					
1901					
1900					
1899					Chromate&
1898					Bichromate
1897					of Soda
1896					1927=
1895					31.462
1894					
1893					1929=
1892					37.401
1891					
					1931=
1890					24.745
1889					
1888					1933=
1887					27.234
1886					
1885					
1884					
1883					
1882					
1881					
1880					

NOTES TO CHROMIUM WORKSHEET

(h) Before 1940 import % is used

(i) Until 1940 this = supply value, including Cr2O3 % where available

(q) Not available or zero until 1940

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Mine Production (Recoverable Cu Content) BusStat	Total Production Preferred Series RFF M013b	Primary Refinery Production From Domestic Ores BusStat	Primary Refinery Production From Foreign Ores BusStat	Primary Refinery Production Total BusStat	Mine Production (Recoverable Cu Content) HistStat 6-1	Smelter Production FTC 6-1	Primary Refinery Production Domestic & Foreign Ores Hist Stat 6-1	Secondary Production From Old Scrap HistStat 6-1
1983	1144.3		1106.4	196.7	1303.0				
1982	1256.2		1172.9	178.8	1351.7	1256.153	1036.776	1173.759	570.695
1981	1695.6		1576.5	125.4	1702.0	1695.531	1427.452	1576.537	659.317
1980	1301.9		1236.7	98.1	1334.8	1301.958	1096.226	1236.680	676.222
1979	1591.3		1555.9	114.5	1670.4	1591.248	1447.582	1555.933	666.128
1978	1490.3		1408.9	124.2	1533.1	1496.483	1399.915	1463.179	552.975
1977	1504.0		1411.0	85.2	2496.2	1503.966	1394.433	1496.185	451.868
1976	1605.6		1422.7	116.6	1539.3	1605.586	1461.256	1539.309	419.126
1975	1413.4		1286.2	157.2	1443.4	1413.366	1374.324	1443.378	369.173
1974	1597.0		1420.9	233.8	1654.7	1597.002	1532.066	1654.658	483.432
1973	1717.9		1698.3	170.2	1868.5	1717.940	1705.065	1868.488	486.214
1972	1664.8		1680.4	192.8	1873.2	1664.840	1649.130	1873.233	458.194
1971	1522.2		1410.5	181.3	1591.8	1522.183	1470.815	1591.782	445.157
1970	1719.7		1521.2	243.9	1765.1	1719.657	1605.265	1765.094	504.071
1969	1544.6		1468.9	273.9	1742.8	1544.579	1547.496	1742.815	574.890
1968	1204.6		1160.9	276.5	1437.4	1204.621	1234.724	1437.386	520.772
1967	954.1		846.6	286.4	1133.0	954.064	841.343	1132.982	482.659
1966	1429.2		1353.1	357.9	1711.0	1429.152	1429.863	1710.984	534.860
1965	1351.7		1335.7	376.1	1711.8	1351.734	1402.806	1711.793	513.436
1964	1246.8		1259.9	396.5	1656.4	1246.780	1301.115	1656.395	473.521
1963	1213.2		1219.3	377.0	1596.4	1213.166	1258.126	1596.351	421.843
1962	1228.4		1214.1	397.6	1611.7	1228.421		1611.730	415.674
1961	1165.2		1181.0	369.1	1550.1	1165.155		1550.139	411.110
1960	1080.2		1121.3	397.6	1518.9	1080.169		1518.927	429.365
1959	824.8		796.5	301.8	1098.2	824.846		1098.247	471.007
1958	979.3		1001.6	350.9	1352.5	979.329	992.918	1352.520	411.367
1957	1086.9	1081	1050.5	403.7	1454.2	1086.859	1081.055	1454.176	444.492
1956	1104.2	1118	1080.2	362.4	1442.6	1104.156	1117.580	1442.633	468.489
1955	998.6	1007	997.5	345.0	1342.5	998.570	1007.311	1342.459	514.585
1954	835.5	834	841.7	370.2	1211.9	835.472	834.381	1211.919	407.066
1953	926.4	943	932.2	360.9	1293.1	926.448	943.391	1293.117	429.388
1952	925.4	927	923.2	254.5	1177.7	925.359	927.365	1177.696	414.635
1951	928.3	931	951.6	255.4	1207.0	928.330	930.774	1206.988	458.124
1950	909.3	911	920.7	319.1	1239.8	909.343	911.352	1239.834	485.211
1949	752.8	758	695.0	232.9	927.9	752.750	757.931	927.927	383.548
1948	834.8	842	860.0	247.4	1107.4	834.813	842.477	1107.446	505.464
1947	847.0	863	909.2	250.8	1160.0	847.563	862.872	1159.970	503.376
1946	608.736	600	578.424	300.228	878.664	608.737	599.656	878.662	406.453
1945	772.896	783	775.740	332.856	1108.596	772.894	782.726	1108.599	497.095
1944	972.552	1003	973.848	247.332	1221.192	972.549	1003.000	1221.187	456.710
1943	1090.824	1093	1082.076	297.180	1379.268	1090.818	1093.000	1379.263	427.521
1942	1080.060	1088	1064.796	349.764	1414.560	1080.061	1088.000	1414.561	427.122
1941	958.152	966	975.408	419.904	1395.312	958.149	966.000	1395.309	412.699
1940	878.088	909	927.240	386.316	1313.556	878.086	909.000	1313.556	333.890
1939	728.316	713	704.868	304.644	1009.512	728.320	712.500	1009.515	286.900
1938	557.760	562	552.576	239.844	792.420	557.763	562.500	792.446	267.300
1937	842.004	835	822.252	244.560	1066.812	841.998	834.500	1066.814	408.900
1936	614.520	611	645.456	177.024	822.492	614.516	611.500	822.489	382.700
1935	380.496	381	338.316	250.488	588.804	386.491	381.500	588.805	361.700
1934	237.396	244	233.028	212.328	445.356	237.401	244.500	445.360	310.900
1933	190.644	225	240.672	130.116	370.788	190.643	225.000	370.789	260.300
1932	238.116	272	222.540	117.900	340.428	238.111	272.000	340.434	180.980
1931	528.876	521	537.300	213.420	751.800	528.875	521.500	750.721	261.300
						(g)			

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Mine Production (Recoverable Cu Content) BusStat	Total Production Preferred Series RFF M013b	Primary Refinery Production From Domestic Ores BusStat	Primary Refinery Production From Foreign Ores BusStat	Primary Refinery Production Total BusStat	Mine Production (Recoverable Cu Content) HistStat 6-1	Smelter Production FTC 6-1	Primary Refinery Production Domestic & Foreign Ores Hist Stat 6-1	Secondary Production From Old Scrap HistStat 6-1
1930	705.072	697	695.616	382.920	1078.524	705.074	697.000	1078.530	342.200
1929	997.560	1001	991.368	378.684	1370.052	997.555	1001.500	1370.056	464.350
1928		913				904.898	913.000	1243.804	365.500
1927		842				824.980	842.000	1162.882	339.400
1926		870				862.638	870.000	1161.243	337.300
1925		837				839.059	837.435	1102.287	291.010
1924		817				803.083	817.124	1130.038	266.200
1923		718				738.870	717.499	989.918	270.900
1922		475				482.292	475.143	617.758	202.800
1921		253				233.095	252.793	475.389	131.990
1920		605				612.275	604.531	763.083	168.960
1919		643				606.167	643.220	885.084	152.600
1918		954				955.011	954.267	1197.149	176.670
1917		943				947.717	943.060	1210.897	194.900
1916		964				1002.938	863.925	1129.694	175.000
1915		694				744.036	694.004	817.102	121.187
1914		575				574.216	575.069	766.891	87.882
1913		612				617.785	612.242	807.534	91.500
1912		622				624.547	621.634	784.052	107.000
1911		549				557.382	548.616	716.938	76.000
1910		540				544.119	540.080	711.020	64.500
1909		546				563.261	546.476	695.511	
1908		471				478.420	471.285	568.981	
1907		434				423.576	434.498	516.258	
1906		459				458.486	458.903	539.526	
1905		444				444.392	444.392		
1904		406				406.269	406.269		
1903		349				349.022	349.022		
1902		330				329.754	329.754		
1901		301				301.036	301.036		
1900		303				303.059	303.058		
1899		284				284.333	284.333		
1898		263				263.256	263.256		
1897		247				247.039	247.039		
1896		230				230.031	230.031		
1895		190				190.307	190.306		
1894		177				177.094	177.094		
1893		165				164.677	164.677		
1892		172				172.499	172.499		
1891		142				142.061	142.065		
1890		130				129.882	129.881		
1889		113				113.388	113.388		
1888		113				113.181	113.181		
1887		90.7				90.739	90.738		
1886		78.9				78.881	78.881		
1885		82.9				82.938	82.938		
1884		72.5				72.473	72.473		
1883		57.8				57.763	57.763		
1882		45.3				45.323	45.323		
1881		35.8				35.840	35.840		
1880		30.2				30.240	30.240		
						(g)			

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Secondary Production	Secondary Production Recovered as Refined	Exports Refined	Exports Refined	Total Exports Refined & Scrap	Exports MR95-99	Imports Refined	Imports Refined	Tot.Imports Refined, Unrefined, & Scrap (Copper Content)	Imports MR92-99
	Total Hist Stat 6-1	Bus Stat 6-1	HistStat	BusStat	BusStat	FTC	HistStat	BusStat	Bus Stat	FTC
1983				96.5	305.6			536.2	787.8	
1982		628.5	33.684	38.6	420.1		284.880	286.4	571.8	
1981		696.6	26.893	31.0	375.4		371.066	396.1	553.9	
1980		631.6	15.971	19.0	359.0		470.630	506.4	608.3	
1979		634.5	81.215	97.8	340.4		224.712	240.2	376.2	
1978		453.0	101.328	109.3	321.7		443.871	463.4	607.5	
1977		376.0	51.528	52.7	220.4		390.776	394.0	528.2	
1976		361.0	111.887	113.1	250.0		381.524	384.0	547.4	
1975		332.0	172.426	172.4	333.1		148.805	146.8	330.0	
1974		482.0	126.526	126.5	309.9		313.569	313.6	607.7	
1973		444.0	189.396	189.4	342.0		202.955	199.9	425.6	
1972		385.0	182.743	182.7	267.7		192.379	189.8	423.6	
1971		371.0	187.654	187.7	283.0		163.988	162.1	365.8	
1970	1247.602	475.0	221.211	222.0	348.9		132.143	132.1	394.2	
1969	1375.493	465.6	200.269	200.3	286.2		131.171	131.1	415.1	
1968	1218.340	400.9	240.745	240.7	360.8		400.278	405.4	716.7	
1967	1159.907	394.5	159.353	159.4	241.8		330.571	328.3	644.1	
1966	1334.249	472.0	273.071	273.1	334.7		164.328	162.7	596.7	
1965	1253.250	429.4	324.965	325.0	422.1		137.443	137.4	523.8	
1964	1093.021	332.4	316.230	316.2	430.6		139.974	137.7	584.8	
1963	974.426	288.4	311.479	311.5	360.5		119.219	118.4	541.6	
1962	921.828	272.9	336.525	336.5	385.7		98.820	98.8	481.3	
1961	848.939	263.0	428.718	428.7	581.1		66.855	66.9	460.5	
1960	871.388	275.7	433.762	433.8	615.5		142.709	142.7	525.9	
1959	930.570	234.0	158.938	158.9	199.4		214.058	214.1	574.8	
1958	797.388	213.2	384.868	384.9	435.5		128.464	132.0	507.7	
1957	841.887	222.5	346.025	346.0	465.4		162.309	162.3	598.7	
1956	930.664	247.0	223.103	223.1	299.9		191.812	190.7	600.2	
1955	989.004	222.8	199.819	199.8	277.0		202.312	202.3	602.4	
1954	839.907	194.8	215.951	216.0	388.3		215.118	215.1	598.6	
1953	958.464	199.4	109.580	109.6	180.4		274.111	274.1	683.6	
1952	903.197	140.7	174.135	174.1	191.7		346.960	347.0	626.4	
1951	932.282	144.7	133.305	133.3	147.9		238.972	239.0	493.7	
1950	977.239	206.7	144.561	144.6	163.5		317.363	317.3	714.9	
1949	713.143	225.3	137.827	137.8	160.9		275.811	275.8	568.8	
1948	972.788	250.3	142.598	142.6	151.9		249.124	249.1	546.8	
1947	961.741	276.9	147.642	147.6	153.1		149.478	149.5	493.3	
1946	803.546	122.112	52.629	52.632	56.436		154.371	154.368	414.672	
1945	1006.516	86.052	48.563	48.564	55.056		531.367	531.372	858.444	
1944	950.942	86.400	68.373	68.376	68.844	238	492.395	492.360	789.000	787
1943	1086.047	122.460	175.859	175.860	176.088	202	402.762	402.768	721.296	713
1942	927.755	85.140	131.406	131.412	133.056	154	401.436	401.436	770.964	764
1941	726.396	99.672	103.602	103.608	107.712	131	346.994	346.992	739.140	736
1940	532.046	117.672	356.431	356.436	370.140	463	68.337	68.340	492.108	491
1939	499.700	116.616	372.777	372.780	396.576	420	16.264	16.260	336.300	336
1938	359.800	92.544	370.545	370.548	408.468	415	1.802	1.800	252.168	252
1937	532.100	156.600	295.064	295.068	334.764	345	7.487	7.488	279.876	280
1936	484.600	132.912	220.390	220.392	246.132	257	4.782	4.788	190.344	190
1935	448.900	148.476	260.735	260.736	300.168	298	18.071	18.072	257.304	257
1934	377.400	121.956	262.366	262.368	305.196	309	27.417	27.420	213.408	213
1933	338.100	85.524	124.582	262.368	154.212	172	5.432	5.436	144.312	144
1932	248.180	60.228	110.977	110.976	143.304	161	83.897	83.892	196.860	196
1931	347.000	78.060	202.698	202.704	248.460	272	87.225	87.228	294.480	293

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Secondary Production Total Hist Stat 6-1	Secondary Production Recovered as Refined Bus Stat 6-1	Exports Refined HistStat	Exports Refined BusStat	Total Exports Refined & Scrap BusStat	Exports MR95-99 FTC	Imports Refined HistStat	Imports Refined BusStat	Tot. Imports Refined, Unrefined, & Scrap (Copper Content) Bus Stat	Imports MR92-99 FTC
1930	467.200	140.268	297.057	297.060	337.620	336	43.105	43.104	411.036	409
1929	626.550	167.076	411.227	411.228	457.788	487	67.007	67.008	492.036	487
1928	536.400		474.737			561	42.365			394
1927	490.200		461.233			535	51.640			359
1926	479.800		428.062			480	85.283			390
1925	420.210		484.033			541	49.887			326
1924	388.300		504.812			558	72.955			384
1923	410.900		364.690			414	80.356			338
1922	335.900		326.333			371	51.572			272
1921	217.300		298.059			314	34.625			175
1920	312.460		275.613			312	54.372			243
1919	287.190		219.080			258	17.569			215
1918	352.670		345.014			372	19.044			288
1917	383.400		515.390			563	3.376			278
1916	350.000		358.308			392	4.206			231
1915	196.187					340				158
1914	127.882					420				153
1913	136.500					463				204
1912	137.500					388				205
1911	107.000					393				168
1910	94.500					354				172
1909						341				161
1908										
1907										
1906										
1905										
1904										
1903										
1902										
1901										
1900										
1899						123				47.861
1898						146				35.295
1897						139				14.462
1896						130				8.698
1895						61				7.308
1894										5.723
1893										5.523
1892										4.033
1891										
1890										
1889										
1888										
1887										
1886										
1885										
1884										
1883										
1882										
1881										
1880										

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Net Imports	Apparent Consumption Refined Copper	Apparent Consumption New (Primary) Copper	Apparent Consumption New (Primary) +Old Scrap	Consumption Refined (by mills etc)	ABMS Indust. Consump. Elec I	ABMS Indust. Consump. Build	ABMS Indust. Consump. Auto	ABMS Indust. Consump. Shipbuilding	ABMS Indust. Consump. Misc
	RFF mc22e 5-2	MIN YB 5-2	MIN F&P 5-2	MIN YB 5-2	BusStat 5-2	FTC20-41	FTC20-41	FTC20-41	FTC20-41	FTC20-41
1983										
1982		1827.789	1475	2044	1790.0					
1981		2232.367	1927	2586	2045.0					
1980		2052.610	1806	2481	2083.0					
1979		2379.275	1913	2578	2470.0					
1978		2413.292	2005	2558	2417.0					
1977		2184.960	1791	2243	2202.0					
1976		1991.886	1825	2245	1995.0					
1975		1534.508	1312	1681	1541.0					
1974		2194.168	1778	2261	2201.0					
1973		2437.048	1902	2388	2444.0					
1972		2238.867	1901	2359	2230.0					
1971		2019.507	1623	2068	2016.0					
1970		2043.303	1585	2089	2042.0					
1969			1683	2258	2142.0					
1968			1576	2097	1878.0					
1967			1320	1803	1982.0					
1966			1594	2128	2379.0					
1965			1526	2039	2035.0					
1964			1495	1969	1864.0					
1963			1423	1845	1753.0					
1962					1609.0					
1961					1486.0					
1960					1374.0					
1959					1487.0					
1958			1157	1568	1277.1					
1957	191.0		1239	1683	1366.4					
1956	321.0		1367	1835	1555.4					
1955	340.0		1336	1851	1537.2					
1954	351.0		1235	1642	1275.6					
1953	531.0		1435	1864	1446.0					
1952	410.0		1360	1775	1400.7					
1951	325.0		1304	1762	1386.0					
1950	468.0		1447	1932	1424.4					
1949	358.0		1072	1456	1129.7					
1948	291.0		1214	1719	1420.6					
1947	212.0		1286	1789	1463.3					
1946	299.0		1391	1797						
1945	719.0		1415	1912						
1944	547.0		1504	2584						
1943	319.0		1502	2708						
1942	551.0		1608	2606						
1941	578.0		1642	2308		848		112		
1940	68.7		1009	1541		499	111	103	9	157.3
1939	-77.4		715	1215		394	99	85	9	126.0
1938	-149.0		407			308	76	55	6	97.0
1937	-52.8		695			444	80	112	6	136.4
1936	-60.5		656	1141		398	79	108	5	127.5
1935	-36.7		441	890		287	55	95	1	107.7
1934	-86.8		323	700		228	41	63	3	102.7
1933	-14.8		339	678		215	38	49	2	95.3
1932	47.8		260	508		215	30	32	2	66.0
1931	45.1		451	798		398	47	62	3	92.0

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Net Imports RFF mc22e 5-2	Apparent Consumption Refined Copper MIN YB 5-2	Apparent Consumption New (Primary) Copper MIN F&P 5-2	Apparent Consumption New (Primary) +Old Scrap MIN YB 5-2	Consumption Refined (by mills etc) BusStat 5-2	ABMS Indust. Consump. Elec I FTC20-41	ABMS Indust. Consump. Build FTC20-41	ABMS Indust. Consump. Auto FTC20-41	ABMS Indust. Consump. Shipbuilding FTC20-41	ABMS Indust. Consump. Misc FTC20-41
1930	45.1		633	1100		598	53	87	5	142.0
1929	0.0		889			698	61	138	2	186.0
1928	-147.0		804			563	63	127	2	169.0
1927	-160.0		711			496	54	101	6	148.0
1926	-88.9		785			537	51	105	3	163.0
1925	-213.0		701			475	47	108	3	149.0
1924	-177.0		677			440	40	95	6	131.0
1923	-79.5		650			404	38	105	4	135.0
1922	-114.0		448			286	37	74	3	91.0
1921	-150.0		305			246	22	48	24	71.0
1920	-83.1		527			307	35	61	38	136.0
1919	-51.0		457							
1918	-94.9									
1917	-308.0									
1916	-176.0									
1915	-196.0									
1914	-288.0									
1913	-283.0									
1912	-206.0									
1911	-247.0									
1910	-197.0									
1909	-200.0									
1908	-241.0									
1907	-151.0									
1906	-128.0									
1905	-177.0									
1904	-199.0									
1903	-85.0									
1902	-110.0									
1901	-26.0									
1900	-124.0									
1899	-89.7									
1898	-137.0									
1897	-137.0									
1896	-138.0									
1895	-64.3									
1894	-82.1									
1893	-90.9									
1892	-45.4									
1891	-54.6									
1890	-18.8									
1889	-35.7									
1888	-36.5									
1887	-19.1									
1886	-19.5									
1885	-36.5									
1884	-33.3									
1883	-15.8									
1882	-1.8									
1881	-3.4									
1880	0.3									

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	ABMS Indust. Consump. Manu. Exp. FTC20-41	ABMS Industrial Consumption Total FTC20-41	ABMS Net Consumption less Custom Intake RFF MC22A	ABMS Consumption RFF MC22B	Consumption Preferred Series RFF MC22H	Fabricators Stocks (end period) BusStat	Total Stocks (end period) BusStat	Copper Sulfate Primary Refinery Production (Copper Content)	Copper Sulfate Other Production (Copper Content)	Copper Sulfate Production (Copper Content) MIN YB 5-7
1983										
1982							668.0			9.243
1981							511.0			10.376
1980							365.0			9.309
1979							288.0			10.236
1978						124.0	491.0			9.426
1977						178.0	649.0			7.935
1976						177.0	651.0			8.421
1975						177.0	538.0			9.204
1974						179.0	374.0			10.523
1973						108.0	157.0			10.840
1972						114.0	271.0			9.513
1971						174.0	277.0			8.662
1970						187.0	348.0			11.338
1969						125.0	171.0			12.642
1968						115.0	172.0			10.946
1967						103.0	158.0			10.032
1966						174.0	240.0			10.031
1965						113.0	174.0			11.822
1964						110.0	156.0			10.472
1963						83.0	160.0			10.417
1962						104.0	221.0			10.003
1961						103.0	183.0			12.153
1960						101.0	240.0			14.495
1959						81.5	121.1			10.073
1958						126.7	181.8			12.149
1957			1170	1239	1239	124.6	288.4			17.670
1956			1277	1367	1367	121.8	237.2			16.702
1955			1293	1336	1336	114.6	164.2			19.522
1954			1129	1235	1235	92.5	131.1			16.327
1953			1265	1435	1435	115.7	199.8			18.236
1952			1345	1360	1360	97.4	130.9			23.634
1951			1338	1304	1304	90.4	131.9			26.736
1950			1321	1447	1447					21.814
1949			918	1072	1072			4.842	14.907	19.749
1948			1264	1214	1214			6.132	18.054	24.186
1947			1233	1286	1286			6.161		
1946			1199	1391	1391			5.070	26.886	31.956
1945			1413	1415	1415			8.237	23.154	31.391
1944			1596	1504	1504			8.269		
1943			1618	1502	1502			7.667		
1942			1464	1608	1608			8.076		
1941		1605	1546	1642	1642			6.984		
1940	148.4	1070		1009	1009			5.643	11.404	17.047
1939	51.9	801		715	715			4.868	6.145	11.013
1938	38.8	608		407	407			4.978	6.283	11.260
1937	45.0	860		695	695					
1936	31.6	749		656	656			4.642		
1935	29.5	575		441	441			3.376		
1934	25.5	463		323	323			3.167	3.565	6.732
1933	15.6	415		339	339			3.240	3.043	6.283
1932	23.0	368		260	260			3.173		
1931	48.0	650		451	451			4.492		

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	ABMS Indust. Consump. Manu. Exp. FTC20-41	ABMS Industrial Consumption Total FTC20-41	ABMS Net Consumption less Custom Intake RFF MC22A	ABMS Consumption RFF MC22B	Consumption Preferred Series RFF MC22H	Fabricators Stocks (end period) BusStat	Total Stocks (end period) BusStat	Copper Sulfate Primary Refinery Production (Copper Content)	Copper Sulfate Other Production (Copper Content)	Copper Sulfate Production (Copper Content) MIN YB 5-7
1930	71.0	71		633	633					
1929	75.0	75		889	889			4.601		
1928	67.0	67		804	804			4.601		
1927	57.0	57		711	711			4.601		
1926	51.0	51		785	785			4.601		
1925	58.0	58		701	701			4.601		
1924	54.0	766		677	677					
1923	52.0	738		650	650					
1922	48.0	539		448	448					
1921	49.0	460		305	305					
1920	107.0	684		527	527					
1919				457	457					
1918				831	831					
1917				697	697					
1916				739	739					
1915				568	568					
1914				351	351					
1913				406	406					
1912				410	410					
1911				355	355					
1910				375	375					
1909				353	353					
1908				240	240					
1907				244	244					
1906				343	343					
1905				281	281					
1904				241	241					
1903				263	263					
1902				276	276					
1901				191	191					
1900				178	178					
1899				206	206			3.412		
1898				150	150					
1897				117	117					
1896				98.1	98.1					
1895				129.0	129.0					
1894				98.7	98.7					
1893				75.7	75.7					
1892				128.0	128.0					
1891				88.2	88.2					
1890					111.0					
1889					77.3					
1888					76.5					
1887					71.6					
1886					59.4					
1885					46.4					
1884					39.2					
1883					42.0					
1882					43.5					
1881					32.4					
1880					30.5					

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Copper Sulfate Shipments (Copper Content =gross/4)	Copper Sulfate Exports (Copper Content =gross/4)	Copper Sulfate Apparent Consumption (Cu Content =gross/4)	Copper Sulfate Agricultural Use (Cu Content =gross/4)	Copper Sulfate Industrial Uses (Cu Content =gross/4)	Copper Sulfate Other Uses (Cu Content =gross/4)
	5-7	5-7	5-7	5-7	5-7	
1983						
1982	9.192	-0.460	9.651			
1981	9.949	-0.348	10.297			
1980	9.407	na	9.407	3.857	5.268	0.282
1979	9.315	na	9.315			
1978	8.600	na	8.600			
1977	7.739	0.654	7.085	4.004	3.082	
1976	7.608	0.518	7.090			
1975	7.956	0.312	7.644	3.956	3.688	
1974	10.900	0.454	10.446	4.615	5.831	
1973	11.023	0.429	10.594	4.789	5.805	
1972	9.491	0.662	8.830			
1971	9.213	0.704	8.509	3.632	4.878	
1970	10.081	0.621	9.460	3.585	5.875	
1969	12.389	0.782	11.607			
1968	10.912	0.232	10.680			
1967	10.161	0.270	9.891	4.241	5.650	
1966						
1965		0.534	11.288			
1964		0.272	10.200			
1963		0.213	10.204			
1962		0.479	9.525			
1961		1.894	10.259			
1960		3.710	10.785			
1959						
1958	11.645	1.812	9.833	5.200	4.525	0.108
1957	17.564	8.411	9.153	3.925	5.200	0.028
1956	16.752	7.544	9.208			
1955	19.778	9.346	10.433			
1954	16.622	7.441	9.182			
1953	18.047	8.165	9.882	4.975	4.500	0.407
1952	23.118	10.855	12.263	6.525	5.738	0.000
1951	26.065	10.782	15.283			
1950	22.825	7.537	15.288			
1949	21.100	7.929	13.171			
1948		10.534	13.652			
1947		8.505				
1946	31.175	10.336	20.839			
1945		8.742	22.649			
1944						
1943						
1942						
1941						
1940						
1939						
1938						
1937						
1936						
1935						
1934		0.482	6.250			
1933		0.344	5.939			
1932		0.517				
1931		0.899				
		(p)	(q)	(r)		(t)

NOTES TO COPPER WORKSHEET

(g) Minerals Yearbook 1970-1982

(p) After 1978 imports begin; amounting to 5% of supply by 1982

(q) When no shipment data, this is calculated as production minus exports

(r) Adjusted to account for exports when "other" is not sufficient

(t) Calculated as apparent consumption minus exports

APPENDIX V: Copper Worksheet (units = 1000 short tons)

	Copper Sulfate Shipments (Copper Content =gross/4)	Copper Sulfate Exports (Copper Content =gross/4)	Copper Sulfate Apparent Consumption (Cu Content =gross/4)	Copper Sulfate Agricultural Use (Cu Content =gross/4)	Copper Sulfate Industrial Uses (Cu Content =gross/4)	Copper Sulfate Other Uses (Cu Content =gross/4)
	5-7	5-7	5-7	5-7	5-7	
1930		0.633				
1929		0.802				
1928						
1927						
1926						
1925						
1924		0.374				
1923		0.286				
1922		0.656				
1921		0.448				
1920		0.473				
1919		1.143				
1918		1.810				
1917						
1916						
1915						
1914						
1913						
1912						
1911						
1910						
1909						
1908						
1907						
1906						
1905						
1904						
1903						
1902						
1901						
1900						
1899		3.675				
1898		1.922				
1897						
1896						
1895						
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1883						
1882						
1881						
1880						
		(p)	(q)	(r)		(t)

NOTES TO COPPER WORKSHEET

(g) Minerals Yearbook 1970-1982

(p) After 1978 imports begin; amounting to 5% of supply by 1982

(q) When no shipment data, this is calculated as production minus exports

(r) Adjusted to account for exports when "other" is not sufficient

(t) Calculated as apparent consumption minus exports

APPENDIX VI: Mercury Worksheet [units = 1000 (76 lb) flasks]

	Total Primary Production MIN YB & RFF M018b 7-1	Production From Ore MIN YB 7-1	Secondary Production (inc GSA) MIN YB 7-1	Imports for Consumption MIN YB 7-1	Exports MIN YB & F&P 7-1	Apparent Consumption (Production +Imp-Exp) 7-1	Consumption (Apparent until 1909) MIN YB 7-1	General Imports MIN YB= MIN F&P	Total Stocks (end year) MIN YB	Use in Agriculture MIN YB 7-2	Use in Catalysts MIN YB 7-2
1982	25.760	25.700	4.473	8.916			48.943	15.217	29.327	0.036	0.499
1981	27.904	27.900	11.244	12.408			59.244	13.024	27.339	0.079	0.815
1980	30.657	30.600	16.806	9.416			58.983	11.564	33.069		0.265
1979	29.519	29.500	15.587	26.448			62.205	28.818	27.582		0.548
1978	24.163	24.100	9.262	41.693			59.393	42.874	38.749		
1977	28.244	28.200	6.566	28.750	0.852	62.708	61.259	28.750	34.178	0.584	1.545
1976	23.133	23.000	3.363	44.415	0.501	70.410	64.870	43.964	31.734	0.607	1.264
1975	7.366	6.900	8.038	43.865	0.339	58.930	50.838	44.472	25.549	0.600	0.838
1974	2.189	1.700	8.293	52.180	0.466	62.196	59.479	52.102	19.877	0.980	1.298
1973	2.227	2.100	10.329	46.026	0.342	58.240	54.283	46.076	17.946	1.800	0.673
1972	7.349	7.000	12.651	28.834	0.963	47.871	52.907	29.179	15.708	1.836	0.800
1971	17.883	17.400	16.666	28.449	7.232	55.766	52.257	29.750	16.862	1.477	1.012
1970	27.296	26.800	8.051	21.972	4.703	52.616	61.503	21.672	16.554	1.811	2.238
1969	29.640	28.550	13.650		0.615		77.372	30.848	22.692	2.689	2.958
1968	28.874	28.860	34.380		7.599		75.422	23.956	22.907	3.430	1.914
1967	23.784	23.770	22.150		3.102		69.517	23.899	18.277	3.732	2.489
1966	22.008	21.990	16.400		0.833		71.509	34.757	20.076	2.374	1.932
1965	19.582	19.350	46.670		8.037		73.560	17.838	20.386	3.116	2.133
1964	14.142	14.110	24.519				81.354	41.107	17.362	3.144	0.924
1963	19.100	19.088	10.520				77.963	43.126	12.181	2.538	0.656
1962	26.277	26.228	5.800				65.301	31.516	14.924	4.266	0.612
1961	31.662	31.633	8.360				55.763	12.527	17.533	2.557	0.874
1960	33.223	33.106	5.350				51.167	19.515	19.761	2.974	0.707
1959	31.256	31.109	4.950				54.895	30.260	13.580	3.202	1.018
1958	38.067	37.210	5.400	30.158	0.320	73.305	52.617	30.925	11.274	6.270	0.965
1957	34.625	34.060	5.800	42.005	1.919	80.511	52.889	45.449	25.388	6.337	0.816
1956	24.177	24.110	5.850	47.316	1.080	76.263	54.143	52.009	22.310	9.930	0.859
1955	18.955	18.820	10.030	20.354	0.451	48.888	57.185	20.948	10.028	7.389	0.871
1954	18.543	18.520	6.100	64.957	0.890	88.710	42.796	65.317	22.486	7.651	0.729
1953	14.337	14.262		83.393	0.546	97.184	52.259	85.784	27.021	6.936	0.594
1952	12.547	12.500		71.855	0.400	84.002	42.556	68.686	34.385	5.886	0.826
1951	7.293	6.934		47.860	0.241	54.912	56.848	44.927	30.172	7.737	2.635
1950	4.535	4.312		56.080	0.447	60.168	49.215	60.564	35.619	4.504	2.743
1949	9.930	9.745		103.141	0.577	112.494	39.857	96.918	20.954	4.667	2.520
1948	14.338	13.891		31.951	0.526	45.763	46.253	41.732	30.165	7.048	3.262
1947	23.244	22.823		13.008	0.884	35.368	35.581	10.228	19.284		
1946	25.348	24.929		13.894	0.907	38.335	31.552		39.900	3.134	3.310
1945	30.763	29.754		68.617	1.038	98.342	62.429		83.900	2.862	3.650
1944	37.688	37.333		19.553	0.750	56.491	42.900		80.900		
1943	51.829	50.761		47.805	0.385	99.249	54.500		86.500		4.523
1942	50.846	49.066		38.941	0.345	89.442	49.700		39.500	1.533	3.253
1941	44.921	43.873		7.740	2.590	50.071	44.800				
1940	37.777	37.264		0.171	9.617	28.331	26.600				
1939	18.633	18.505		3.499	1.208	20.924	20.924				
1938	17.991	17.816		2.362	0.713	19.640	19.640				
1937	16.508	16.316		18.917	0.454	34.971	34.971				
1936	16.569	14.007		18.088	0.263	34.394	34.394		2.513		
1935	17.518	15.280		7.815			25.200		3.582		
1934	15.445	13.778		10.192			25.400		4.346		
1933	9.669	8.831		20.315			29.700		5.370		
1932	12.622	11.770		3.886	0.214	16.294	16.294	8.114	3.840		
1931	24.947	22.625		0.549	4.984	20.512	20.512	0.356	0.088		

(d)

APPENDIX VI: Mercury Worksheet [units = 1000 (76 lb) flasks]

	Total Primary Production MIN YB & RFF M018b 7-1	Production From Ore MIN YB 7-1	Secondary Production (inc GSA) MIN YB 7-1	Imports for Consumption MIN YB 7-1	Exports MIN YB & F&P 7-1	Apparent Consumption (Production +Imp-Exp) 7-1	Consumption (Apparent until 1909) MIN YB 7-1	General Imports MIN YB= MIN F&P	Total Stocks (end year) MIN YB	Use in Agriculture MIN YB 7-2	Use in Catalysts MIN YB 7-2
1930	21.553	18.719		3.725			25.200	2.943	0.305		
1929	23.682	19.461		14.917			38.500	14.292			
1928	17.870	14.841		14.562			32.300	15.378		0.365	1.000
1927	11.128	10.711		19.941			30.900	24.326			
1926	7.541			25.634	0.114	33.061	33.061				
1925	9.053			20.580	0.201	29.432	29.432				
1924	9.952			12.996	0.205	22.743	22.743				
1923	7.833			17.836	0.314	25.355	25.355				
1922	6.291			16.697	0.287	22.701	22.701				
1921	6.256			10.462	0.388	16.330	16.330				
1920	13.216			13.982	1.533	25.665	25.665				
1919	21.133			10.495	8.987	22.641	22.641				
1918	32.450			6.631	3.057	36.024	36.024				
1917	35.683			5.138	10.636	30.185	30.185				
1916	29.538			5.585	8.763	26.360	26.360				
1915	20.756			5.551	3.328	22.979	22.979				
1914	16.330			8.090	1.427	22.993	22.993				
1913	19.947			2.259	1.125	21.081	21.081				
1912	24.734			1.088	0.306	25.516	25.516				
1911	20.976			6.210	0.287	26.899	26.899				
1910	20.330			0.009	1.898	18.441	18.441				
1909	21.214			0.210	6.713	14.711	14.711				
1908	19.882			0.199	2.957	17.124	17.124				
1907	21.696			0.218	5.064	16.849	16.849				
1906	26.255			0.001	6.371	19.885	19.885				
1905	30.735			0.035	13.356	17.414	17.414				
1904	35.315										
1903	35.634										
1902	34.291										
1901	29.700										
1900	28.300										
1899	30.654			0.002	16.626	14.030	14.030				
1898	31.297			0.001	12.914	18.383	18.383				
1897	26.823			0.599	13.260	14.163	14.163				
1896	30.967			0.004	20.075	10.896	10.896				
1895	36.342			0.197	15.644	20.895	20.895				
1894	30.616			0.000	14.503	16.113	16.113				
1893	30.362			0.550	16.740	14.172	14.172				
1892	28.177			1.267	3.541	25.903	25.903				
1891	23.055			1.631	3.738	20.947	20.947				
1890	23.077			10.564	2.083	31.558	31.558				
1889	26.658			4.494	5.145	26.007	26.007				
1888	33.469			1.748	10.754	24.462	24.462				
1887	34.048			5.525	11.469	28.104	28.104				
1886	30.178			8.288	8.144	30.322	30.322				
1885	32.284			3.390	6.847	28.828	28.828				
1884	32.123			1.798	7.418	26.502	26.502				
1883	47.032			20.431	30.270	37.193	37.193				
1882	53.079			7.867	34.098	26.848	26.848				
1881	61.251			1.823	35.338	27.736	27.736				
1880	60.320			1.536	37.455	24.401	24.401				

(d)

APPENDIX VI: Mercury Worksheet [units = 1000 (76 lb) flasks]

	Use in Dental Preparations MIN YB 7-2	Use in Electrical Apparratus MIN YB 7-2	Use in Electrolytic Prep. of Chlorine &Caustic Soda 7-2	Use in General Laboratory MIN YB 7-2	Use in Industrial & Control Instruments MIN YB 7-2	Use in Antimildew /fouling Paint MIN YB 7-2	Use in Pharmaceuticals MIN YB 7-2	Other Uses Known & Unknown Calc. 7-2
1982	1.213		6.221	0.272		6.794	0.000	33.908
1981	1.866		7.323	0.328		7.049	0.000	41.784
1980	1.041		9.470	0.363		8.621	0.000	39.223
1979	0.793		12.180	0.410		9.979		38.295
1978	0.512		11.166	0.420		8.956		38.339
1977	1.230	29.180	10.744	0.406	5.221	8.365		3.984
1976	2.001	27.498	16.054	0.595	5.067	7.845	0.060	3.879
1975	2.340	16.971	15.222	0.335	4.598	6.928	0.445	2.561
1974	3.024	19.678	16.897	0.476	6.202	6.813	0.597	3.514
1973	2.679	18.000	13.070	0.658	7.155	7.603	0.606	2.039
1972	2.983	15.553	11.519	0.594	6.541	8.222	0.578	4.281
1971	2.361	16.885	12.154	1.798	4.871	8.605	0.682	2.412
1970	2.505	15.952	15.011	1.806	4.832	12.129	0.690	4.529
1969	3.075	18.490	20.720	1.936	6.655	7.049	0.712	13.088
1968	5.749	19.166	17.424	1.989	7.978	8.611	0.424	8.737
1967	2.605	13.823	14.306	1.940	7.459	6.303	0.283	16.577
1966	2.381	13.339	11.541	2.217	7.294	7.902	0.232	22.297
1965	1.887	13.931	8.753	1.119	4.628	7.790	3.261	26.942
1964	2.920	10.690	9.572	17.329	4.972	5.445	5.047	21.311
1963	2.652	11.115	7.999	5.062	4.943	6.655	4.081	32.262
1962	2.332	11.564	7.314	1.752	5.186	4.678	3.378	24.219
1961	2.432	10.255	6.056	1.484	5.627	6.061	2.515	17.902
1960	2.038	9.268	6.211	1.302	6.525	4.221	1.729	16.192
1959	2.093	8.905	5.828	1.110	5.164	3.514	1.717	21.344
1958	1.989	9.335	4.547	0.968	6.054	0.749	2.815	18.925
1957	1.615	9.151	4.025	0.894	6.028	0.568	1.751	21.704
1956	1.567	9.764	3.351	0.984	6.114	0.511	1.600	19.463
1955	1.394	9.268	3.108	0.976	5.628	0.724	1.578	26.249
1954	1.612	10.833	2.137	1.129	5.185	0.512	1.846	11.162
1953	1.317	9.630	2.380	1.241	5.546	0.655	1.858	22.102
1952	1.178	8.018	2.507	0.629	6.412	1.178	1.395	14.527
1951	0.957	10.250	1.543	0.524	6.158	2.500	2.761	21.783
1950	1.650	12.049	1.309	0.646	5.385	3.133	5.996	11.800
1949	1.128	7.323	0.755	0.345	5.016	1.683	3.443	12.977
1948	1.137	6.471	0.806	0.442	5.653	0.996	3.382	17.056
1947								
1946	1.162	3.849	0.546	0.196	3.960	0.994	4.093	10.308
1945	0.742	24.468	0.597	0.337	3.776	1.661	11.166	13.170
1944								
1943	0.580	3.284	0.500	0.180	3.674	2.702	14.563	24.494
1942	1.378	4.550	0.549	0.294	3.529	1.220	8.088	25.306
1941								
1940								
1939								
1938								
1937								
1936								
1935								
1934								
1933								
1932								
1931								
			(o)		(q)			

NOTES TO MERCURY WORKSHEET

(d) to 1952 = Total minus Ore Production

(o) No separate data prior to 1942-lumped with other catalysts

(q) Prior to 1966 "other" includes all uses of redistilled mercury including those for which primary breakdown is given

APPENDIX VI: Mercury Worksheet [units = 1000 (76 lb) flasks]

	Use in Dental Preparations MIN YB 7-2	Use in Electrical Apparatus MIN YB 7-2	Use in Electrolytic Prep. of Chlorine &Caustic Soda 7-2	Use in General Laboratory MIN YB 7-2	Use in Industrial & Control Instruments MIN YB 7-2	Use in Anti-mildew /fouling Paint MIN YB 7-2	Use in Pharmaceuticals MIN YB 7-2	Other Uses Known & Unknown Calc. 7-2
1930								
1929								
1928	0.815	2.556		0.628	2.996		5.493	18.447
1927								
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NOTES TO MERCURY WORKSHEET

(d) to 1952 = Total minus Ore Production

(o) No separate data prior to 1942-lumped with other catalysts

(q) Prior to 1966 "other" includes all uses of redistilled mercury including those for which primary breakdown is given

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	PRODUCTION							
	US Mine (Pb Content) MIN YB 8-1	Primary Smelter Total MIN YB 8-1	**Antimonial Lead (Primary Pb Content) MIN YB 8-1**	Refined Lead From Foreign Base Bullion MIN YB 8-1	Secondary (Inc. For. Base Bull.) (Pb Cont.) MIN YB 8-1	Primary+ Secondary (Pb Content) MYB or sum 8-1	Primary Smelter (Domestic Ores) MIN YB	Primary Smelter (Foreign Ores) MIN YB
1983	494.938				555.675			
1982	564.852	564.560	**5.095**		629.724	1199.379	506.914	57.645
1981	491.118	546.000	**3.316**		706.697	1256.013	485.279	60.721
1980	606.675	603.615	**0.938**		744.697	1349.250	560.154	43.461
1979	579.341	634.503	**2.862**		883.357	1520.721	584.192	50.311
1978	583.851	622.997	**3.212**		847.938	1474.147	552.967	70.030
1977	592.491	604.838	**3.293**		835.102	1443.233	536.450	68.389
1976	609.546	652.877	**4.642**		726.569	1384.088	568.536	84.341
1975	621.464	636.122	**2.125**		658.456	1296.703	530.215	105.907
1974	663.870	673.024	**9.867**		698.698	1381.589	580.078	92.946
1973	603.024	674.516	**13.223**		654.286	1342.025	567.256	107.260
1972	618.915	680.399	**8.185**		616.597	1305.181	577.398	103.001
1971	578.550	650.015	**16.116**		596.797	1262.928	573.022	76.993
1970	571.767	263.368	11.655		597.390	872.413	528.086	138.644
1969	509.013	638.655			603.900	1242.555	513.931	124.724
1968	359.156	467.310			550.900	1018.210	349.039	118.271
1967	316.931	379.894	9.083		553.772	942.749	258.507	121.387
1966	327.368	440.735	11.182		572.834	1024.751	318.646	122.089
1965	301.147	418.249	6.612		575.819	1000.680	305.007	113.242
1964	286.010	449.429	8.607		541.582	999.618	294.254	155.175
1963	253.369	394.732	9.256		493.471	897.459	239.660	155.072
1962	236.956	376.063	27.383		444.202	847.648	245.645	130.418
1961	261.921	449.565	24.966		452.792	927.323	288.078	161.487
1960	246.669	382.436	2.385		469.903	854.724	228.899	153.537
1959	255.586	340.931	12.402		451.387	804.720	225.270	115.661
1958	267.377	470.156	16.446	0.775	402.562	888.389	269.082	201.074
1957	338.216	533.533	19.870	0.060	489.289	1042.632	347.675	185.858
1956	352.826	542.308	13.367	0.036	506.791	1062.720	349.188	193.120
1955	338.025	479.157	14.586	0.162	502.213	995.794	321.132	158.025
1954	325.419	486.712	12.797	0.088	481.013	980.434	322.271	164.441
1953	342.644	467.891	21.087	0.168	486.905	975.715	328.012	139.879
1952	390.162	472.852	18.666	0.402	471.696	962.812	338.358	89.494
1951	388.164	417.693	26.590	3.065	521.175	962.393	342.644	75.049
1950	430.827	508.314	15.072	3.264	485.539	1005.661	418.809	89.505
1949	409.908	477.338	5.312	1.476	413.659	894.833	404.449	72.889
1948	390.476	406.694	45.479	6.452	506.523	952.244	339.413	67.281
1947	384.221	441.010	24.686	0.063	512.033	977.666	381.109	59.901
1946	335.475	338.197	13.345	0.098	392.885	744.329	293.309	44.888
1945	390.831	443.585	9.981	0.118	363.157	816.605	356.535	87.050
1944	416.861	464.763	18.757	0.095	331.511	814.936	394.443	70.320
1943	453.313	469.612	27.257	0.132	342.226	838.963	406.544	63.068
1942	496.239	566.839	36.617	17.987	340.988	926.457	467.367	99.472
1941	461.426	570.967	22.865	26.284	423.700	991.248	470.517	100.540
1940	457.392	533.179	10.387	16.551	276.897	803.912	433.065	100.114
1939	413.979	484.035	7.297	38.416	279.916	732.832	420.967	63.068
1938	369.726	383.669	10.144	18.843	243.743	618.713	331.964	51.705
1937	364.892	467.317		12.000	286.100		443.000	24.317
1936	372.919	399.156		6.000	208.900		387.668	11.488
1935	331.103	324.560	5.176	0.396	270.796	600.136	310.505	14.055
1934	287.339	311.236	6.231	1.154	209.554	525.867	299.841	11.395
1933	272.677	263.676	4.949	6.286	230.786	493.125	249.713	13.963
1932	292.968	281.941	5.043	11.277	209.577	485.284	248.917	33.024
1931	404.622	442.764	5.231	30.250	264.950	682.695	390.260	52.504
		(c)	(d)	(e)	(f)	(g)	(h)	(i)

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	PRODUCTION							
	US Mine (Pb Content) MIN YB 8-1	Primary Smelter Total MIN YB 8-1	Antimonial Lead (Primary Pb Content) MIN YB 8-1	Refined Lead From Foreign Base Bullion MIN YB 8-1	Secondary (Inc. For. Base Bull.) (Pb Cont.) MIN YB 8-1	Primary+ Secondary (Pb Content) MYB or sum 8-1	Primary Smelter (Domestic Ores) MIN YB	Primary Smelter (Foreign Ores) MIN YB
1930	558.313	643.033	21.830	34.945	290.745	906.102	573.740	69.293
1929	647.995	774.633	38.309	72.460	383.460	1098.390	672.498	102.135
1928	627.153	781.071		73.000	381.600		626.000	155.071
1927	665.489	796.530		74.000	350.000		668.000	128.530
1926	683.917	798.941		75.000	352.300		681.000	117.941
1925	684.439	766.969		76.000	302.880		655.000	111.969
1924	596.068	690.493	20.787	77.701	282.201	901.915	566.407	124.086
1923	547.217	618.322	14.190	50.193	244.683	817.537	543.841	74.481
1922	477.633	532.662		50.018	209.578		468.746	63.916
1921	414.491	448.589		43.247	147.027		398.222	50.367
1920	496.814	529.657		44.394	169.044		476.849	52.808
1919	429.589	482.220		50.131	172.231		424.433	57.787
1918	562.402	640.195		84.956	182.056		539.905	100.290
1917	628.464	610.769		46.447	139.947		548.450	62.319
1916	601.392	571.134		12.821	109.121		552.228	18.906
1915	542.098	550.055		33.448	112.348		507.026	43.029
1914	504.769	542.122		21.689	82.751		512.794	29.328
1913	483.113	462.460		37.359	110.193		411.878	50.582
1912	442.126	480.894			67.168		393.000	87.894
1911	426.585	486.979			54.284		392.000	94.979
1910	382.692	470.272			55.422		375.000	95.272
1909	385.113	446.909			41.687		353.000	93.909
1908	330.237	396.564			18.533		312.000	84.564
1907	364.715	413.389			25.498		352.000	61.389
1906	0.000	404.746					336.000	68.746
1905		388.307					311.000	77.307
1904		393.452					301.000	92.452
1903		368.939					283.000	85.939
1902		367.892					269.000	98.892
1901		371.032					262.000	109.032
1900		367.773					264.000	103.773
1899		298.047					203.000	95.047
1898		302.148					206.000	96.148
1897		282.169					202.000	80.169
1896		257.487					182.000	75.487
1895		235.822					162.000	73.822
1894		213.650					155.000	58.650
1893		224.320					160.000	64.320
1892		208.223					169.000	39.223
1891		198.363					174.000	24.363
1890		157.844					140.000	17.844
1889		178.357					152.000	26.357
1888		156.015					148.000	8.015
1887		156.630					142.000	14.630
1886		132.189					128.000	4.189
1885		126.192				129.000	126.000	
1884		136.297				140.000	136.000	
1883		140.297				144.000	140.000	
1882		129.780				133.000	130.000	
1881		114.495				117.000	114.000	
1880		95.725				98.000	96.000	
		(c)	(d)	(e)	(f)	(g)	(h)	(i)

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	CONSUMPTION								
	Metal,exc. Batteries (Pb Content) calc. 8-3	Storage Batteries (Pb Content) MIN YB 8-3	Pigments White Lead (Pb Content) MIN YB 8-3	Pigments RED&Lith (Pb Content) MIN YB 8-3	Pigments Colors/ Paint (Pb Content) MIN YB 8-3	Pigments Other (Pb Content) MIN YB 8-3	Pigment Total (Pb Content) sum 8-3	TEL&Other Auto Chem-icals (Pb Content) MIN YB 8-3	Other Chemicals (Pb Content) MIN YB 8-3
1983									
1982									
1981									
1980	221.220	711.384					86.454	140.989	
1979	261.614	897.648					100.079	206.072	
1978									
1977	240.290	945.876	6.612	78.071	14.714	0.585	99.982	232.910	0.129
1976	262.922	822.404	2.993	85.403	16.634	0.561	105.591	239.758	0.146
1975	264.354	699.414	2.498	65.457	10.618	0.499	79.072	208.605	0.181
1974	328.348	851.881	1.996	96.163	17.336	0.718	116.213	250.502	0.708
1973	339.033	769.447	1.749	89.577	16.963	0.477	108.766	274.410	0.944
1972	337.767	726.592	2.814	69.799	16.264	0.337	89.214	278.340	0.849
1971	366.563	679.803	4.731	61.838	13.916	0.773	81.258	264.240	0.401
1970	351.452	593.453	5.936	77.215	14.407	1.178	98.736	278.505	0.623
1969									
1968									
1967								247.191	
1966								246.900	
1965									
1964									
1963	356.664	439.081	8.846	70.649			99.075	192.811	0.632
1962	380.623	419.906	11.091	76.325			102.968	168.926	2.715
1961									
1960									
1959								160.000	3.000
1958	382.822	312.725	13.589	64.892			95.901	159.412	3.233
1957	448.948	361.015	15.701	78.323			115.361	177.001	3.556
1956									
1955									
1954									
1953	501.482	367.575	17.775	88.649	12.859	10.307	129.590	162.443	6.975
1952	476.542	350.930	22.943	76.742	12.839	9.775	122.299	146.723	3.996
1951	500.009	375.384	25.578	88.031	12.796	13.099	139.504	139.504	6.949
1950	515.527	398.409	36.181	101.974	13.464	14.768	166.387	113.387	11.680
1949	414.454	313.718	18.400	70.832	8.400	9.515	107.147	94.644	4.191
1948	513.827	354.405	30.970	80.356	10.832	20.230	142.388	83.809	10.280
1947									
1946	212.507	56.726	43.294	128.513			171.807	47.965	8.169
1945	250.694	60.179	35.611	157.171			192.782	75.890	8.567
1944	284.972	68.769	54.333	157.080			211.413	83.067	10.703
1943	290.254	68.239	36.809	124.715			161.524	65.320	8.172
1942	291.559	62.604	56.476	100.563			157.039	50.152	6.298
1941	390.245	73.982	83.230	143.496			226.72[illegible]	48.327	8.861
1940	351.900	220.200	65.500	59.400			124.900	45.000	
1939	273.700	198.000	75.000	57.200			132.200	40.000	
1938	213.500	167.000	71.000	43.000			114.000	37.200	
1937	289.600	192.000	86.000	57.000			143.000	36.500	
1936	254.450	191.000	85.500	54.000			139.500	33.500	
1935	195.700	175.000	80.000	47.500			127.500	30.000	
1934	200.800	163.000	64.500	28.000			92.500	27.000	
1933	197.600	147.000	59.100	19.000			78.100	11.150	
1932	185.700	138.000	54.500	15.800			70.300	3.150	
1931	285.200	157.000	77.500	18.000			95.500	4.860	
			(l)	(m)	(n)	(o)	(p)	(q)	(r)

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	CONSUMPTION								
	Metal,exc. Batteries (Pb Content) calc. 8-3	Storage Batteries (Pb Content) MIN YB 8-3	Pigments White Lead (Pb Content) MIN YB 8-3	Pigments RED&Lith (Pb Content) MIN YB 8-3	Pigments Colors/ Paint (Pb Content) MIN YB 8-3	Pigments Other (Pb Content) MIN YB 8-3	Pigment Total (Pb Content) sum 8-3	TEL&Other Auto Chemicals (Pb Content) MIN YB 8-3	Other Chemicals (Pb Content) MIN YB 8-3
1930	449.700	163.000	83.900	32.000			115.900	4.240	
1929	562.600	210.000	119.700	30.000			149.700	2.720	
1928	510.600	220.000	123.000	31.000			154.000		
1927	461.450	175.000	126.000	38.000			164.000		
1926	510.400	190.000	120.000	36.000			156.000		
1925	463.000	180.000	131.000	42.000			173.000		
1924	420.500	170.000	150.000	34.000			184.000		
1923	412.500	143.000	130.000	46.000			176.000		
1922	334.650	130.000	156.000	30.000			186.000		
1921									
1920									
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1880									
			(l)	(m)	(n)	(o)	(p)	(q)	(r)

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	CONSUMPTION				Imports	Exports	Primary+	Primary	Primary
	Chemicals Total (Pb Content) sum 8-3	Lead Arsenate (Pb Content) MIN YB 8-3	Unaccounted For (Pb Content) MIN YB 8-3	Total (Pb Content) sum 8-2 & 8-3	Refined Pigs,Bars &Old (Pb Content) MIN YB 8-2	Refined Pigs&Bars (Pb Content) MIN YB 8-2	Secondary Consumption calc & MIN YB 8-2	Consump.= Production+ Net Imports RFF mc24f & calc 8-2	Consump. (Preferred Series) (ABM from 1951) 8-2
1983				1266.005					
1982				1185.435				564.560	
1981				1286.509				546.000	
1980			19.760	1179.807	93.827	181.284		524.275	
1979			31.896	1497.308	205.880	11.735	1497.308	810.628	
1978				1432.744	253.698	9.067	1432.674	844.923	
1977	233.039		63.151	1582.338	258.472	9.845	1582.338	853.465	
1976	239.904		59.251	1490.072	145.844	5.907	1490.073	792.814	830.5
1975	208.786		45.472	1297.098	116.156	21.254	1297.098	720.243	682.8
1974	251.210		51.775	1599.427	119.579	61.983	1599.427	730.620	982.2
1973	275.354	1.363	47.246	1541.209	180.789	66.576	1541.209	788.729	1158.7
1972	279.189	1.794	50.698	1485.254	248.639	8.377	1485.254	920.661	986.5
1971	264.641		39.249	1431.514	198.970	5.900	1431.514	843.085	916.8
1970	279.128		37.783	1360.552	244.623	7.747	1360.552	500.244	
1969				1389.358	278.873	4.968	1389.358	912.560	
1968				1328.790	337.620	8.281	1328.790	796.649	
1967				1260.516	363.596	6.536	1260.516	736.954	
1966				1323.877	285.788	5.435	1323.877	721.088	822.7
1965				1241.482	223.461	7.811	1241.482	633.899	716.4
1964				1202.138	211.140	10.175	1202.138	650.394	739.6
1963	193.443	1.610	73.485	1163.358	220.398	1.088	1163.358	614.042	730.3
1962	171.641	2.468	32.029	1109.635	257.866	2.108	1109.635	631.821	732.5
1961		2.277		1027.216	247.427	2.133	1027.216	694.859	695.8
1960		2.219		1021.172	213.347	1.967	1021.172	593.816	581.7
1959	163.000	4.391		1091.149	262.632	2.756	1091.149	600.807	671.6
1958	162.645	3.529	28.765	986.387	351.759	1.359	986.387	820.556	706.9
1957	180.557	3.698	28.536	1138.115	321.708	4.339	1138.115	873.000	702.5
1956		3.176		1209.717	262.204	4.628	1209.717	821.000	742.9
1955		4.732		1212.644	263.977	0.403	1212.644	778.000	809.9
1954		5.151		1094.871	274.286	0.596	1094.871	760.000	763.5
1953	169.418	4.732	28.807	1201.604	379.119	0.803	1201.604	875.000	784.2
1952	150.719	4.903	25.402	1130.795	510.718	1.762	1130.795	1008.000	781.9
1951	146.453	8.570	14.873	1184.793	179.021	1.281	1184.793	599.000	677.5
1950	125.067	13.288	19.303	1237.981	434.410	2.735	1237.981	953.000	885.0
1949	98.835	5.531	17.989	957.674	272.437	0.969	957.674	795.000	579.0
1948	94.089	7.806	21.380	1133.895	244.692	0.399	1133.895	682.000	745.0
1947		9.399		1172.000	158.705	1.523	1172.000	604.000	744.0
1946	56.134	18.613	14.801	530.588	104.083	0.598	956.476	452.000	542.0
1945	84.457	22.175	27.212	637.499	227.311	1.408	1051.602	638.000	760.0
1944	93.770	29.864	34.032	722.820	223.379	15.523	1119.000	673.000	810.0
1943	73.492	27.970	53.986	675.465	244.033	2.003	1113.000	706.000	850.0
1942	56.450	21.762	17.697	607.111	387.693	1.940	1043.000	928.000	1110.0
1941	57.188	22.014	42.492	812.647	325.999	14.359	1050.000	812.000	970.0
1940	45.000	21.953	18.047	782.000	36.882	23.755	782.000	671.000	800.0
1939	40.000	19.993	3.107	667.000	4.772	74.392	667.000	421.000	500.0
1938	37.200	20.871	-6.571	546.000	2.001	45.866	625.000	339.000	400.0
1937	36.500	21.507	-3.907	678.700	2.355	20.091	826.000	453.000	551.0
1936	33.500		15.100	633.550	1.979	18.313	753.000	384.000	490.0
1935	30.000		10.700	538.900	1.368	6.982	659.000	318.000	389.0
1934	27.000		8.000	491.300	0.285	5.909	541.000	300.000	333.0
1933	11.150		18.850	452.700	0.045	22.835	538.000	238.000	313.0
1932	3.150		19.050	416.200	0.044	23.516	473.000	257.000	275.0
1931	4.860		25.140	567.700	0.010	21.665	634.000	410.000	399.0
		(t)			(w)	(x)			

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	CONSUMPTION								
	Chemicals Total (Pb Content) sum 8-3	Lead Arsenate (Pb Content) MIN YB 8-3	Unaccounted For (Pb Content) MIN YB 8-3	Total (Pb Content) sum 8-2 & 8-3	Imports Refined Pigs,Bars &Old (Pb Content) MIN YB 8-2	Exports Refined Pigs&Bars (Pb Content) MIN YB 8-2	Primary+ Secondary Consumption calc & MIN YB 8-2	Primary Consump.= Production+ Net Imports RFF mc24f & calc 8-2	Primary Consump. (Preferred Series) (ABM from 1951) 8-2
1930	4.240		35.760	768.600	0.571	48.307	834.000	590.000	575.0
1929	2.720		47.280	972.300	10.089	73.251	1038.000	700.000	727.0
1928			46.000	930.600	10.244	116.269	1011.000	651.000	702.0
1927			40.500	840.950	4.967	125.267	971.000	690.000	695.0
1926			44.500	900.900	12.183	71.936	1032.000	736.000	755.0
1925			40.500	856.500	7.732	103.519	915.000	660.000	688.0
1924		7.258	30.742	812.500	13.681	82.090		607.000	635.0
1923		5.238	31.262	768.000	21.463	50.735		616.000	604.0
1922			32.500	683.150	4.282	38.178		503.000	519.0
1921					30.995	26.624		436.000	469.0
1920					34.451	20.093		548.000	567.0
1919		3.973			5.087	51.486		442.000	457.0
1918					0.570	101.247		534.000	572.0
1917					0.878	91.340		527.000	543.0
1916					3.194	110.380		472.000	485.0
1915					0.499	126.924		428.000	442.0
1914					0.288	58.722		451.000	476.0
1913					2.311	0.000		415.000	442.0
1912					2.596	0.000		401.000	409.0
1911					3.556	0.000		368.000	405.0
1910					3.388	0.000		405.000	399.0
1909					3.548	0.000		376.000	389.0
1908					2.673	0.000		338.000	336.0
1907					7.834	0.055		372.000	412.0
1906					12.441	0.074		367.000	396.0
1905					5.190	0.063		341.000	365.0
1904					8.667	0.035		323.000	337.0
1903					4.486	0.056		301.000	316.0
1902					6.222	3.271		292.000	350.0
1901					1.802	2.393		269.000	286.0
1900					1.837	0.997		259.000	283.0
1899					1.737	0.047		208.000	238.0
1898					0.156	0.059		215.000	240.0
1897					8.025	3.863		226.000	231.0
1896					5.276	8.180		206.000	225.0
1895					54.776	0.848		239.000	254.0
1894					19.584			191.000	202.0
1893					1.980			191.000	175.0
1892					0.775			197.000	192.0
1891					1.696			196.000	190.0
1890					9.668			155.000	160.0
1889					1.387			154.000	167.0
1888					1.291			149.000	161.0
1887					3.858			146.000	157.0
1886					8.791			137.000	152.0
1885					2.931			129.000	139.0
1884					1.536			138.000	148.0
1883					2.019			143.000	154.0
1882					3.040			133.000	143.0
1881					2.161			116.000	125.0
1880					3.362			100.000	106.0
		(t)			(w)	(x)			

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	Total Lead in Pigments	NY Mine Production (Pb Content) MIN YB
1983		
1982		
1981		
1980	418.833	0.966
1979	602.239	0.505
1978		1.091
1977	516.768	2.778
1976	564.971	3.196
1975		3.027
1974	557.979	3.076
1973	510.885	2.304
1972		1.089
1971		0.877
1970		1.280
1969		
1968		
1967	317.600	
1966	331.300	
1965		
1964		
1963	299.378	
1962	287.037	
1961		
1960		
1959		
1958	238.784	0.579
1957	270.243	1.667
1956		1.608
1955		1.037
1954		1.187
1953	129.590	1.435
1952	122.299	1.120
1951		1.500
1950		1.484
1949	169.108	1.317
1948	227.873	1.231
1947		1.496
1946		1.073
1945	234.292	0.862
1944	266.972	
1943		
1942		
1941		
1940	213.104	
1939	215.561	
1938	175.840	
1937		
1936	220.096	
1935	197.404	
1934	165.211	
1933	149.958	
1932	132.512	
1931	172.760	
	(ab)	(ac)

NOTES TO LEAD WORKSHEET

(c) Historical Statistics thru 1970, then summed

(d) Before 1930 includes production from scrap

(e) 1925-28 & 1936-37 estimated

(f) From 1913-1958 includes refined lead produced from foreign base bullion

(g) Before 1930 includes 1/3 of antimonal lead only. 1880-85 RFF mo14a

(h) Thru 1912 RFF M014d

(i) thru 1912 calculated as total of domestic

(j-w) Prior to 1946 follows ABMS classification

(l-p) Classification change in 1980; Pigment total remains same

(n-r) Prior to 1946 included in Miscellaneous

(q) Author's calculation prior to 1930

(t) Apparent supply- see Arsenic Worksheet

(w) Historical Statistics thru 1970. From 1977 = grand total minus lead & bullion

(x) Historical Satistics thru 1970. From 1971 = unwrought + wrought lead and alloys

(ab) From 1979 includes leady oxide

(ac) NA prior to 1935

APPENDIX VII: Lead Worksheet (units = 1000 short tons)

	Total Lead in Pigments	NY Mine Production (Pb Content) MIN YB
1930	197.557	
1929	260.513	
1928		
1927		
1926		
1925		
1924	266.813	
1923	250.153	
1922		
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1882		
1881		
1880		
	(ab)	(ac)

NOTES TO LEAD WORKSHEET

(c) Historical Statistics thru 1970, then summed

(d) Before 1930 includes production from scrap

(e) 1925-28 & 1936-37 estimated

(f) From 1913-1958 includes refined lead produced from foreign base bullion

(g) Before 1930 includes 1/3 of antimonal lead only. 1880-85 RFF mo14a

(h) Thru 1912 RFF M014d

(i) thru 1912 calculated as total of domestic

(j-w) Prior to 1946 follows ABMS classification

(l-p) Classification change in 1980;
Pigment total remains same

(n-r) Prior to 1946 included in Miscellaneous

(q) Author's calculation prior to 1930

(t) Apparent supply- see Arsenic Worksheet

(w) Historical Statistics thru 1970.
From 1977 = grand total minus lead & bullion

(x) Historical Satistics thru 1970.
From 1971 = unwrought + wrought lead and alloys

(ab) From 1979 includes leady oxide

(ac) NA prior to 1935

APPENDIX VIII: Slab Zinc Worksheet (units = 1000 short tons)

	Slab Zinc Production							
	Primary Smelter from Domestic Ores	Primary Smelter from Foreign Ores	Mines Recov-. Zinc Content HISTSTAT (MINYB 1971 on) 9-1	Primary Smelter from Ore Total HISTSTAT (sum 1971 on) 9-1	From Scrap (Redi-stilled Slab Zinc) 9-1	TOTAL 9-1	Secondary exc. Redistilled Slab Zinc (difference calculated to 62, then MINYB) 9-1	Secondary All Forms TOTAL HISTSTAT (sum 1963 on) 9-1
1982	213.059	38.462	0.000	251.521	81.889	333.410	232.236	314.125
1981	286.419	95.601	344.382	382.021	55.327	437.348	320.396	375.723
1980	255.571	119.718	349.547	375.289	32.404	407.692	303.100	335.503
1979	281.469	239.353	294.693	520.822	58.656	579.478	349.232	407.889
1978	294.703	153.605	333.636	448.308	38.332	486.640	335.155	373.487
1977	355.174	94.971	449.620	450.145	56.611	506.756	313.128	369.739
1976	381.872	116.983	484.513	498.855	68.555	567.410	304.336	372.891
1975	307.959	130.092	469.355	438.051	57.886	495.937	225.315	283.201
1974	346.993	208.195	499.872	555.188	78.535	633.723	259.947	338.482
1973	399.119	184.360	478.850	583.479	83.187	666.666	300.073	383.260
1972	400.969	232.211	478.318	633.180	73.718	706.898	314.043	387.761
1971	403.750	362.683	502.543	633.180	80.923	714.103	279.399	360.322
1970	403.953	473.858	534.136	877.811	77.156	954.967	264.074	341.230
1969	458.754	581.843	553.124	1040.597	70.553	1111.150	307.714	378.267
1968	499.491	521.400	529.446	1020.891	79.865	1100.756	276.092	355.957
1967	438.553	500.277	549.413	938.830	73.505	1012.335	247.254	320.759
1966	523.580	501.486	572.558	1025.066	83.263	1108.329	277.967	361.230
1965	551.215	443.187	611.153	994.402	83.619	1078.021	271.694	355.313
1964	531.967	422.117	574.858	954.084	71.596	1025.680	227.713	299.309
1963	474.007	418.577	529.254	892.584	60.303	952.887	208.715	269.018
1962			505.491	879.395	58.880	938.275	203.137	262.017
1961			464.390	846.795	55.237	902.032	182.730	237.967
1960			435.427	799.516	68.731	868.247	197.089	265.820
1959			425.303	798.666	57.818	856.484	218.436	276.254
1958	346.240	435.006	412.005	781.246	46.605	827.851	183.727	230.332
1957	539.692	446.104	531.735	985.796	72.481	1058.277	191.623	264.104
1956	470.093	513.517	542.340	983.610	72.127	1055.737	209.228	281.355
1955	582.913	380.591	514.671	963.504	66.042	1029.546	238.733	304.775
1954	380.312	422.113	473.471	802.425	68.013	870.438	203.761	271.774
1953	495.436	420.669	547.430	916.105	52.875	968.980	241.803	294.678
1952	575.828	328.651	666.001	904.479	55.111	959.590	255.312	310.423
1951	621.826	259.807	681.189	881.633	48.657	930.290	265.720	314.377
1950	588.291	255.176	623.375	843.467	66.970	910.437	259.060	326.030
1949	591.454	223.328	593.203	814.782	55.041	869.823	182.772	237.813
1948	537.966	249.798	629.977	787.764	62.320	850.084	262.319	324.639
1947	510.058	292.437	637.608	802.495	59.542	862.037	251.251	310.793
1946	459.205	269.057	574.833	728.262	44.516	772.778	256.166	300.682
1945	467.084	297.477	614.358	764.561	49.242	813.803	311.202	360.444
1944	574.453	294.849	718.642	869.302	49.037	918.339	296.432	345.469
1943	594.250	348.059	744.196	942.309	48.215	990.524	320.273	368.488
1942	629.957	261.915	768.025	891.872	53.195	945.067	277.331	330.526
1941	652.599	169.421	749.125	822.020	59.503	881.523	224.464	283.967
1940	598.988	85.287	665.068	675.275	48.917	724.192	173.096	222.013
1939	491.058	16.178	583.807	507.236	50.428	557.664	139.212	189.640
1938	436.007	10.334	516.703	446.341	31.613	477.954	87.387	119.000
1937			626.362	556.904		556.904		166.000
1936	491.803	0.329	575.574	492.132	42.209	534.341	118.791	161.000
1935	412.184	8.450	517.903	420.634	28.650	449.284	100.350	129.000
1934	355.366	8.224	438.726	363.590	19.691	383.281	75.309	95.000
1933	306.010	1.172	384.280	307.182	30.087	337.269	89.913	120.000
1932	207.148	0.000	285.231	207.148	14.718	221.866	55.882	70.600
1931	291.996	0.000	410.318	291.996	21.625	313.621	80.375	102.000
			(d)				(h)	(i)

APPENDIX VIII: Slab Zinc Worksheet (units = 1000 short tons)

	Slab Zinc Production							
	Primary Smelter from Domestic Ores	Primary Smelter from Foreign Ores	Mines Recov-. Zinc Content HISTSTAT (MINYB 1971 on) 9-1	Primary Smelter from Ore Total HISTSTAT (sum 1971 on) 9-1	From Scrap (Redi-stilled Slab Zinc) 9-1	TOTAL 9-1	Secondary exc. Redistilled Slab Zinc (difference calculated to 62, then MINYB) 9-1	Secondary All Forms TOTAL HISTSTAT (sum 1963 on) 9-1
1930	489.361	8.684	595.425	498.045	34.849	532.894	92.551	127.400
1929	612.136	13.311	724.478	625.447	47.348	672.795	128.852	176.200
1928	591.525	11.056	695.170	602.581	48.666	651.247	133.034	181.700
1927	576.960	15.556	718.541	592.516	42.784	635.300	125.516	168.300
1926	611.991	6.431	774.563	618.422	40.799	659.221	127.201	168.000
1925	555.631	17.315	710.847	572.946	39.181	612.127	116.819	156.000
1924	515.831	1.508	637.977	517.339	35.486	552.825	121.514	157.000
1923	508.335	2.099	610.690	510.434	39.434	549.868	124.566	164.000
1922			472.032	354.277		354.277	137.086	161.000
1921			256.640	200.500		200.500	79.466	93.000
1920			587.524	463.377		463.377	109.722	141.000
1919			548.846	465.743		465.743	98.862	130.300
1918			636.091	517.927		517.927	102.040	137.000
1917			713.556	669.573		669.573	86.804	132.000
1916			703.169	668.343		668.343	84.087	129.200
1915			588.060	489.519		489.519	75.757	108.800
1914			415.774	353.049		353.049	60.769	84.600
1913			413.824	346.676		346.676	66.127	89.528
1912			385.621	338.806		338.806	71.242	94.111
1911			331.515	286.526		286.526	55.406	74.747
1910			324.444	269.184		269.184	50.828	68.998
1909			302.373	255.760		255.760	30.968	48.232
1908			234.064	210.424		210.424	9.022	23.226
1907			253.017	249.860		249.860	8.666	25.532
1906				224.770		224.770		
1905			268.000	203.849		203.849		
1904			245.200	186.702		186.702		
1903			216.400	159.219		159.219		
1902			208.300	156.927		156.927		
1901			186.200	140.822		140.822		
1900			169.000	123.886		123.886		
1899			168.200	129.051		129.051		
1898			148.100	115.399		115.399		
1897			126.600	99.980		99.980		
1896			98.500	81.499		81.499		
1895			112.800	89.686		89.686		
1894			97.900	75.328		75.328		
1893			103.400	78.832		78.832		
1892			114.300	87.260		87.260		
1891			104.400	80.873		80.873		
1890			83.300	63.683		63.683		
1889			75.800	58.860		58.860		
1888			75.200	55.903		55.903		
1887			67.700	50.340		50.340		
1886			59.700	42.641		42.641		
1885			55.100	40.688		40.688		
1884			51.200	38.544		38.544		
1883			48.600	36.872		36.872		
1882			43.700	33.765		33.765		
1881			39.700	30.358		30.358		
1880			32.800	25.100		25.100		
			(d)				(h)	(i)

APPENDIX VIII: Slab Zinc Worksheet (units = 1000 short tons)

	Slab Zinc Consumption					
	Refined Imports (=Blocks, Pigs or Slabs HISTSTATS MYB(1970) 9-1	Refined Exports HISTSTATS MYB(1970) 9-1	TOTAL RFF MC26F MYB(1958) 9-1	Indus-trial Uses 9-1	Recov-erable Zinc Content -Ores 9-1	Recov-erable Zinc Content -Second-ary 9-1
1982		0.000				
1981		0.000				
1980	0.000	0.000				
1979	0.000	0.000				
1978	0.000	0.000				
1977	555.147	0.237	1507.635	1101.765	301.508	310.531
1976	695.131	3.513	1536.890	1134.141	101.241	95.339
1975	374.922	6.897	1231.815	925.330	82.732	223.753
1974	543.806	19.062	1673.013	1287.696	127.113	258.204
1973	590.751	14.566	1931.925	1503.938	129.651	298.336
1972	516.643	4.324	1844.023	1418.349	118.305	307.369
1971		13.346	1650.694	1254.059	119.254	277.381
1970	260.132	0.288	1571.596	1186.951	124.781	259.864
1969	324.758	9.298	1814.167	1385.380		
1968	304.687	33.011	1745.357	1350.656		
1967	222.002	16.809	1605.862	1250.673		
1966	280.307	1.406	1820.012	1423.666		
1965	153.957	5.939	1742.067	1354.092		
1964	134.118	26.515	1535.751	1207.268		
1963	132.332	33.853	1414.216	1105.113	104.705	204.398
1962	135.995	36.102	1333.311	1031.821	101.582	199.908
1961	125.186	50.055	1207.469	931.213	97.251	179.005
1960	120.925	75.144	1158.938	877.884	88.275	192.779
1959	164.462	11.629	1278.376	956.197	108.070	214.109
1958	185.693	2.073	1142.138	868.300	94.938	178.900
1957	268.828	10.785	1231.593	935.620	110.311	185.662
1956	244.726	8.813	1323.022	1008.790	113.388	200.844
1955	195.059	18.069	1469.080	1119.812	118.135	231.133
1954	160.138	24.994	1180.692	884.299	99.247	197.146
1953	227.654	17.969	1199	985.927		
1952	113.053	57.714	1095	852.783		
1951	88.043	36.510	977	933.971		
1950	155.332	12.917	995	967.134		
1949	125.564	58.709	854	711.841		
1948	92.495	65.537	874	817.735		
1947	72.063	106.669	832	786.360		
1946	104.065	47.224	845	801.242		
1945	96.760	7.782	1024	852.311		
1944	63.626	21.576	1118	888.626		
1943	56.155	97.439	1152	816.777		
1942	36.352	133.938	976	728.169		
1941	40.[illegible]8	89.309	926	827.435		
1940	10.146	79.091	742	719.000		
1939	30.960	4.515	631	626.000		
1938	7.230		532	421.000		
1937	37.208	0.249	663	610.000		
1936	11.660	0.037	581	582.000		
1935	4.444	1.617	524	473.000		
1934	1.725	5.105	440	359.900		
1933	1.890	1.145	383	350.300		
1932	0.310	6.471	277	259.000		
1931	0.274	0.643	403	370.000		

NOTES TO ZINC WORKSHEET

Sources except where noted:
1880-1970, Historical Statistics.
1971-1983, Minerals Yearbooks.

(d) [Nriagu 80z] through 1905

(h) Assumed zero until 1907.
Calculated as secondary minus 6.7% slab production, 1908-1922.
Calculated as secondary minus redistilled 1923-1962, then direct input 1963-1983

(i) Calculated as sum of redistilled and non-redistilled from 1963 on

APPENDIX VIII: Slab Zinc Worksheet (units = 1000 short tons)

	---------------- Slab Zinc Consumption --------------					
	Refined Imports (=Blocks, Pigs or Slabs HISTSTATS MYB(1970) 9-1	Refined Exports HISTSTATS MYB(1970) 9-1	TOTAL RFF MC26F MYB(1958) 9-1	Indus-trial Uses 9-1	Recov-erable Zinc Content -Ores 9-1	Recov-erable Zinc Content -Second-ary 9-1
1930	0.281	4.633	599	450.900		49.300
1929	0.226	14.411	699	634.300		65.400
1928	0.001	25.289	648	626.500		70.700
1927	0.039	45.695	621	583.100		64.800
1926	0.000	42.920	635	622.300		64.570
1925	0.001	76.351	558	579.100		
1924	0.011	72.583	553	512.000		
1923	0.001	49.211	548	515.000		
1922	0.400	30.286	431	439.900		
1921	6.598	3.009	268	262.500		
1920	0.000	102.178	517	424.200		
1919	0.032	122.002	418	402.000		
1918	0.011	86.438	547			
1917	0.018	201.968	554			
1916	0.021	193.853	626			
1915	0.063	131.378	491			
1914	0.195	64.802	338			
1913	5.165	7.783	401			
1912	10.719	6.634	376			
1911	0.323	6.872	312			
1910	0.989	3.990	316			
1909	9.419	2.566	320			
1908	0.776	2.640	212			
1907	1.709	0.563	253			
1906	1.021	4.670	200			
1905	0.428	5.516	236			
1904	0.341	10.147	200			
1903	0.202	1.521	177			
1902	0.448	3.237	155			
1901	0.278	3.390	147			
1900	0.884	22.410	113			
1899	1.392	6.755	140			
1898	1.303	10.499	130			
1897	1.453	14.245	109			
1896	0.520	10.130	88.8			
1895	0.372	1.530	114			
1894	0.194	1.804	97.7			
1893	0.213	3.723	101			
1892	0.149	6.247	108			
1891	0.404	2.147	96			
1890	0.999	1.649	80.6			
1889	1.026	0.440	76.7			
1888	1.913	0.031	77.7			
1887	4.194	0.068	74.1			
1886	2.150	0.459	62.0			
1885	1.758	0.051	58.3			
1884	2.935	0.063	54.3			
1883	8.534	0.426	58.3			
1882	9.204	0.745	53.9			
1881	1.430	0.746	41.4			
1880	4.046	0.684	37.6			

NOTES TO ZINC WORKSHEET

APPENDIX IX: Zinc Pigments & Salts Worksheet (units = 1000 short tons): Source, Minerals Yearbooks

	ZINC OXIDE SHIPMENTS							ZINC OXIDE	
	Distribution by Industry								
	Rubber	Paints	Ceramics	Floor Covring/ Textiles	Photo-Copying	Other	Total US Shipments	Apparent Consumption	Net Imports for Consumption
	9-3	9-3	9-3	9-3	9-3	9-3	9-3	9-3,4	9-4
1980	68.118	13.410	6.285		10.587	51.267	149.667	182.564	32.896
1979	102.598	13.782	10.181		17.800	53.801	198.161	227.827	29.665
1978	108.014	14.591	10.191		21.050	46.170	200.017		
1977	112.137	13.800	8.106		23.537	51.972	209.552	223.570	14.018
1976	104.669	16.801	8.433		24.148	44.026	198.078	213.153	15.075
1975	96.209	11.016	6.300		24.647	31.313	169.485		
1974	108.976	17.029	12.177		35.167	59.193	232.542	246.385	13.843
1973	129.462	26.115	11.678		38.724	46.854	252.833	273.568	20.735
1972	129.170	27.244	10.702		36.190	42.561	245.867	245.867	
1971	124.472	24.990	8.125		34.504	35.412	227.503	227.503	
1970	111.421	21.894	9.011		31.850	39.107	213.283	213.283	
1969									
1968									
1967									
1966									
1965									
1964									
1963	82.776	34.382	9.381			35.732	162.271	173.266	10.995
1962	80.247	31.381	11.092	0.659		31.470	154.849	165.678	10.829
1961	71.534	30.405	10.058	2.359		30.852	145.208		
1960	75.120	31.610	9.840	2.647		25.561	144.778		
1959	79.505	33.708	10.486	3.332		27.203	154.234		
1958	68.176	33.335	9.095	3.298		22.087	135.991	145.177	9.186
1957	81.745	32.605	8.459	4.872		23.586	151.267	153.368	2.101
1956	80.459	32.485	10.160	9.883		21.968	154.955	155.874	0.919
1955	86.677	33.932	10.617	13.544		23.771	168.541	169.212	0.671
1954	71.058	31.157	8.990	8.071		21.009	140.285	139.522	-0.763
1953	78.439	31.920	8.862	10.952		18.454	148.627	146.842	-1.785
1952	72.774	31.424	7.760	8.675		21.577	142.210	134.768	-7.442
1951	71.507	32.934	10.324	10.379		22.572	147.716	140.603	-7.113
1950	82.944	39.699	12.679	9.973		15.534	160.829	162.830	2.001
1949	58.496	26.205	6.982	7.865		10.584	110.132	105.331	-4.801
1948	82.895	26.779	12.327	14.412		14.545	150.958	142.343	-8.615
1947	82.248	32.867	11.350	13.835		20.471	160.771	141.807	-18.964
1946	83.776	34.785	9.056	12.870		17.364	157.851	146.937	-10.914
1945	63.447	28.014	5.086	12.177		19.231	127.955	120.853	-7.102
1944	59.518	24.999	3.653	9.563		42.942	140.675		
1943	67.898	29.852	3.203	6.633		35.816	143.402		
1942	52.717	25.122	2.934	5.224		13.680	99.677		
1941	90.429	30.304	8.596	6.991		12.513	148.833		
1940	70.979	23.268	6.352	4.752		7.862	113.213		
1939	70.187	25.334	6.572	5.641		6.818	114.552		
1938	46.266	20.884	4.908	3.030		4.041	79.129		
1937	67.061	27.987	5.216	9.019		5.369	114.652		
1936	72.885	33.149	6.102	7.178		7.486	126.800		
1935	57.734	25.289	4.028	7.179		5.467	99.697		
1934	50.145	23.741	4.781	2.963		5.458	87.088		
1933	53.869	29.218	4.087	2.639		8.729	98.542		
1932	37.679	22.369	2.837	1.782		7.583	72.250		
1931	47.972	31.357	4.695	3.171		8.505	95.700		
1930	58.073	40.986	3.691	4.469		11.923	119.142		
1929	80.892	54.440	5.109	4.068		16.102	160.611		
1928							160.904		
1927							151.246		
1926							146.923		
1925							151.354		
1924							131.470	129.356	-2.114
1923							126.987	123.889	-3.098
1922							128.465	127.242	-1.223
1921							74.329	73.161	-1.168
1920							99.444	89.725	-9.719
1919							117.639		
1918							100.286		
1917							107.586		
1916							100.339		
1915							109.261		
1914							82.809		
1913							75.700		
1912							84.002		
1911							63.827		
1910							58.481		

APPENDIX IX: Zinc Pigments & Salts Worksheet (units = 1000 short tons): Source, Minerals Yearbooks

	- LEADED ZINC OXIDE - SHIPMENTS			----- ZINC CHLORIDE -----			-------- LITHOPONE SHIPMENTS --------					----LITHOPONE----	
	Distribution by --Industry--						--Distribution by Industry---						
	Paints 9-4	Other 9-4	Leaded Zinc Oxide Total 9-4	Zinc Chloride Shipment Total 9-4	Net Imports for Consumption 9-4	Apparent Consumption Calc. 9-4	Paint, Etc. 9-5	Floor Covering & Textile 9-5	Rubber 9-5	Other 9-5	Lithopone Total 9-5	Net Imports for Consumption 9-5	Apparent Consumption Calc. 9-5
1980				20.283	1.111	21.394						1.311	
1979				22.050	1.324	23.373						0.185	
1978													
1977				21.371	1.878	23.249						-0.435	
1976				25.184	1.372	26.556						-0.710	
1975													
1974					2.227							-0.923	
1973					2.054							-0.902	
1972													
1971													
1970													
1969													
1968													
1967													
1966													
1965													
1964													
1963	14.809	0.664	15.473	50.922	0.936	51.858						-0.680	
1962	14.959	0.735	15.694	50.438	1.000	51.438						-0.258	
1961	16.533	1.474	18.007										
1960	17.616	1.662	19.278										
1959	20.748	1.878	22.626										
1958	23.021	0.267	23.288	65.761	0.547	66.308						-0.544	
1957	23.094	1.109	24.203	58.569	0.601	59.170						-0.934	
1956	26.825	0.339	27.164	53.201	0.632	53.833						-1.244	
1955	32.178	0.483	32.661	54.161	0.500	54.661						-1.862	
1954	33.690	0.282	33.972	48.252	0.260	48.512						-2.948	
1953	39.276	0.436	39.712		0.179		37.452	8.381	1.723	4.883	52.439	-3.897	48.542
1952	37.607	0.285	37.892		0.275		45.267	8.707	1.523	6.335	61.832	-9.974	51.858
1951	43.678	0.663	44.341		0.714		76.614	9.434	3.295	13.494	102.837	-19.679	83.158
1950	63.002	0.971	63.973		0.210		78.177	13.242	4.092	10.139	105.650	-8.156	97.494
1949	35.938	0.784	36.722	55.208	0.017	55.225	56.146	12.982	3.245	5.962	78.335	-14.448	63.887
1948	64.912	2.529	67.441	68.701	0.000	68.701	104.441	20.859	4.192	10.541	140.033	-21.015	119.018
1947	77.994	3.465	81.459	65.521	0.000	65.521	134.830	17.469	3.085	9.640	165.024	-13.652	151.372
1946	64.816	3.155	67.971	57.316	0.002	57.318	123.279	15.167	1.607	6.948	147.001	-9.651	137.350
1945	58.852	3.746	62.598	56.230	0.000	56.230	109.398	15.821	0.977	9.965	136.161	-11.576	124.585
1944	62.223	2.172	64.395	57.545			108.800	14.746	0.726	18.633	142.905		
1943	42.303	1.525	43.828	53.707			103.860	15.990	1.078	14.795	135.723		
1942	47.052	1.076	48.128	52.374			109.216	15.775	1.047	11.282	137.320		
1941	67.472	1.448	68.920				132.691	21.114	3.547	19.290	176.642		
1940	44.341	1.021	45.362				117.075	18.738	3.387	12.602	151.802		
1939	41.519	1.165	42.684				113.995	17.429	3.189	8.146	142.759		
1938	37.348	0.868	38.216				101.924	15.400	3.148	5.274	125.746		
1937	39.584	0.759	40.343				122.915	20.194	4.383	7.279	154.771		
1936	40.156	0.356	40.512				122.461	23.085	4.908	7.865	158.319		
1935	29.632	0.344	29.976				124.615	19.440	4.435	10.996	159.486		
1934	20.376	0.130	20.506	19.614			114.472	14.811	4.596	11.686	145.565		
1933	22.488	0.380	22.868	32.187			106.995	18.472	5.078	10.286	140.831		
1932	14.072	0.233	14.305	23.524			93.465	17.601	3.955	6.646	121.667		
1931	18.292	0.285	18.577	34.885			119.446	20.780	5.833	5.791	151.850		
1930	16.717	0.562	17.279	29.043			126.076	23.656	5.997	8.336	164.065		
1929	26.981	0.168	27.149	43.189			150.804	37.506	7.176	10.829	206.315		
1928			24.223	45.669			140.122	35.416	6.898	18.032	200.468		
1927			26.064	40.141							176.994		
1926			23.859	47.296							159.931		
1925			31.750	45.619							145.019		
1924			26.729	51.054							109.469	5.907	115.376
1923			23.504	42.431							98.199	8.955	107.154
1922			19.613	41.627							83.360	8.647	92.007
1921			16.103	59.457							55.016	5.247	60.263
1920			30.460	68.945							89.373	1.714	91.087
1919			27.591	59.228							78.365		
1918			26.714								62.403		
1917			23.450								63.713		
1916			23.003								51.291		
1915			18.758								46.494		
1914			11.317								32.819		
1913			9.421								29.685		
1912			11.410								24.220		
1911			6.765								16.866		
1910			6.823								12.655		

APPENDIX IX: Zinc Pigments & Salts Worksheet (units = 1000 short tons): Source, Minerals Yearbooks

	------------ ZINC SULFATE SHIPMENTS --------------					------- ZINC SULFATE ---------		
	------------ Distribution by Industry ------------							
	Agri- culture GrossWgt 9-6	Rayon GrossWgt 9-6	Chem- icals GrossWgt 9-6	Paint Etc. GrossWgt 9-6	Other GrossWgt 9-6	Zinc Sulfate Total GrossWgt 9-6	Net Imports for Consump- tion 9-6	Apparent Consump- tion Calc. 9-6
1980	30.609				8.739	39.348	4.267	43.615
1979	20.406				8.116	28.522	7.550	36.072
1978	14.085				9.970	24.056		
1977	11.084				11.323	22.407	5.689	28.096
1976	12.797				21.547	34.344	5.435	39.779
1975	8.470				15.022	23.492		
1974	14.508				29.627	44.135	7.906	52.041
1973	13.909				31.288	45.197	4.410	49.607
1972	10.496				29.099	39.595		39.595
1971	16.268				33.035	49.303		49.303
1970	17.213				36.856	54.069		54.069
1969								
1968								
1967								
1966								
1965								
1964								
1963	10.785				29.326	40.111	0.885	40.996
1962	8.544				22.687	31.231	0.832	32.063
1961	5.673	12.284			10.934	28.891		
1960	4.320	15.727			8.749	28.796		
1959	5.262	26.062			9.346	40.670		
1958	11.525	19.796			2.416	33.737	0.565	34.302
1957	9.818	19.903			3.899	33.620	0.722	34.342
1956	7.051	21.083			4.066	32.200	0.824	33.024
1955	8.187	10.732			4.945	23.864	0.634	24.498
1954	7.067	6.615			5.345	19.027	0.399	19.426
1953	6.773	9.008	2.539	0.106	3.794	22.220	0.046	22.266
1952	5.111	8.181	1.675	0.172	4.448	19.587	0.066	19.653
1951	5.588	10.073	2.871	0.032	4.960	23.524	0.201	23.725
1950	5.841	11.217	1.879	0.189	4.786	23.912	0.159	24.071
1949	4.429	10.591	1.197	0.663	3.185	20.065	0.120	20.185
1948	5.210	9.900	1.734	0.121	4.548	21.513	0.180	21.693
1947	7.827	8.210	2.120	0.061	3.329	21.547	0.295	21.842
1946	10.816	7.634	2.254	0.174	4.053	24.931	0.415	25.346
1945	6.645	6.729	2.617	0.589	4.274	20.854	0.421	21.275
1944	4.974	5.954	1.459	1.330	3.439	17.156		
1943	3.329	4.537	1.642	2.439	3.702	15.649		
1942	4.123	3.149	2.595	1.917	2.547	14.331		
1941						19.201		
1940						11.937		
1939						10.157		
1938						7.757		
1937						10.521		
1936						9.721		
1935						7.892		
1934						7.379		
1933						5.698		
1932						4.252		
1931						5.290		
1930						6.249		
1929						7.454		
1928						4.733		
1927						6.418		
1926						6.612		
1925						5.593		
1924						4.674		
1923						5.375		
1922						5.078		
1921						3.295		
1920						3.072		
1919						2.763		
1918								
1917								
1916								
1915								
1914								
1913								
1912								
1911								
1910								

APPENDIX IX: Zinc Pigments & Salts Worksheet (units = 1000 short tons): Source, Minerals Yearbooks

	Imports For Consumption Pigments & Comp N.E.C. 9-7	-------ZINC CONTENT OF ZINC PIGMENT PRODUCTION-------					
		Lithopone (Zn Content) 9-7	Zinc Oxide (Zn Content) 9-7	Leaded Zinc Oxide (Zn Content) 9-7	Zinc Sulfate (Zn Content) 9-7	Zinc Chloride (Zn Content) 9-7	Total Zinc in Pigment (Zn Con) Sum 9-7
1980	2.995		125.165		15.697	6.246	147.108
1979	2.140		152.347		11.969	9.845	174.161
1978							
1977	1.733		165.355		12.021	10.118	187.494
1976	1.180		155.634		13.597	10.634	179.865
1975							
1974	3.310		204.506		13.876		218.382
1973	2.443		211.916		14.565		226.481
1972							
1971							
1970							
1969							
1968							
1967							
1966							
1965							
1964							
1963	0.423		125.558	9.252	13.372	11.130	159.312
1962	0.462		126.740	8.610	10.922	11.715	157.987
1961							
1960							
1959							
1958	0.296		105.989	14.065	11.869	11.700	143.623
1957	0.342		122.251	15.933	11.948	13.873	164.005
1956	0.527						
1955	0.265						
1954	0.106						
1953	0.023	10.511	124.276	20.228	7.511	13.644	176.170
1952	0.000	11.603	110.762	18.568	6.341	11.399	158.673
1951	0.000						
1950	0.033						
1949		14.009	87.096	18.930	6.545	12.157	138.737
1948		29.589	117.256	33.088	6.113	14.965	201.011
1947							
1946							
1945		26.679	111.368	30.298	6.514	12.494	187.353
1944		26.335	121.835	32.654	5.051	12.573	198.448
1943							
1942							
1941							
1940		27.760	93.307	22.520	3.384		146.971
1939		27.410	82.671	21.055	2.831		133.967
1938		23.906	60.238	18.502	2.326		104.972
1937							
1936							
1935							
1934		31.355	71.530	11.573	1.942	4.235	120.635
1933		29.037	77.742	11.062	1.714	6.781	126.336
1932		25.484	53.391	7.580	1.033	5.157	92.645
1931		32.598	73.641	9.543	1.354	6.418	123.554
1930		35.225	98.558	11.588	2.047	6.537	153.955
1929		41.593	136.935	14.264	1.851	9.876	204.519
1928							
1927							
1926							
1925							
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1910							

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Motor Fuel Production Hist/Bus 11-6	Motor Fuel Exports Hist/Bus 11-6	Consumption Motor Fuels HWY STATS 11-6	Distillates Production Hist/Bus 11-6	Distillates Imports Hist/Bus 11-6	Distillates Total Demand Hist/Bus 11-6	Residual Oil Production Hist/Bus 11-5	Residual Oil Imports Hist/Bus 11-5	Residual Oil Total Demand Hist/Bus 11-5	Lubricants Production Hist/Bus 11-5
1983	2323.3		2426.5			981.9			518.6	
1982	2322.1		2396.1			974.9			626.5	
1981	2349.4		2415.6			1032.5			762.0	
1980	2394.1		2420.5			1049.0			918.0	
1979	2514.6		2581.5			1208.5			1031.6	
1978	2630.5		2719.5			1252.6			1103.2	
1977	2581.2		2633.5			1223.3			1120.9	
1976	2517.0		2567.2			1146.7			1025.1	
1975	2393.6		2703.5			1040.6			898.6	
1974	2337.5		2638.0			1075.9			963.2	
1973	2401.9		2707.9			1128.7			1030.2	
1972	2320.0		2613.5			1066.1			925.6	
1971	2202.6		2435.9			971.3			838.0	
1970	2105.3	1.4	2312.3	895.7	53.8	927.2	257.5	557.8	804.3	66.2
1969	2028.2	2.4	2214.2	846.9	50.9	900.3	265.9	461.6	721.9	65.1
1968	1940.0	2.1	2092.3	839.4	48.1	874.5	275.8	409.9	668.2	65.7
1967	1845.8	4.9	1966.4	804.4	18.5	818.2	276.0	395.9	651.9	64.9
1966	1792.6	5.8	1895.1	784.7	13.8	797.4	264.0	376.8	626.4	65.4
1965	1704.4	6.4	1807.1	765.1	13.0	775.8	268.6	345.2	587.0	62.9
1964	1661.3	8.0	1730.2	742.0	11.8	750.4	266.8	295.8	554.6	63.7
1963	1625.2	7.0	1650.3	764.6	9.1	747.3	275.9	272.8	538.9	63.1
1962	1583.4	6.6	1586.6	719.6	11.8	732.4	295.7	264.3	545.8	61.5
1961	1534.5	9.0	1548.8	696.0	17.4	694.4	315.6	243.3	548.7	59.3
1960	1510.1	13.5	1517.1	667.1	12.8	685.3	332.1	233.2	559.4	59.4
1959	1473.4	16.7	1481.6	678.9	17.7	660.0	347.9	222.6	563.5	56.1
1958	1412.0	27.4	1406.9	631.4	14.9	653.4	363.4	182.0	531.1	51.3
1957	1415.3	38.6	1367.7	668.6	8.6	616.1	415.7	173.3	548.8	55.3
1956	1396.8	35.6	1326.5	665.7	5.2	615.9	426.7	162.9	562.8	59.2
1955	1331.5	34.5	1264.7	602.5	4.4	581.1	420.3	152.0	557.1	55.8
1954	1233.0	34.4	1181.8	542.3	3.2	526.3	416.8	129.1	522.3	53.2
1953	1234.0	37.9	1140.6	528.1	3.4	488.1	450.0	131.5	560.5	52.5
1952	1141.5	36.3	1084.2	517.9	2.7	479.3	453.9	128.5	555.2	55.6
1951	1108.9	40.1	1022.9	475.8	1.8	447.3	469.4	119.2	564.4	61.5
1950	998.1	24.7	959.2	398.9	2.6	394.9	425.2	120.0	553.8	51.7
1949	939.1	39.3	877.2	340.8	1.8	329.3	424.9	75.2	496.0	45.4
1948	896.0	37.3	826.4	379.3	2.5	340.6	480.0	53.3	500.5	51.4
1947	814.8	47.4	762.8	312.2	4.2	298.3	447.8	54.2	518.5	51.8
1946	748.4	45.3	695.3	287.9	5.2	242.9	431.4	44.6	480.0	45.6
1945	774.5	88.1	531.0	249.2	4.8	226.1	469.5	31.6	523.4	41.9
1944	722.7	100.5	464.8	239.2	7.0	209.3	461.5	36.5	512.0	41.1
1943	592.4	51.6	449.3	211.5	15.3	208.1	417.3	27.2	467.0	38.7
1942	587.0	35.1	540.3	196.7	3.6	185.7	358.9	18.4	405.7	38.6
1941	671.1	27.1	636.2	189.2	5.1	172.8	342.4	37.4	383.4	39.5
1940	597.4	25.4	579.4	183.3	3.3	160.9	316.2	29.4	340.2	36.8
1939	596.5	44.6	544.1	161.7		135.0	305.9	15.7	323.5	35.0
1938	556.0	50.1	513.8	151.8	16.0	145.0	294.9	21.1	316.0	30.8
1937	559.1	34.8	507.3	146.7	17.0	141.7	312.1	22.1	334.2	35.3
1936	504.8	26.1	469.9	125.9	18.2	125.2	288.0	18.8	306.8	30.9
1935	457.8	27.4	424.0	100.2	15.0	100.2	259.8	16.1	275.9	27.9
1934	416.9	23.0	398.2	95.0	12.6	93.4	240.4	12.6	253.0	26.4
1933	401.6	26.8	368.6	78.9	13.2	80.3	237.5	13.2	250.7	23.8
1932	392.6	33.8	369.4	69.5	21.3	80.3	225.3	21.3	246.6	22.4
1931	431.5	45.7	397.9	83.4	25.0	95.9	253.1	25.0	278.1	26.7
			(a)			(b)			(c)	

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Motor Fuel Production Hist/Bus 11-6	Motor Fuel Exports Hist/Bus 11-6	Consumption Motor Fuels HWY STATS 11-6	Distillates Production Hist/Bus 11-6	Distillates Imports Hist/Bus 11-6	Distillates Total Demand Hist/Bus 11-6	Residual Oil Production Hist/Bus 11-5	Residual Oil Imports Hist/Bus 11-5	Residual Oil Total Demand Hist/Bus 11-5	Lubricants Production Hist/Bus 11-5
1930	432.2	65.6	375.7	81.6	26.1	95.4	290.9	26.1	317.0	34.2
1929	435.1	62.1	358.4	448.9	20.5	402.2	448.9	20.5	469.5	34.4
1928	376.9	53.4	311.7	427.2	7.3	370.4	427.2	7.3	434.5	34.7
1927	330.4	45.0	284.2	393.1	8.1	342.2	393.1	8.1	401.2	31.7
1926	299.7	43.8	251.2	365.2	14.4	324.8	365.2	14.4	379.6	32.3
1925	259.6	31.7	217.7	365.0	12.2	322.5	365.0	12.2	377.2	31.1
1924	213.3	29.2	185.9	320.5	12.9	285.3	320.5	12.9	333.4	27.5
1923	179.9	21.1	150.3	287.5	12.3	256.6	287.5	12.3	299.8	26.1
1922	147.7	14.4	119.4	254.9	2.9	219.6	254.9	2.9	257.9	23.3
1921	122.7	13.4	96.8	230.1		195.6	230.1		230.1	20.9
1920	116.3	15.7	82.1	211.0		179.3	211.0		211.0	24.9
1919	96.4		65.4	185.0		157.3	185.0		185.0	20.2
1918	84.0		68.9	165.8		140.9	165.8		165.8	20.0
1917	71.7		58.8	146.6		124.6	146.6		146.6	17.1
1916	59.4		48.7	127.4		108.3	127.4		127.4	15.6
1915	47.1		38.6	108.2		92.0	108.2		108.2	14.0
1914	34.8		28.5	89.0		75.7	89.0		89.0	12.5
1913	30.4		24.9	79.5		67.6	79.5		79.5	12.6
1912	26.0		21.3	70.0		59.5	70.0		70.0	12.7
1911	21.6		17.7	60.5		51.4	60.5		60.5	12.8
1910	17.2		14.1	51.0		43.4	51.0		51.0	12.9
1909	12.9		10.5	41.5		35.3	41.9		41.9	13.0
1908	11.7		9.6	35.3		30.0	35.3		35.3	11.9
1907	10.5		8.6	29.1		24.7	29.1		29.1	10.9
1906	9.2		7.6	22.8		19.4	22.8		22.8	9.8
1905	8.1		6.6	16.6		14.1	16.6		16.6	8.8
1904	6.9		5.7				10.4		10.4	7.7
1903	6.9		5.6				9.7		9.7	7.0
1902	6.8		5.6				8.9		8.9	6.3
1901	6.8		5.6				8.2		8.2	5.6
1900	6.7		5.5				7.4		7.4	4.8
1899	6.7		5.5				6.7		6.7	4.1
1898	6.6		5.4				6.1		6.1	3.9
1897	6.5		5.3				5.6		5.6	3.8
1896	6.3		5.2				5.0		5.0	3.6
1895	6.2		5.1				4.5		4.5	3.5
1894	6.1		5.0				3.9		3.9	3.3
1893	5.7		4.6				3.4		3.4	3.0
1892	5.2		4.3				2.8		2.8	2.7
1891	4.8		3.9				2.3		2.3	2.4
1890	4.3		3.6				1.7		1.7	2.1
1889	3.9		3.2				1.2		1.2	1.8
1888	3.6		3.0				1.1		1.1	1.6
1887	3.3		2.7				1.0		1.0	1.4
1886	3.0		2.5				0.9		0.9	1.1
1885	2.7		2.2				0.8		0.8	1.1
1884	2.4		2.0				0.7		0.7	0.9
1883	2.3		1.9				0.6		0.6	0.8

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Lubricants Exports Hist/Bus 11-5	Lubricants Total Demand Hist/Bus 11-5	Total Petroleum Production Hist/Bus 11-4	Total Refined Imports Hist/Bus 11-4	Total Refined Exports Hist/Bus 11-4	Total Petroleum Demand Hist/Bus 11-4	Petroleum consumpt. Preferred series RFF MC-9 11-4	Runs to Stills Gutm. 11-3,4	Lubricants Production as % of runs 11-3	Kerosene Production 11-3
1983		53.4	3171.0	525.9	209.9	5559.4				40.0
1982		51.0	3156.7	514.0	211.2	5582.9				42.0
1981		56.0	3128.6	534.2	133.9	5861.1				43.6
1980		58.3	3146.4	582.5	94.3	6242.4		4921.3	1.32%	50.1
1979		65.5	3121.3	685.6	86.1	6757.1		5346.5	1.33%	66.8
1978		62.6	3178.2	722.9	74.3	6879.0		5379.7	1.29%	56.3
1977		58.3	3009.3	789.1	70.3	6727.5		5329.7	1.21%	62.6
1976		55.7	2976.2	729.5	78.7	6390.8		5175.7	1.19%	55.7
1975		50.2	3056.8	699.2	74.3	5957.5		4800.7	1.17%	56.7
1974		56.7	3202.6	917.6	79.4	6078.2		4701.1	1.50%	56.9
1973		59.2	3360.9	1049.3	83.7	6317.3		4834.7	1.42%	80.1
1972		52.8	3455.4	878.5	81.2	5990.3		4583.3	1.43%	80.1
1971		49.3	3453.9	774.3	81.3	5552.6		4372.7	1.50%	87.5
1970	16.1	49.7	3517.4	725.5	89.5	5364.5		4245.8	1.56%	95.7
1969	16.4	48.8	3371.8	602.7	83.4	5159.9		4144.2	1.57%	102.9
1968	18.0	48.5	3329.0	537.7	82.7	4901.8		4033.7	1.63%	101.6
1967	18.7	44.1	3215.7	514.3	85.5	4584.5		3827.3	1.69%	100.4
1966	17.1	48.9	3027.8	492.0	70.9	4410.8		3682.8	1.78%	102.1
1965	16.6	47.1	2848.5	448.7	67.2	4202.0		3526.5	1.78%	94.5
1964	18.2	45.8	2786.8	388.1	72.5	4034.2		3417.1	1.86%	95.0
1963	18.3	43.6	2752.7	362.1	74.2	3921.4		3360.8	1.88%	165.8
1962	17.7	43.6	2676.2	348.8	59.6	3796.0		3252.4	1.89%	157.4
1961	17.1	41.5	2621.8	318.1	60.3	3641.3		3156.4	1.88%	142.6
1960	15.8	42.7	2574.9	292.5	70.8	3585.8		3119.1	1.90%	135.8
1959	14.0	42.9	2574.6	297.2	74.5	3447.2		3071.0	1.83%	110.7
1958	13.0	39.5	2449.0	272.6	96.3	3328.0		2926.7	1.75%	110.0
1957	13.8	41.2	2616.9	201.3	156.9	3082.0	3082.0	3040.5	1.83%	108.9
1956	13.9	43.9	2617.3	183.8	128.8	3075.0	3075.0	3040.2	1.95%	123.5
1955	14.3	42.5	2484.4	170.1	122.6	2949.0	2949.0	2856.6	1.95%	117.1
1954	15.1	38.5	2315.0	144.5	116.1	2704.0	2704.0	2657.1	2.00%	122.3
1953	13.0	40.5	2357.1	141.0	126.7	2648.0	2648.0	2666.2	1.97%	123.2
1952	16.0	38.2	2289.8	138.9	131.5	2543.0	2543.0	2545.2	2.18%	132.3
1951	17.4	42.3	2247.7	129.1	125.4	2452.0	2452.0	2469.7	2.49%	135.7
1950	14.3	38.9	1973.6	132.5	76.5	2265.0	2265.0	2189.5	2.36%	118.5
1949	12.6	33.1	1841.9	81.9	86.3	2019.0	2019.0	2029.7	2.24%	102.2
1948	13.4	36.0	2020.2	59.1	94.9	2019.6	2019.6	2124.6	2.42%	121.9
1947	14.9	36.5	1857.0	61.9	118.1	1902.3	1902.3	1922.9	2.69%	110.4
1946	11.1	34.9	1733.9	51.6	110.7	1708.9	1708.9	1793.1	2.60%	104.4
1945	6.6	35.3	1713.7	39.3	150.0	1692.1	1692.1	1794.2	2.33%	81.0
1944	8.7	32.4	1677.9	47.5	173.4	1596.6	1596.6	1735.7	2.37%	78.3
1943	8.9	31.5	1505.6	49.6	108.6	1452.6	1452.6	1490.9	2.59%	72.3
1942	8.3	29.1	1386.6	23.7	83.1	1382.6	1382.6	1390.7	2.78%	67.5
1941	9.9	30.3	1402.2	46.5	75.6	1418.6	1418.6	1457.0	2.71%	72.6
1940	10.5	24.7	1353.2	41.1	79.0	1267.8	1267.8	1333.7	2.76%	73.9
1939	11.9	23.7	1265.0	26.0	116.9	1176.5	1176.5	1277.4	2.74%	68.5
1938	9.4	21.2	1206.9	27.9	116.5	1084.2	1084.2	1205.0	2.56%	64.6
1937	11.0	23.3	1224.6	29.7	102.1	1118.2	1118.2	1222.8	2.89%	65.3
1936	8.7	22.3	1102.1	24.8	79.1	1047.5	1047.5	1102.4	2.81%	56.1
1935	8.5	19.7	986.7	20.4	74.3	943.1	943.1	996.8	2.79%	55.8
1934	7.7	18.5	908.9	14.9	71.7	881.3	881.3	923.8	2.85%	53.9
1933	8.2	17.2	865.3	13.5	67.6	832.6	832.6	886.6	2.68%	49.0
1932	6.9	16.6	827.5	29.8	74.3	798.0	798.0	846.3	2.65%	43.8
1931	8.1	20.1	914.0	38.8	98.9	857.2	857.2	929.7	2.87%	42.4
		(d)	(e)	(h)	(h)	(f)	(g)			

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Lubricants Exports Hist/Bus 11-5	Lubricants Total Demand Hist/Bus 11-5	Total Petroleum Production Hist/Bus 11-4	Total Refined Imports Hist/Bus 11-4	Total Refined Exports Hist/Bus 11-4	Total Petroleum Demand Hist/Bus 11-4	Petroleum consumpt. Preferred series RFF MC-9 11-4	Runs to Stills Gutm. 11-3,4	Lubricants Production as % of runs 11-3	Kerosene Production 11-3
1930	9.9	21.6	931.4	43.5	132.8	870.3	870.3	970.6	3.52%	49.2
1929	10.9	23.6	1013.1	29.8	136.7	883.9	883.9	1034.2	3.32%	55.9
1928	11.0	23.2	935.4	11.8	136.0	814.2	814.2	948.5	3.65%	59.4
1927	9.8	21.7	845.5	13.4	125.8	760.4	760.4	861.0	3.68%	56.1
1926	9.4	22.6	791.1	20.9	116.5	746.9	746.9	807.0	4.00%	61.8
1925	9.7	20.6	745.9	16.4	100.5	698.1	698.1	759.6	4.09%	59.7
1924	9.1	18.1	649.7	16.8	98.9	663.8	663.8	658.5	4.18%	60.0
1923	8.4	17.3	572.2	17.6	84.4	630.7	630.7	587.9	4.44%	55.9
1922	7.9	15.5	504.4	8.7	63.5	517.3	517.3	504.4	4.62%	54.9
1921	6.9	12.0	445.9	3.4	62.0	444.7	444.7	445.9	4.69%	46.3
1920	9.6	14.7	437.1	2.6	70.3	445.0	445.0	437.1	5.71%	55.2
1919		13.6	365.3	1.4	57.5	365.1	365.1	365.3	5.54%	55.0
1918		13.8	330.5	1.2	62.1	351.0	351.0	330.5	5.65%	53.3
1917		17.1	295.7	1.4	59.0	300.8	300.8	295.7	5.79%	51.6
1916		15.6	260.9	0.4	58.0	257.5	257.5	260.9	5.97%	49.9
1915		14.0	226.1		51.7	242.5	242.5	226.1	6.20%	48.2
1914		12.5	191.3		50.4	228.0	228.0	191.3	6.52%	46.5
1913		12.6	177.2		46.2	214.4	214.4	177.2	7.10%	45.2
1912		12.7	163.1		40.3	184.7	184.7	163.1	7.77%	43.9
1911		12.8	149.0		37.3	177.8	177.8	149.0	8.57%	42.6
1910		12.9	134.9		31.5	173.0	173.0	134.9	9.54%	41.3
1909		13.0	120.8		33.3	144.0	144.0	120.8	10.73%	40.0
1908		11.9	110.0		33.3	141.0	141.0	110.0	10.83%	38.5
1907		10.9	99.3		27.8	134.0	134.0	99.3	10.95%	37.0
1906		9.8	88.5		26.7	94.8	94.8	88.5	11.10%	35.5
1905		8.8	77.8		26.1	105.0	105.0	77.8	11.30%	34.0
1904		7.7	67.0		21.7	92.2	92.2	67.0	11.55%	32.5
1903		7.0	64.0		19.3	77.1	77.1	64.0	10.96%	32.0
1902		6.3	61.0		21.9	63.5	63.5	61.0	10.30%	31.5
1901		5.6	58.0		22.7	43.7	43.7	58.0	9.58%	31.0
1900		4.8	55.0		20.2	40.1	40.1	55.0	8.78%	30.5
1899		4.1	52.0		19.8	34.5	34.5	52.0	7.88%	30.0
1898		3.9	51.2		20.8	31.9	31.9	51.2	7.70%	29.9
1897		3.8	50.3		20.8	36.8	36.8	50.3	7.51%	29.8
1896		3.6	49.5		18.6	39.8	39.8	49.5	7.32%	29.7
1895		3.5	48.6		18.4	31.8	31.8	48.6	7.11%	29.6
1894		3.3	47.8		18.7	27.7	27.7	47.8	6.90%	29.5
1893		3.0	44.4		16.5	29.2	29.2	44.4	6.76%	27.6
1892		2.7	41.0		15.2	32.8	32.8	41.0	6.59%	25.8
1891		2.4	37.5		13.7	38.3	38.3	37.5	6.39%	23.9
1890		2.1	34.1		14.2	29.3	29.3	34.1	6.15%	22.1
1889		1.8	30.7		14.2	19.0	19.0	30.7	5.86%	20.2
1888		1.6	28.9		11.2	14.0	14.0	28.9	5.59%	19.2
1887		1.4	27.1		12.4	14.0	14.0	27.1	5.28%	18.1
1886		1.1	25.3		12.3	14.0	14.0	25.3	4.45%	17.1
1885		1.1	23.6		11.4	8.5	8.5	23.6	4.51%	16.0
1884		0.9	21.8		11.1	11.2	11.2	21.8	4.04%	15.0
1883		0.8	20.9		11.3	10.7	10.7	20.9	3.91%	14.3

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Kerosene Production as % of runs 11-3	Residual Fuels Production as % of runs 11-3	Distillates Production as % of runs 11-3	NJ Consumption MotorFuel HWY STATS	NY Consumption MotorFuel HWY STATS	NJ+NY Consumption MotorFuel HWY STATS	Gasoline Used on Highways HWY STATS	Special Fuels on Highways HWY STATS	Total Hwy Use Motor Fuel HWY STATS	Non-Hwy Uses Motor Fuel HWY STATS
1983										
1982										
1981										
1980	1.40%	11.75%	21.31%							
1979	1.20%	11.51%	22.60%							
1978	1.18%	11.31%	23.28%							
1977	1.16%	12.01%	22.95%							
1976	1.08%	9.74%	20.68%							
1975	1.18%	9.39%	20.18%	22.5	37.6	60.1	2365.6	229.3	2594.9	86.7
1974	1.21%	8.31%	20.72%	21.9	37.6	59.5	2297.7	233.2	2531.0	86.3
1973	1.66%	7.33%	21.31%	22.5	41.4	63.8	2396.1	234.2	2630.3	92.8
1972	1.75%	6.38%	21.02%	21.9	40.2	62.0	2298.6	202.8	2501.5	91.0
1971	2.00%	6.28%	20.86%	20.1	38.8	58.8	2142.5	180.3	2322.8	93.2
1970	2.25%	6.06%	21.13%	19.3	36.7	56.0	2038.1	160.3	2198.3	95.3
1969	2.48%	6.42%	20.47%	18.2	36.1	54.3	1947.7	150.7	2098.5	97.7
1968	2.52%	6.84%	20.84%	17.6	33.2	50.8	1839.5	135.5	1975.0	100.2
1967	2.62%	7.21%	21.03%	16.6	32.2	48.8	1730.5	120.2	1850.7	99.5
1966	2.77%	7.17%	21.34%	16.2	31.4	47.7	1666.0	111.7	1777.7	102.7
1965	2.68%	7.62%	21.70%	15.9	30.3	46.2	1594.7	98.2	1693.0	100.2
1964	2.78%	7.81%	21.73%	15.1	29.4	44.5	1530.2	86.5	1616.7	99.9
1963	4.93%	8.24%	22.76%	14.5	28.0	42.5	1458.9	77.2	1536.1	101.0
1962	4.84%	9.09%	22.14%	13.9	27.2	41.1	1398.8	70.2	1469.0	104.9
1961	4.52%	10.00%	22.07%	13.6	29.1	42.6	1347.8	64.3	1412.1	124.5
1960	4.35%	10.65%	21.39%	13.4	28.0	41.3	1319.7	58.4	1378.1	127.0
1959	3.60%	11.33%	22.11%	13.1	26.7	39.8	1288.1	53.1	1341.3	128.2
1958	3.76%	12.42%	21.57%	12.2	25.7	37.9	1227.7	44.2	1271.9	123.1
1957	3.58%	13.67%	21.99%	11.9	25.0	36.9	1195.9	39.0	1234.9	121.2
1956	4.06%	14.04%	21.90%	11.8	23.8	35.6	1162.0	33.6	1195.6	117.5
1955	4.10%	14.71%	21.09%	11.4	22.6	34.0	1107.8	28.7	1136.5	115.1
1954	4.60%	15.68%	20.41%	10.6	21.1	31.7	1031.4	24.9	1056.3	113.2
1953	4.62%	16.88%	19.81%	9.7	20.1	29.8	995.4	22.4	1017.8	110.7
1952	5.20%	17.83%	20.45%	9.1	18.9	28.0	946.7	19.9	966.6	106.0
1951	5.50%	19.01%	19.27%	8.8	17.9	26.7	891.2	16.9	908.1	103.5
1950	5.41%	19.38%	18.22%	8.2	17.0	25.2	836.3	12.8	849.1	99.5
1949	5.03%	20.93%	16.79%	7.3	15.8	23.1	762.2	10.2	772.3	95.5
1948	5.74%	21.95%	17.92%	6.8	14.6	21.4			725.3	92.1
1947	5.74%	23.29%	16.23%	6.4	13.5	19.9			671.8	82.5
1946	5.82%	24.06%	16.06%	5.9	12.3	18.2			610.7	76.8
1945	4.52%	26.17%	13.89%	4.5	9.2	13.7			455.9	69.0
1944	4.51%	26.59%	13.78%	4.2	8.2	12.4			391.2	68.2
1943	4.85%	27.99%	14.19%	4.1	7.7	11.9			381.1	62.8
1942	4.85%	25.81%	14.14%	5.1	9.9	15.0			474.8	59.5
1941	4.98%	23.50%	12.98%	6.4	13.0	19.4			576.0	53.3
1940	5.54%	23.71%	13.74%	5.9	12.5	18.4			523.8	46.8
1939	5.36%	23.95%	12.66%	5.5	12.1	17.6			493.2	42.7
1938	5.36%	24.47%	12.60%	5.3	11.4	16.7			466.9	39.1
1937	5.34%	25.52%	12.00%	5.1	11.4	16.5			463.2	37.9
1936	5.09%	26.12%	11.42%	4.6	10.8	15.5			430.9	33.3
1935	5.60%	26.07%	10.06%	4.2	10.1	14.3			389.2	29.7
1934	5.83%	26.02%	10.28%	4.0	9.9	13.9			367.0	26.4
1933	5.52%	25.96%	8.90%	3.9	9.6	13.5			341.6	24.3
1932	5.18%	26.62%	8.21%	3.9	9.9	13.8			341.4	25.9
1931	4.57%	27.22%	9.02%	4.0	10.2	14.2			368.0	27.7

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Kerosene Production as % of runs 11-3	Residual Fuels Production as % of runs 11-3	Distillates Production as % of runs 11-3	NJ Consumption MotorFuel HWY STATS	NY Consumption MotorFuel HWY STATS	NJ+NY Consumption MotorFuel HWY STATS	Gasoline Used on Highways HWY STATS	Special Fuels on Highways HWY STATS	Total Hwy Use Motor Fuel HWY STATS	Non-Hwy Uses Motor Fuel HWY STATS
1930	5.07%	29.98%	8.40%	3.8	9.5	13.3			351.3	24.4
1929	5.41%	43.41%		3.5	8.6	12.1			336.7	21.7
1928	6.26%	45.04%		2.9	7.5	10.5			294.3	17.4
1927	6.52%	44.49%		2.6	7.2	9.8			269.8	14.4
1926	7.65%	45.26%		2.3	6.0	8.3			239.6	11.6
1925	7.86%	48.05%		1.9	5.1	7.1			208.3	9.4
1924	9.12%	48.67%							178.5	7.4
1923	9.51%	48.90%							144.7	5.6
1922	10.89%	50.54%							115.3	4.1
1921	10.39%	51.60%							93.7	3.1
1920	12.64%	48.27%							79.7	2.4
1919	15.06%	50.64%							63.6	1.8
1918	16.13%	50.17%								
1917	17.45%	49.58%								
1916	19.13%	48.83%								
1915	21.32%	47.85%								
1914	24.31%	46.52%								
1913	25.51%	44.86%								
1912	26.92%	42.92%								
1911	28.59%	40.60%								
1910	30.62%	37.81%								
1909	33.11%	34.35%								
1908	34.99%	32.06%								
1907	37.27%	29.27%								
1906	40.10%	25.80%								
1905	43.72%	21.37%								
1904	48.51%	15.52%								
1903	50.00%	15.09%								
1902	51.64%	14.61%								
1901	53.45%	14.09%								
1900	55.45%	13.51%								
1899	57.69%	12.87%								
1898	58.44%	12.00%								
1897	59.22%	11.11%								
1896	60.02%	10.19%								
1895	60.86%	9.24%								
1894	61.72%	8.25%								
1893	62.28%	7.65%								
1892	62.94%	6.94%								
1891	63.72%	6.11%								
1890	64.65%	5.11%								
1889	65.80%	3.89%								
1888	66.27%	3.76%								
1887	66.80%	3.61%								
1886	67.41%	3.45%								
1885	68.01%	3.25%								
1884	68.93%	3.02%								
1883	68.03%	2.63%								

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Total Motor Fuel Burned HWY STATS	Loss Allow ances HWY STATS	Gaso line Demand Hist/Bus	Petroleum consumpt. Preferred series RFF MC-9i	Nat Gas Prod RFF MC9a	Benzol Prod RFF Mc9b	Petroleum consumpt. Preferred series RFF MC-9
1983							
1982			2396.1				
1981			2415.6				
1980			2420.5				
1979			2581.5				
1978			2719.5				
1977			2633.5				
1976			2567.2				
1975	2681.6	22.0	2450.3				
1974	2617.2	21.3	2402.4				
1973	2723.1	22.6	2452.7				
1972	2592.5	20.9	2350.7				
1971	2416.0	20.0	2213.2				
1970	2293.6	18.7	2131.3				
1969	2196.2	18.0	2042.5				
1968	2075.1	17.2	1956.0				
1967	1950.3	16.1	1842.7				
1966	1880.5	14.6	1793.4				
1965	1793.2	13.9	1720.2				
1964	1716.6	13.5	1657.9				
1963	1637.2	13.1	1632.1				
1962	1573.8	12.7	1584.7				
1961	1536.5	12.2	1533.2				
1960	1505.1	12.0	1511.7				
1959	1469.5	12.1	1485.3				
1958	1395.0	11.8	1435.9				
1957	1356.1	11.6	1393.0	3219.0	137.0		3082.0
1956	1313.1	13.4	1373.1	3213.0	138.0		3075.0
1955	1251.6	13.1	1334.2	3088.0	139.0		2949.0
1954	1169.5	12.3	1230.6	2832.0	128.0		2704.0
1953	1128.5	12.1	1205.8	2775.0	127.0		2648.0
1952	1072.6	11.6	1157.3	2664.0	121.0		2543.0
1951	1011.5	11.4	1089.6	2570.0	118.0		2452.0
1950	948.6	10.7	994.3	2375.0	110.0		2265.0
1949	867.8	9.4	913.7	2118.0	99.0		2019.0
1948	817.4	9.0	871.3	2114.0	94.0	0.4	2019.6
1947	754.3	8.5	795.0	1990.0	87.0	0.7	1902.3
1946	687.5	7.7	735.4	1793.0	82.0	2.1	1708.9
1945	524.9	6.1	696.3	1773.0	78.0	2.9	1692.1
1944	459.3	5.5	632.5	1671.0	72.0	2.4	1596.6
1943	443.9	5.4	568.2	1521.0	66.0	2.4	1452.6
1942	534.3	6.0	589.1	1450.0	65.0	2.4	1382.6
1941	629.3	6.9	667.5	1486.0	64.0	3.4	1418.6
1940	570.7	8.7	589.5	1327.0	56.0	3.2	1267.8
1939	535.9	8.2	555.5	1231.0	52.0	2.5	1176.5
1938	506.0	7.8		1137.0	51.0	1.8	1084.2
1937	501.1	6.2		1170.0	49.0	2.8	1118.2
1936	464.3	5.7		1093.0	43.0	2.5	1047.5
1935	418.8	5.2		984.0	39.0	1.9	943.1
1934	393.4	4.8		920.0	37.0	1.7	881.3
1933	365.9	2.7		868.0	34.0	1.4	832.6
1932	367.3	2.1		835.0	36.0	1.0	798.0
1931	395.7	2.2		903.0	44.0	1.8	857.2
				(g)			

NOTES TO PETROLEUM WORKSHEET

SOURCE:
Unless otherwise noted, Historical Statistics of the US thru 1938 and Business Statistics (BEA) from 1939 on (abbreviated Hist/Bus) Production % in estimates from average of following 10 year data

GASOLINE DEMAND
all quantities in mil. bbbls)
Source:dir.dmnd:'82 Bus Stats., '82-'61;'79 Bus. Stats., '60-'47;
Source:Production,Exports:HistStats 1970-1920; Prod. 1919-1880,Gutmanis'

DISTILLATE FUEL OIL DEMAND
(all quantities in mil. bbls)
(Source:Dir.Dmnd:'82Bus Stats., '82-'61; '79 Bus.Stats., '60-'47; '69Bus.Stats.,'46-'39)
(Source: Prod.,Imports, '70 HistStats. '70-'20; Prod., Gutmanis''19-'05 Note:'19 -'05 data is res + dist. combined)

Note 2: Imports, '34-'20, are Dist.+ Resid. combined

RESIDUAL FUEL OIL DEMAND
(all quantities in mil. bbls)
(Source:Dir.Demnd:'82 Bus.Stats.,'82-'61;'79 Bus. Stats., '60-'47; '69 Bus.Stats.,'47-'39)
(Source:Computed Demnd: Prod.,Hist.Stats, '70-'20,

Note:Resid + Dist: Combined,'29-'20, Imports,Hist.Stats.,'70-20, Note:Residual + Dist. combined, '34-'22) Prod. Gutmanis, '19-1880, Note:Resid.+Dist. combined

LUBRICANTS DEMAND
(all quantities in mil. bbls)
Source: '82 Bus. Stats., '82-'61;'79 Bus. Stats. '60-'47; '69 Bus. Stats., '46-'39; BEA hand-written,'38-'18; Gutmanis'Data,Prod.,1917-1880; Product'n,1970-1918,Hist.Stats; Exports,1970-1920,Hist.Stats.)

APPENDIX X: Petroleum Worksheet (units = 1,000,000 bbls)

	Total Motor Fuel Burned HWY STATS	Loss Allowances HWY STATS	Gasoline Demand Hist/Bus	Petroleum consumpt. Preferred series RFF MC-9i	Nat Gas Prod RFF MC9a	Benzol Prod RFF Mc9b	Petroleum consumpt. Preferred series RFF MC-9
1930	375.7			926.0	53.0	2.7	870.3
1929	358.4			940.0	53.0	3.1	883.9
1928	311.7			860.0	43.0	2.8	814.2
1927	284.2			802.0	39.0	2.6	760.4
1926	251.2			781.0	32.0	2.1	746.9
1925	217.7			727.0	27.0	1.9	698.1
1924	185.9			688.0	22.0	2.2	663.8
1923	150.3			652.0	19.0	2.3	630.7
1922	119.4			531.0	12.0	1.7	517.3
1921	96.8			457.0	11.0	1.3	444.7
1920	82.1			456.0	9.2	1.8	445.0
1919	65.4			375.0	8.4	1.5	365.1
1918				359.0	6.7	1.3	351.0
1917				306.0	5.2		300.8
1916				260.0	2.5		257.5
1915				244.0	1.5		242.5
1914				229.0	1.0		228.0
1913				215.0	0.6		214.4
1912				185.0	0.3		184.7
1911				178.0	0.2		177.8
1910				173.0			173.0
1909				144.0			144.0
1908				141.0			141.0
1907				134.0			134.0
1906				94.8			94.8
1905				105.0			105.0
1904				92.2			92.2
1903				77.1			77.1
1902				63.5			63.5
1901				43.7			43.7
1900				40.1			40.1
1899				34.5			34.5
1898				31.9			31.9
1897				36.8			36.8
1896				39.8			39.8
1895				31.8			31.8
1894				27.7			27.7
1893				29.2			29.2
1892				32.8			32.8
1891				38.3			38.3
1890				29.3			29.3
1889				19.0			19.0
1888				14.0			14.0
1887				14.0			14.0
1886				14.0			14.0
1885				8.5			8.5
1884				11.2			11.2
1883				10.7			10.7

NOTES TO PETROLEUM WORKSHEET

TOTAL PETROLEUM DEMAND

Source:Demand dir. '82 Bus.Stat, '82-'61;'79 Bus.Stat,'60-'47; '69 Bus.Stat.,'47-39

Note:Gross crude input called Crude runs to stills) Used Hist.Stats. for 1970-1918 crude Ptrl. input; used Gutmanis' runs-to-stills for 1917-1880 crude petroleum

Note:used Hist.Stats. for output, exports, imports; 1920-70 Calculated demand as (output+imports-exports)

(a) =80% ofProduction (1880-1918), Highway Statistics (1919-1975), Business Statistics (1976-1983)

(b) Apparent consumption(85% Prod+Imp-Exp)thru 1938, then BusStat Demand

(c) Apparent consumption (Prod+Imp-Exp) thru 1938, then BusStat Demand

(d) Apparent consumption (Prod+Imp-Exp) thru 1917, then BusStat Demand

(e) Gutmanis "Runs to Stills"(1880-1922), HistStat "Refinery Output" (1923-38), Business Statistics "Crude Petroleum Production"(1939-83)

(f) RFF Prefferred Consumption (Petroleum Only) 1880-1957 then Business Statistics Demand

(g) RFF Table MC-9 column i minus cols b&c

(h) 1880-1918 from RFF Tables MC-7,8

APPENDIX XI: Coal Worksheet (units = 1,000,000 short tons)

	Anthracite			Bituminous Consumption						
	Production 11-2	Net Exports 11-2	Apparent Consumption (Prod-Exp) 11-2	TOTAL Hist/Bus RFF mc10g 11-1	by Electric Utilities 11-1	by Class I Railroads 11-1	in Coke Production 11-1	in Other Industry 11-1	Residential/ Commercial 11-1	Coke Production
1983	4.113	0.776	3.337	733.850	624.175	0.000	37.005			
1982	4.588	0.980	3.608	703.561	592.591	0.000	40.859	63.513	6.598	
1981	5.423	2.249	3.174	728.543	595.575	0.000	60.888	66.639	5.440	
1980	6.056	1.795	4.261	669.061	568.322	0.000	66.493	59.322	4.924	
1979	4.835	1.233	3.602	677.286	526.005	0.000	77.009	67.141	7.131	
1978	5.037	0.866	4.171	621.330	480.171	0.000	71.078	62.167	7.914	
1977	5.861	0.625	5.236	620.487	475.701	0.000	77.369	60.389	7.020	
1976	6.228	0.615	5.613	598.750	447.021	0.000	84.324	60.493	6.900	
1975	6.203	0.640	5.563	557.535	404.483	0.000	83.272	62.474	7.282	
1974	6.617	0.735	5.882	552.954	390.068	0.000	89.747	63.974	8.840	
1973	6.830	0.717	6.113	556.912	386.879	0.000	93.634	67.193	8.200	
1972	7.106	0.743	6.363	518.348	348.612	0.000	87.272	71.981	8.748	
1971	8.727	0.671	8.056	494.862	326.280	0.000	82.809	74.215	11.351	
1970	9.729	0.789	8.940	517.158	320.460	0.000	96.009	88.319	12.072	66.525
1969	10.473	0.627	9.846	507.275	308.461	0.000	92.901	90.934	14.666	64.709
1968	11.461	0.518	10.943	498.830	294.739	0.000	90.765	97.685	15.224	63.653
1967	12.256	0.595	11.661	480.416	271.784	0.000	92.272	98.794	17.099	64.580
1966	12.941	0.766	12.175	486.266	264.202	0.000	95.892	105.598	19.965	67.402
1965	14.866	0.851	14.015	459.164	242.729	0.000	94.779	101.953	19.048	66.854
1964	17.184	1.575	15.609	431.116	223.032	0.000	88.757	99.001	19.615	62.145
1963	18.267	3.353	14.914	409.225	209.038	0.000	77.633	98.336	23.548	54.278
1962	16.894	1.869	15.025	387.774	190.833	0.000	74.262	93.804	28.188	51.910
1961	17.446	1.435	16.011	374.405	179.629	0.000	73.881	92.390	27.735	51.711
1960	18.817	1.440	17.377	380.429	173.882	2.101	81.015	92.081	30.405	57.229
1959	20.649	1.788	18.861	366.256	165.788	2.600	79.181	88.580	29.138	55.864
1958	21.171	2.280	18.891	366.703	152.928	3.725	76.580	96.896	35.619	53.604
1957	25.338	4.332	21.006	413.668	157.398	8.401	108.020	102.773	35.712	75.951
1956	28.900	5.244	23.656	432.858	154.983	12.308	105.913	109.517	48.667	74.483
1955	26.205	3.152	23.053	423.412	140.550	15.473	107.377	105.493	53.020	75.302
1954	29.083	2.845	26.238	363.060	115.235	17.370	85.391	92.022	51.798	59.662
1953	30.949	2.693	28.256	426.798	112.283	27.735	112.874	112.091	59.976	78.837
1952	40.583	4.563	36.020	418.757	103.309	37.962	97.614	111.172	66.861	68.254
1951	42.670	5.929	36.741	468.904	101.898	54.005	113.448	122.955	74.378	79.331
1950	44.077	3.874	40.203	454.202	88.262	60.969	103.845	114.662	84.422	72.718
1949	42.702	4.943	37.759	445.538	80.610	68.123	91.236	115.124	88.389	63.637
1948	57.140	6.675	50.465	519.909	95.620	94.838	107.306	132.799	86.794	74.862
1947	57.190	8.510	48.680	545.891	86.009	109.296	104.800	146.042	96.657	73.446
1946	60.507	6.487	54.020	500.386	68.743	110.166	83.288	136.873	98.684	58.498
1945	54.934	3.691	51.243	559.567	71.603	125.120	95.349	145.006	119.297	67.308
1944	63.701	4.174	59.527	589.599	76.656	132.049	105.296	150.417	122.112	74.038
1943	60.644	3.973	56.671	593.797	74.036	130.283	102.460	163.855	120.121	71.676
1942	60.328	4.299	56.029	540.050	63.472	115.410	100.850	154.951	102.141	70.569
1941	56.368	3.305	53.063	492.115	59.888	97.384	93.138	143.999	94.402	65.187
1940	41.485	2.533	38.952	430.910	49.126	85.130	81.386	127.592	84.687	57.072
1939	51.487	2.292	49.195	376.098	42.304	79.072	63.514	119.674	68.770	44.327
1938	46.099	1.546	44.553	336.281	36.440	73.921	46.626	110.486	66.498	32.496
1937	51.856	1.518	50.338	430.777	41.045	88.080	74.502	147.386	76.331	52.375
1936	54.580	1.063	53.517	408.293	38.104	86.391	65.942	134.760	80.044	46.275
1935	52.159	1.038	51.121	356.326	30.986	77.109	50.515	114.639	80.444	35.141
1934	57.168	0.820	56.348	343.814	29.707	76.037	45.978	106.162	83.507	31.822
1933	49.541	0.579	48.962	317.685	27.088	72.548	40.089	98.266	77.396	27.589
1932	49.855	0.696	49.159	306.917	30.290	66.498	31.917	106.117	70.745	21.789
1931	59.646	1.140	58.506	371.869	38.735	81.725	48.613	120.361	80.240	33.484
1930	69.385	1.877	67.508	454.990	42.898	98.400	69.805	144.234	96.156	47.972
1929	73.828	2.919	70.909	519.555	44.937	113.894	86.787	161.790	107.860	59.884
								(a)	(b)	

APPENDIX XI: Coal Worksheet (units = 1,000,000 short tons)

	--------- Anthracite ---------			------------------ Bituminous Consumption ------------------						
	Production 11-2	Net Exports 11-2	Apparent Consumption (Prod-Exp) 11-2	TOTAL Hist/Bus RFF mc10g 11-1	by Electric Utilities 11-1	by Class I Railroads 11-1	in Coke Production 11-1	in Other Industry 11-1	Residential/ Commercial 11-1	Coke Production
1928	75.348	2.951	72.397	498.828	41.350	112.382	77.184	158.171	105.447	52.806
1927	80.096	3.207	76.889	499.801	41.888	115.883	74.448	157.810	105.207	51.092
1926	84.437	3.216	81.221	532.581	41.311	122.823	82.872	166.703	111.136	56.866
1925	61.817	2.796	59.021	499.193	40.222	117.714	74.533	157.115	104.743	51.267
1924	87.927	3.900	84.027	484.004	37.556	117.247	64.975	155.860	103.906	44.270
1923	93.339	4.790	88.549	518.993	38.966	131.492	84.360	155.449	103.633	56.978
1922	54.683	2.415	52.268	426.915	34.179	113.163	54.339	132.371	88.248	37.124
1921	90.473	4.668	85.805	391.849	31.585	107.910	37.188	124.028	82.685	25.288
1920	89.598	5.372	84.226	508.595	37.124	135.414	76.191	149.628	99.752	51.345
1919	88.092	4.894	83.198	481.658	35.100	119.692	65.587	151.833	101.222	44.181
1918	98.826	4.931	93.895	530.593	34.500	134.214	85.028	162.397	108.265	56.478
1917	99.612	5.994	93.618	529.409	33.500	133.421	83.753	162.616	108.410	55.607
1916	87.578	4.660	82.918	483.000						54.534
1915	88.995	3.964	85.031	426.000						41.581
1914	90.822	4.272	86.550	407.000						34.556
1913	91.525	4.652	86.873	462.000						46.300
1912	84.362	4.129	80.233	435.000						43.984
1911	90.464	3.977	86.487	395.000						35.551
1910	84.485	3.375	81.110	407.000						41.709
1909	81.070	3.180	77.890	371.000						39.315
1908	83.269	3.065	80.204	324.000						26.034
1907	85.604	3.011	82.593	387.000						40.780
1906	71.282	2.447	68.835	337.000						36.401
1905	77.660	2.460	75.200	309.000						32.231
1904	73.157	2.415	70.742	274.000						23.661
1903	74.607	2.053	72.554	281.000						25.274
1902	41.374	0.826	40.548	256.000						25.402
1901	67.472	2.233	65.239	222.000						21.796
1900	57.368	1.853	55.515	208.000						20.533
1899	60.418	1.913	58.505	191.000						19.669
1898	53.388	1.509	51.879	165.000						16.047
1897	52.612	1.428	51.184	146.000						13.289
1896	54.346	1.398	52.948	136.000						11.789
1895	57.999	1.489	56.510	134.000						13.334
1894	51.921	1.513	50.408	118.000						9.204
1893	53.968	1.433	52.535	128.000						9.478
1892	52.473	0.881	51.592	126.000						12.011
1891	50.665	0.923	49.742	117.000						10.353
1890	46.469	0.720	45.749	111.000						11.508
1889	45.547	0.731	44.816	95.800						10.258
1888	46.620	0.816	45.804	102.300						8.540
1887	42.088	0.765	41.323	88.700						7.612
1886	39.035	0.745	38.290	74.900						6.845
1885	38.336	0.653	37.683	71.900						5.107
1884	37.157	0.725	36.432	71.800						4.874
1883	38.457	0.624	37.833	65.100						5.465
1882	35.121	0.620	34.501	59.400						4.793
1881	31.920	0.517	31.403	52.400						4.114
1880	28.650	0.440	28.210	51.100						3.338
								(a)	(b)	

Source: Historical Statistics prior to 1939, Business Statistics (1939-1983)
Where indicated, RFF data used prior to 1917

(a) sum or difference of other categories when not given explicitly in source

(b) Allocated between industrial and residential in ratio of 60-40 (1917-1932) which is ratio maintained in first ten years for which separate data given