Contents

Introduction and Acknowledgments iv
Aluminum 1
Antimony 5
Arsenic 7
Beryllium 9
Bismuth 13
Cadmium 17
Calcium 21
Cesium 23
Chromium 25
Cobalt 31
Columbium (Niobium) 35
Copper 39
Gallium 43
Germanium 45
Gold 49
Hafnium 55
Indium 57
Iron and Steel 61
Iron and Steel Scrap 65
Iron Ore 69
Lead 73
Lithium 77
Magnesium 79
Manganese 83
Mercury 87
Molybdenum 89
Nickel 91
Platinum-Group Metals (Platinum, Palladium, Iridium, Osmium, Rhodium, and Ruthenium) 99
Rare-Earth Metals (Cerium, Dysprosium, Erbium, Europium, Gadolinium, Holmium, Lanthanum, Lutetium, Neodymium, Praseodymium, Promethium, Samarium, Scandium, Terbium, Thulium, Ytterbium, and Yttrium) 109
Rhenium 127
Rubidium 129
Selenium 131
Silicon 135
Silver 139
Tantalum 143
Tellurium 147
Thallium 151
Thorium 155
Tin 159
Titanium 161
Tungsten 165
Vanadium 169
Zinc 171
Zirconium 175
Appendix—Price Deflators, 1959-98 179

Introduction and Acknowledgments

The purpose of this publication is to make an extended price history for a wide range of metals available in a single document. Such information can be useful for the analysis of mineral commodity issues, as well as for other purposes. The chapter for each mineral commodity includes a graph of annual current and constant dollar prices for 1959 through 1998, where available; a list of significant events that affected prices; a brief discussion of the metal and its history; and one or more tables that list current dollar prices.

In some cases, the "metal prices" presented herein are for some alternative form of an element or, instead of a price, a value, such as the Customs value for an import as appraised by the U.S. Customs Service. Also included are prices for steel, steel scrap, and iron ore—steel because of its importance to the elements used to alloy with it and steel scrap and iron ore because of their use in steelmaking. A few minor metals, such as potassium, sodium, and strontium, for which the price histories were insufficient, were excluded.

The annual prices given may be averages for the year, yearend prices, or some other price as appropriate for a particular commodity. Certain trade journals have been the source of much of this price information—American Metal Market, Chemical Market Reporter, Engineering and Mining Journal, Industrial Minerals, Metal Bulletin, Mining Journal, Platt's Metals Week, Roskill Information Services Ltd. commodity reports, and Ryan's Notes. Some of these have issued annual price compilations or booklets. Price information also is available in such publications of the U.S. Geological Survey (USGS) and the former U.S. Bureau of Mines (USBM) as Minerals Yearbook, Mineral Industry Surveys, Mineral Commodity Summaries, and Mineral Facts and Problems. In addition to the prices themselves, these journals and publications contain information relevant to price that has been helpful in the preparation of this publication.

Prices in this report have been recast in 1992 constant dollars to show the effects of inflation as measured by the Bureau of Labor Statistics' Consumer Price Index for All Urban Consumers, a widely used measure of overall inflation in the United States. These prices are not tabulated, but a table of the deflators used is given as an appendix. Constant dollar prices can be used to show how prices have kept pace with inflation. If, over time, prices do not increase as fast or faster than the rate of inflation, then prices that producers receive will have less purchasing power. An example of different rates of growth can be seen in the current and 1992 dollar prices of copper. U.S. copper prices increased at an average annual rate of 4.4% between 1970 and 1997, but when recast in 1992 dollars, they declined at an average annual rate of -1.0%.

This publication is an update and revision of a 1993 publication by the USBM, Metal Prices in the United States Through 1991. Copies of the 1993 publication, which presented more background information and price history than the present publication, may be ordered from the National Technical Information Service (NTIS); the NTIS order number is PB97-120794INZ. Historical information on U.S. prices for a more-limited group of metals also can be found in other publications, such as Potter and Christy (1962) and Manthy (1978).

The individual chapters in this publication were prepared by mineral commodity specialists in the USGS and edited by Janet Sachs. Micheal George prepared the tables and graphs. George Swisko provided guidance on price indices. Layout was done by Georgetta Russell, and the cover was designed by Sherry Musick.

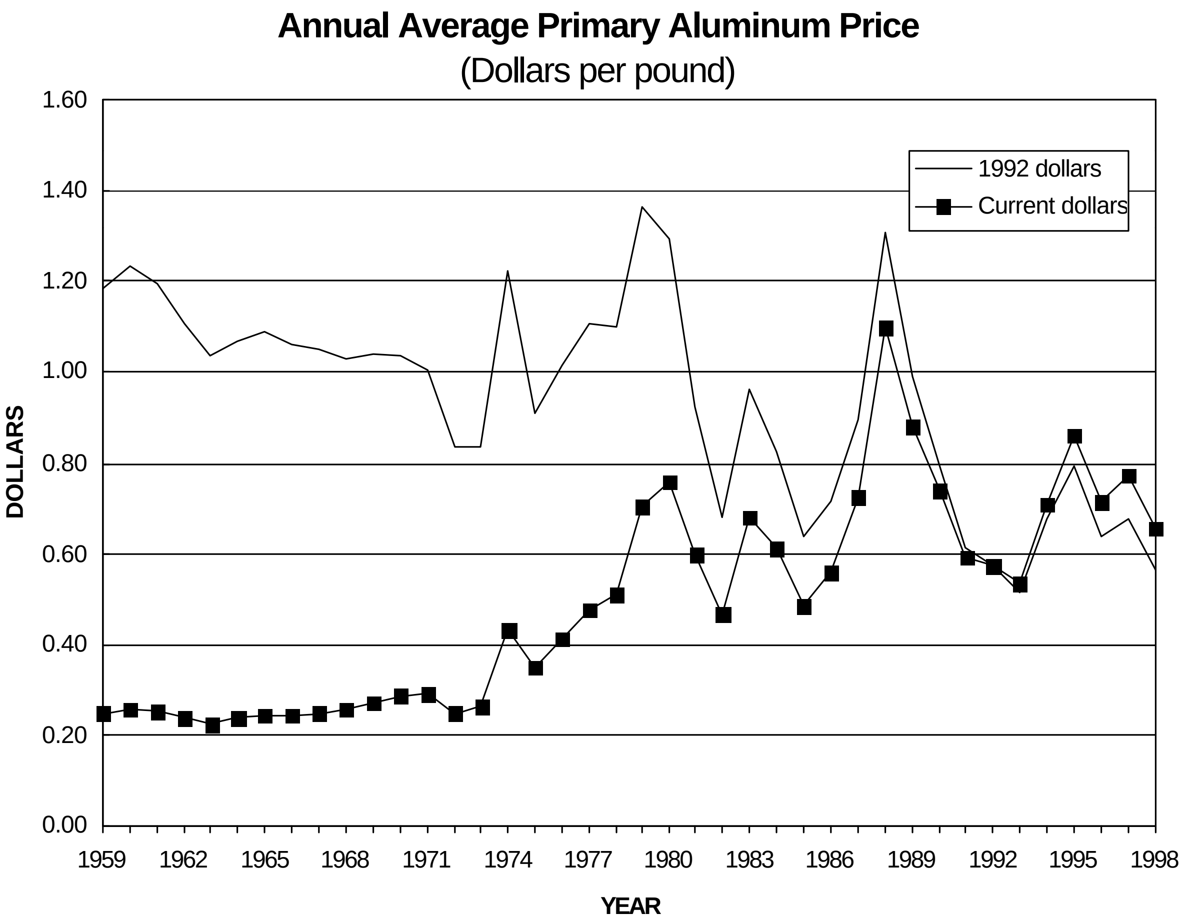
References Cited

Manthy, R.S., 1978, Natural resource commodities—A century of statistics—Prices, output, consumption, foreign trade, and employment in the United States, 1870-1973: Baltimore, MD, Johns Hopkins University Press, 240 p.

Potter, Neal, and Christy, F.T., Jr., 1962, Trends in natural resource commodities—Statistics of prices, output, consumption, foreign trade, and employment in the United States, 1870-1957: Baltimore, MD, The Johns Hopkins Press, 568 p.

Aluminum

by Patricia A. Plunkert



Significant events affecting aluminum prices since 1958

1971-74	Price controls
1973-75	Organization of Petroleum Exporting Countries (OPEC) oil embargo and sharp recession
1986-88	Worldwide supply shortages
1991	Dissolution of the Soviet Union

Aluminum metal was first isolated by Hans Christian Oersted in 1825. As late as the early 1880's, it was considered to be a semiprecious metal and was sold in troy-ounce quantities; the retail price of aluminum metal was reported to be higher than that of silver. A commercially viable large-scale production method had yet to be developed. Domestic production levels during this period were in the 1,000- to 3,000-troy-ounce range, and many uses were considered to be experimental (Mining Engineering, 1987).

In 1886, formal patent applications were filed for the electrolytic reduction process for aluminum. This process, which came to be known as the Hall-Heroult process, led to the mass commercial production of aluminum metal. As the process was developed and refined, production levels increased rapidly. By 1895, domestic production levels had reached 1 million pounds. As production levels continued to increase, domestic producers kept the price of aluminum low to encourage its use by consumers. In the early 1900's, they held aluminum metal prices at a low steady level to compete against copper in the electrical industry (U.S. Department of Commerce, 1956, p. II.1-II.4).

With the outbreak of World War I in Europe in 1914, shortages of aluminum metal began to appear, and prices began to rise dramatically because of the increased demand for aluminum in war materials, which included airplanes and munitions. In March 1918, the President imposed price controls on aluminum metal, and the use of aluminum for military equipment and essential civilian needs was placed under Government regulation (Hill, 1921).

The 1920's saw the demand for aluminum metal expanding, especially in the growing domestic automobile industry. The advent of the Great Depression, however, brought about a general decrease in demand for aluminum in all sectors of the economy, especially in the automobile and aircraft industries.

In 1939, the production and consumption of aluminum shattered all previous records, enhanced by the preparations for national defense and the expanding conflicts in Europe and Asia. The aviation industry alone consumed twice the quantity of aluminum as in 1937, the previous peak year. In 1940, producers lowered the price for aluminum to give the metal a better price relation to competing materials. During the war years, aluminum prices were placed under formal control and held at $0.15 per pound (U.S. Department of Commerce, 1956, p. IV.6).

After the war, the aluminum industry benefited from its price advantage over copper and other nonferrous metals. Aluminum, which was cheaper and more readily available than some other metals, was used in new applications and made substantial inroads in the construction and transportation industries.

Rearmament programs during the Korean conflict increased the demand for aluminum. In 1951, the allocation of aluminum supplies and the price of aluminum metal were again placed under Government control (Blue, 1954, p. 137-138). At the end of the conflict, domestic aluminum producers began an aggressive program to develop civilian uses for aluminum metal.

During the 1960's, aluminum prices remained relatively stable in the low- to mid-$0.20-per-pound range. Capacity increases were able to keep pace with the continuous growth in demand during this period.

In the early 1970's, the price for aluminum, as well as for other metals, was controlled by the Cost of Living Council in an attempt to check inflation. As these controls were gradually removed during 1974, prices rose to reflect the increased cost of energy brought about by the surge in world oil prices.

In the late 1970's and throughout the 1980's, aluminum prices, for the most part, reflected the law of supply and demand. During the early 1980's, the aluminum industry suffered from a period of oversupply, high inventories, excess capacity, and weak demand, causing aluminum prices to tumble. By 1986, however, excess capacity had been permanently closed, inventories were low, and the worldwide demand for aluminum made a dramatic surge upward. This extremely tight supply-demand situation, which continued throughout 1987 and 1988, brought about a dramatic increase in aluminum prices.

During the 1990's, however, the speculative effect of the futures market began to exert its presence on aluminum prices. Prices were not only reacting to the laws of supply and demand, but also to the perceived direction of the market as reflected on the futures exchanges.

In the early 1990's, the major influence on aluminum prices was the dissolution of the Soviet Union. To generate hard currency, large quantities of Russian aluminum ingot entered the world market. Unfortunately, the aluminum market had just entered an economic downturn and was unable to absorb the Russian material. This period of oversupply, decreasing demand, and increasing inventories depressed world aluminum prices.

By the mid-1990's, production cutbacks, increased demand, declining inventories, and the perceived improvement in the world market led to a dramatic rebound in aluminum prices. Prices began to cycle downward again during the late 1990's as the economic crisis in the Asian market exerted pressure on the prices of several commodities, including aluminum. Once again, the aluminum market was entering a period of oversupply. The perceived downward influences of the Asian crisis, however, may have hastened the decline in prices before the actual oversupply condition occurred in the marketplace.

References Cited

Blue, Delwin, 1954, Aluminum, *in* Minerals Yearbook 1951, v. I: U.S. Bureau of Mines, p. 128-150.

Hill, J.M., 1921, Bauxite and aluminum, *in* Metals, pt. I *of* Mineral resources of the United States 1918: U.S. Geological Survey, p. 513-526.

Mining Engineering, 1987, Aluminum—The first 100 years and a look to the future: Mining Engineering, v. 39, no. 3, March, p. 178-180.

U.S. Department of Commerce, 1956, Materials Survey—Aluminum: Compiled by the U.S. Department of Commerce for the Office of Defense Mobilization, 320 p.

Annual Average Primary Aluminum Price
(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1850	17.00	1888	NA	1926	0.270	1964	0.237
1851	NA	1889	NA	1927	0.254	1965	0.245
1852	NA	1890	NA	1928	0.243	1966	0.245
1853	NA	1891	NA	1929	0.243	1967	0.250
1854	NA	1892	NA	1930	0.238	1968	0.256
1855	NA	1893	NA	1931	0.233	1969	0.272
1856	NA	1894	NA	1932	0.233	1970	0.287
1857	NA	1895	0.587	1933	0.233	1971	0.290
1858	NA	1896	0.507	1934	0.234	1972	0.250
1859	NA	1897	0.390	1935	0.200	1973	0.264
1860	NA	1898	0.306	1936	0.205	1974	0.431
1861	NA	1899	0.327	1937	0.199	1975	0.348
1862	NA	1900	0.327	1938	0.200	1976	0.412
1863	NA	1901	0.330	1939	0.200	1977	0.478
1864	NA	1902	0.330	1940	0.187	1978	0.510
1865	NA	1903	0.330	1941	0.165	1979	0.707
1866	NA	1904	0.350	1942	0.150	1980	0.761
1867	NA	1905	0.350	1943	0.150	1981	0.598
1868	NA	1906	0.358	1944	0.150	1982	0.468
1869	NA	1907	0.450	1945	0.150	1983	0.683
1870	NA	1908	0.287	1946	0.150	1984	0.611
1871	NA	1909	0.220	1947	0.150	1985	0.488
1872	9.00	1910	0.223	1948	0.157	1986	0.559
1873	NA	1911	0.201	1949	0.170	1987	0.723
1874	NA	1912	0.220	1950	0.177	1988	1.101
1875	NA	1913	0.236	1951	0.190	1989	0.878
1876	NA	1914	0.186	1952	0.194	1990	0.740
1877	NA	1915	0.340	1953	0.209	1991	0.595
1878	NA	1916	0.607	1954	0.218	1992	0.575
1879	NA	1917	0.516	1955	0.237	1993	0.533
1880	NA	1918	0.335	1956	0.240	1994	0.712
1881	NA	1919	0.321	1957	0.254	1995	0.859
1882	NA	1920	0.327	1958	0.248	1996	0.713
1883	NA	1921	0.221	1959	0.247	1997	0.771
1884	NA	1922	0.187	1960	0.260	1998	0.655
1885	NA	1923	0.254	1961	0.255		
1886	NA	1924	0.270	1962	0.239		
1887	8.00	1925	0.272	1963	0.226		

NA Not available

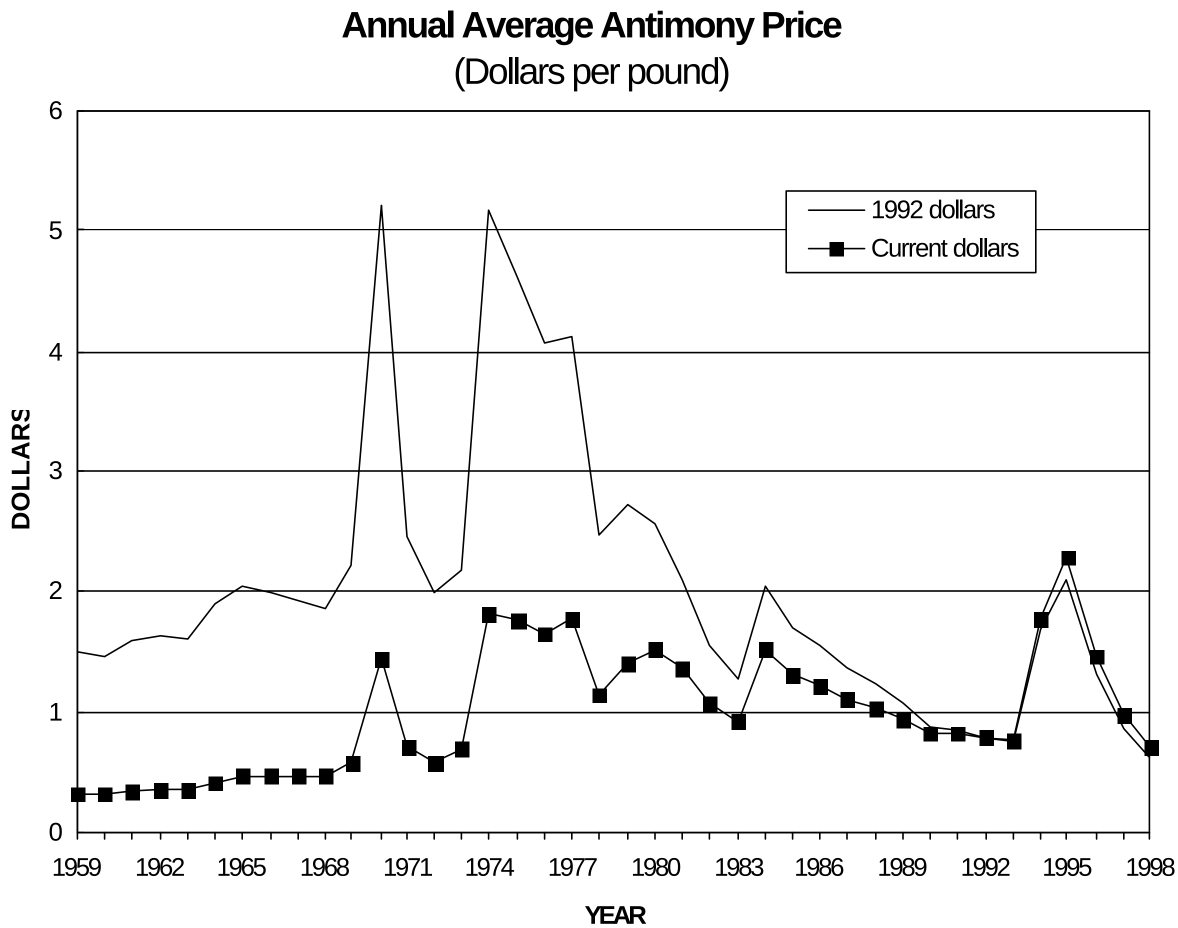
[1] To convert to dollars per metric ton, multiply by 2,204.62.

Note:
1850-94, *in* U.S. Geological Survey Minerals Yearbooks and predecessor volumes.
1895-98, 98%-pure aluminum, *in* American Bureau of Metal Statistics.
1899-1900, 99%-pure aluminum ingot, *in* American Bureau of Metal Statistics.
1901-04, 99.75%-pure aluminum ingots in 2,000-pound lots, *in* American Bureau of Metal Statistics.
1905, 99.75%-pure aluminum ingots in 2,000-pound lots, *in* American Metal Market/Metal Statistics, 1955.
1906-19, 99%-pure No. 1 aluminum ingots, *in* American Metal Market/Metal Statistics, 1955.
1920-21, 98%- to 99%-pure aluminum, *in* American Metal Market/Metal Statistics, 1955.
1922-28, 98%-pure aluminum metal, *in* American Metal Market/Metal Statistics, 1955.
1929-35, 99%-pure aluminum metal, *in* American Metal Market/Metal Statistics, 1955.
1936-54, 99%-plus pure aluminum virgin ingot, *in* American Metal Market/ Metal Statistics, 1955.
1955-56, 99%-pure aluminum virgin ingot, *in* Engineering & Mining Journal.
1957-71, 99.5%-pure unalloyed aluminum ingot, *in* Engineering & Mining Journal.
1972, 99.5%-pure unalloyed aluminum ingot, *in* Metals Week.
1973-82, U.S. market spot price, *in* Metals Week.
1983-92, 99.7%-pure aluminum ingot, U.S. market spot price, *in* Metals Week.
1993-98, 99.7%-pure aluminum ingot, U.S. market spot price, *in* Platt's Metals Week.

(This page intentionally left blank.)

Antimony

by James F. Carlin, Jr.



Significant events affecting antimony prices since 1958

1970	High demand and short supply worldwide, resulting in a price spike
1974	High demand and short supply from China, resulting in a price spike
1994-95	Severe short supply from China, resulting in a price spike

Antimony metal accounts for only a small fraction of the antimony consumed in the United States. It is used for a variety of alloys, including those in lead-acid storage batteries and in special solders for joining pipes that carry potable water. Domestically, most antimony is converted to antimony trioxide, which is primarily consumed in the flame-retardant industry, finding application in such uses as children's clothing and aircraft seats. The major producers, in order of importance, are China, Bolivia, Russia, and South Africa. During the past 40 years, antimony has been subject to a few periods of extreme price swings. Generally, these have been the result of spikes or declines in the American and/or foreign demand for antimony or changes in the pattern of the world production—where supply disruptions in any of the major producing countries can cause a marked price change. In 1970, a combination of high worldwide demand and short supply from a few countries caused a considerable price spike in the early part of that year; the price quickly subsided by yearend. In 1974, sharply increased demand, especially for antimony trioxide, and supply disruptions from China combined to produce the highest antimony price recorded up to that time. During the next 20 years, prices generally subsided. By 1994, China had clearly emerged as the predominant world antimony producer. That year and the following year, severe flooding in the antimony mining regions of China produced major supply dislocations that caused the price to triple within 2 years (Roskill Information Services Ltd., 1997, p. 172-179). After 1995, the price fell steadily to a level, in 1998, that had not been seen in 25 years.

Reference Cited

Roskill Information Services Ltd., 1997, The economics of antimony: London, Roskill Information Services Ltd., 184 p.

Annual Average Antimony Price
(Dollars per pound[1])

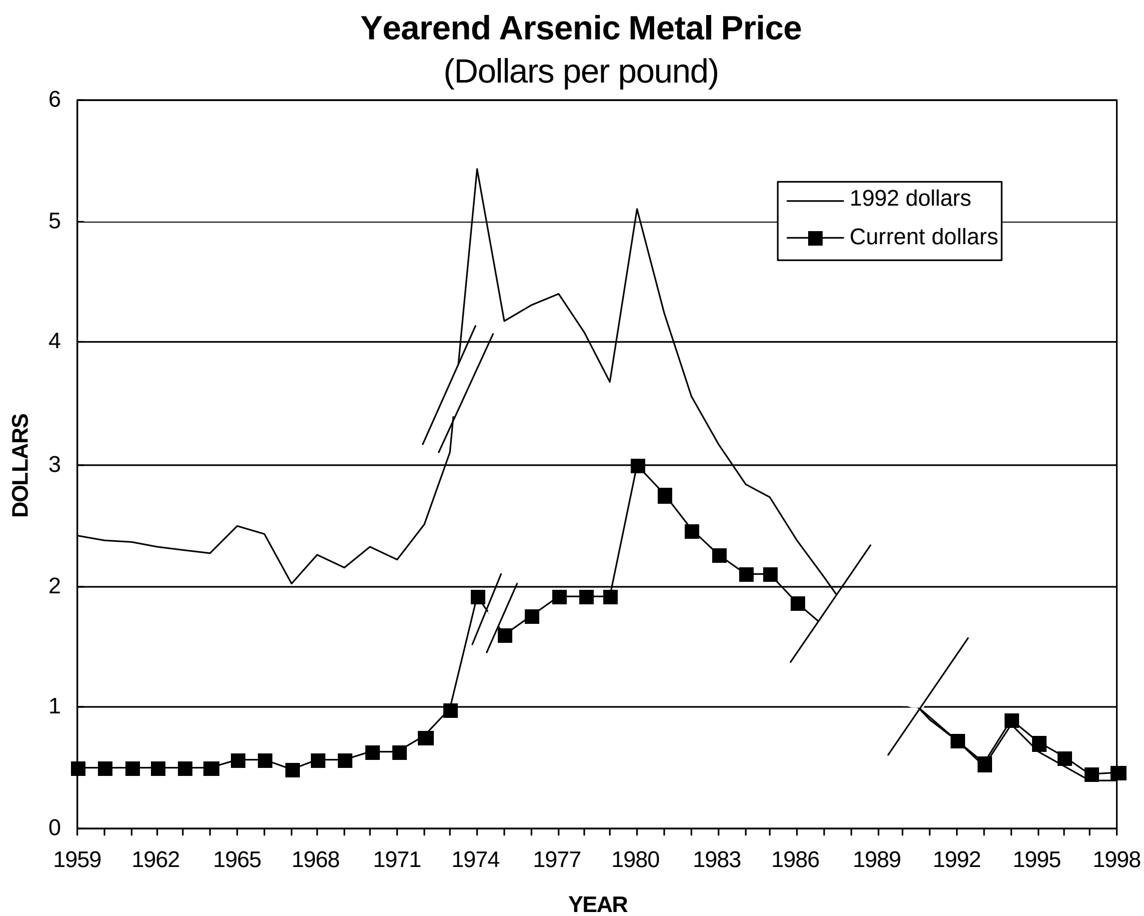
Year	Price	Year	Price	Year	Price	Year	Price
1900	0.095	1925	0.175	1950	0.290	1975	1.770
1901	0.082	1926	0.159	1951	0.440	1976	1.650
1902	0.061	1927	0.123	1952	0.440	1977	1.780
1903	0.060	1928	0.103	1953	0.360	1978	1.150
1904	0.064	1929	0.089	1954	0.310	1979	1.410
1905	0.102	1930	0.077	1955	0.320	1980	1.510
1906	0.217	1931	0.067	1956	0.360	1981	1.360
1907	0.148	1932	0.056	1957	0.350	1982	1.070
1908	0.080	1933	0.065	1958	0.320	1983	0.910
1909	0.075	1934	0.089	1959	0.310	1984	1.510
1910	0.074	1935	0.136	1960	0.310	1985	1.310
1911	0.075	1936	0.122	1961	0.340	1986	1.220
1912	0.078	1937	0.154	1962	0.350	1987	1.110
1913	0.075	1938	0.124	1963	0.350	1988	1.040
1914	0.088	1939	0.124	1964	0.420	1989	0.940
1915	0.303	1940	0.140	1965	0.460	1990	0.820
1916	0.254	1941	0.140	1966	0.460	1991	0.820
1917	0.207	1942	0.156	1967	0.460	1992	0.790
1918	0.126	1943	0.159	1968	0.460	1993	0.770
1919	0.082	1944	0.158	1969	0.580	1994	1.780
1920	0.085	1945	0.160	1970	1.440	1995	2.280
1921	0.050	1946	0.170	1971	0.710	1996	1.470
1922	0.054	1947	0.340	1972	0.590	1997	0.980
1923	0.078	1948	0.370	1973	0.690	1998	0.718
1924	0.108	1949	0.390	1974	1.820		

[1] To convert to dollars per metric ton, multiply by 2,204.62.

Note:
1900-36, New York dealer price for 99.30%- to 99.50%-pure antimony, *in* Engineering and Mining Journal.
1937-66, New York dealer price for 99.30%- to 99.50%-pure antimony, *in* E&MJ Metal and Mineral Markets.
1967-81, New York dealer price for 99.30%- to 99.50%-pure antimony, *in* Metals Week.
1982-93, New York dealer price for 99.50%- to 99.60%-pure antimony, *in* Metals Week [through June 14, 1993].
1993-98, New York dealer price for 99.50%- to 99.60%-pure antimony, *in* Platt's Metals Week.

Arsenic

by Robert G. Reese, Jr.



Significant events affecting arsenic prices since 1958

1972-74	Consumption in lead-acid batteries growing; domestic production resumes in 1974
Mid-1970's	Hearings on effects of arsenic on health and environment
1980	Contraction in production capacity as plants that do not meet health and environmental standards are closed
1986	Domestic production ceases

A widely distributed element, arsenic is often found associated with various nonferrous metal ores. Although not a producer at present, historically, the United States has produced arsenic. The first domestic production, which was a byproduct of the smelting of gold and silver ores, came near the beginning of the 20th century (Greenspoon, 1976, p. 99).

Most of the arsenic used domestically is consumed as the trioxide, mainly in the manufacture of preservatives for pressure-treated wood but also in the manufacture of herbicides. The amount of arsenic consumed as metal domestically is very small, accounting for probably less than 3% of total arsenic demand. The major end uses for arsenic metal are as minor additives in nonferrous metal alloys, principally lead alloys used in lead-acid storage batteries and certain copper alloys.

During the early 1970's, demand for arsenic metal was growing, mainly in response to the increased use of the metal in the grids of lead-acid batteries. In the mid-1970's, the price stabilized.

During this time, however, the United States and other countries began hearings on the health and environmental impacts of arsenic exposure. During the late 1970's, various domestic and foreign regulations related to arsenic exposure and emissions were adopted. The arsenic metal price peaked in 1980 as world producers raised their prices partly to compensate for the cost of modernizing their plants and partly in response to the elimination of some capacity by producers unable or unwilling to modernize their plants.

After 1980, induced by an ample supply and a static or possibly declining demand, the arsenic metal price began a long decline. Domestically produced metal was unavailable after 1986, and China became the sole world source of metal.

Reference Cited

Greenspoon, G.N., 1976, Arsenic, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 667, p. 99-106.

Yearend Arsenic Metal Price[1]
(Dollars per pound[2])

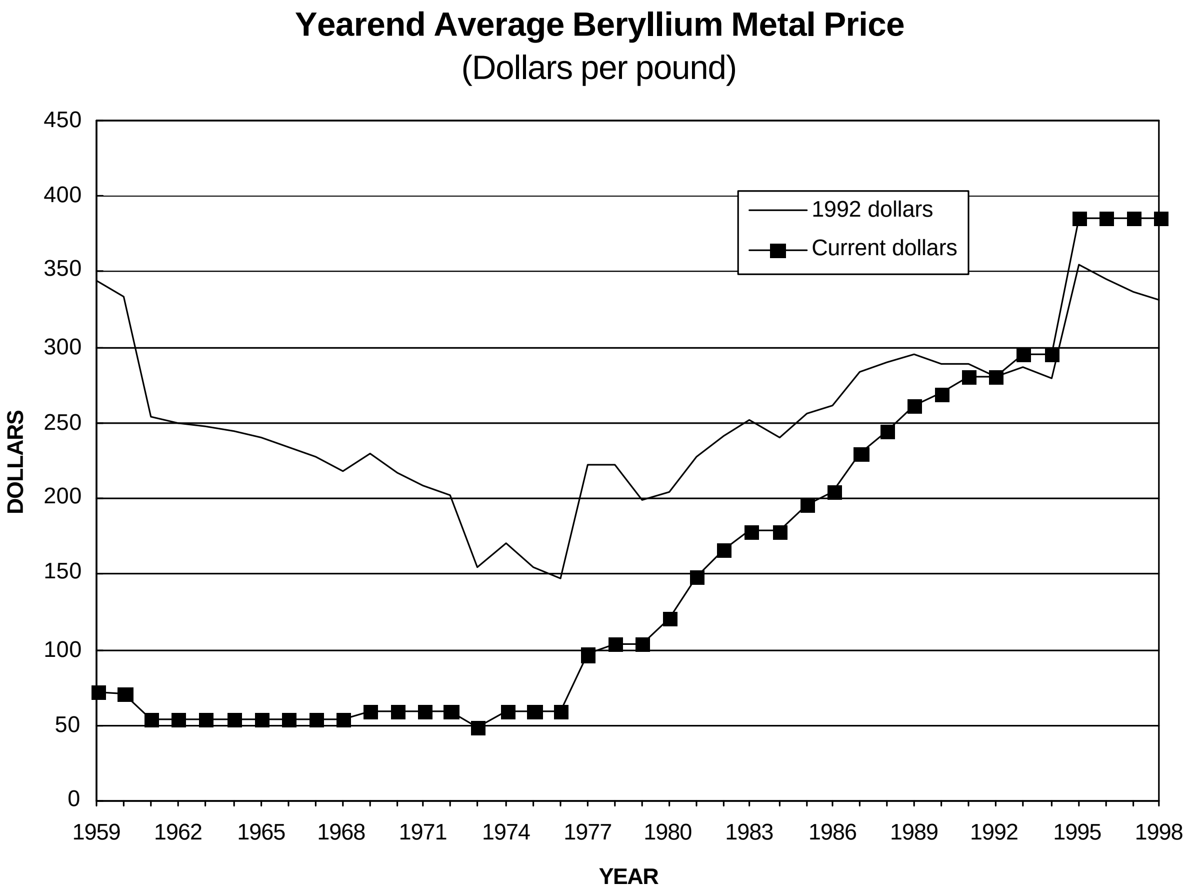
Year	Price	Year	Price	Year	Price	Year	Price
1959	0.50	1969	0.56	1979	1.90	1989	NA
1960	0.50	1970	0.64	1980	3.00	1990	NA
1961	0.50	1971	0.64	1981	2.75	1991	NA
1962	0.50	1972	0.75	1982	2.45	1992	0.73
1963	0.50	1973	0.98	1983	2.25	1993	0.53
1964	0.50	1974	1.91	1984	2.10	1994	0.90
1965	0.56	1975	1.60	1985	2.10	1995	0.70
1966	0.56	1976	1.75	1986	1.85	1996	0.58
1967	0.48	1977	1.90	1987	NA	1997	0.45
1968	0.56	1978	1.90	1988	NA	1998	0.46

NA Not available.
[1] Prices are rounded to the nearest whole cent. Prices are shown as midpoints in a range where appropriate.
[2] To convert to dollars per metric ton, multiply by 2,204.62.

Note:
1959-74, London prices for 99.5%-pure metal, *in* Metal Bulletin.
1975-86, U.S. producer prices for 99%- to 99.5%-pure metal, *in* Metals Week.
1992-98, London prices for minimum 99%-pure metal, *in* Metal Bulletin.

Beryllium

by Larry D. Cunningham



Significant events affecting beryllium prices since 1958

1969	Bertrandite mine established in the United States providing a significant raw materials source
1977	Effects of inflation rates, increased energy costs, and additional costs associated with complying with air emission standards results in increased prices
1979	Beryllium metal price set by one producer
1988	Purchase of beryllium metal for the National Defense Stockpile (NDS)
1990	Conversion of NDS beryl ore to beryllium metal for the NDS
1991	Recession, dissolution of the Soviet Union

Beryllium is one of the lightest of all metals and has one of the highest melting points of any light metal. Beryllium has physical and chemical properties, such as its stiffness, high resistance to corrosion from acids, and high thermal conductivity, that make it useful for various applications in its alloy, oxide, and metallic forms. Beryllium metal is used principally in aerospace and defense applications because of its stiffness, light weight, and dimensional stability over a wide temperature range. Beryllium-copper alloys are used in a wide variety of applications because of their electrical and thermal conductivity, high strength and hardness, good corrosion and fatigue resistance, and nonmagnetic properties. Beryllium oxide is an excellent heat conductor, with high strength and hardness, and acts as an electrical insulator in some applications. The United States, one of only three countries that process beryllium ores and concentrates into beryllium products, supplies most of the rest of the world with these products (Cunningham, 1997). Because of its use in aerospace and defense applications, beryllium is classified as "critical and strategic," and over the years, various beryllium materials have been purchased for the NDS. Steel, titanium, phosphor bronze, and aluminum nitride can be substituted for beryllium in some applications but usually at a performance penalty. The quoted price for beryllium metal during most of the 1980's and 1990's, as presented in the table and graph, may not reflect true transaction prices for the material. The quoted prices reflect the more high-end/high-purity form of the material.

In 1956, the Atomic Energy Commission awarded 5-year contracts to two domestic companies for each to produce about 45 metric tons (t) of beryllium annually (Eilertsen, 1958). Beryllium metal was also considered for aircraft structural components and components in inertial guidance systems for advanced missiles. These new applications increased beryllium metal demand, which led to improvements in beryllium processing and a reduction in price.

Prior to 1970, the United States was nearly 100% import dependent for its beryl ore needs. In 1969, however, a bertrandite mine opened in Utah that provided a large secure source of domestic raw material supply (Petkof, 1985). During most of the 1960's, the price for beryllium metal remained stable.

By 1977 and continuing through the 1990's, the effects of inflation rates and rising operating costs were reflected in increased beryllium prices. Energy requirements for producing beryllium metal are high. Processing requires the use of induction furnaces that consume large quantities of energy. Also, because of the toxic nature of beryllium, the industry must maintain careful control over the quantity of beryllium dust and fumes in the workplace. Under the Clean Air Act, the U.S. Environmental Protection Agency issues standards for certain hazardous air pollutants, including beryllium, and the Occupational Safety and Health Administration issues standards for airborne beryllium particles. To comply with these standards, plants are required to install and maintain pollution control equipment. Beryllium dust and fumes have been recognized as the cause of beryllosis, a serious chronic lung disease. Although the exact cause of the disease is uncertain, the problem appears to be controlled when established preventative measures are exercised. In beryllium-processing plants, harmful effects are prevented by maintaining clean workplaces; requiring the use of safety equipment, such as personal respirators; collection of dust, fumes, and mists at the source of deposition in dust collectors; medical programs; and other procedures to provide safe working conditions (Rossman, Preuss, and Powers, 1991; Kramer, 1994). This control of potential health hazards adds to the cost of beryllium metal and other beryllium products. The additional costs are ultimately passed on to the consumer in the form of increased prices.

In 1979, one of two domestic beryllium producers discontinued beryllium metal production, leaving the price of the metal to be set by one company (Petkof, 1980). In 1988, the U.S. Government purchased about 27 t of "vacuum hot-pressed beryllium billets" worth an estimated $19 million; the metal was delivered to the NDS by yearend 1989 (Kramer, 1990). The average unit value for the NDS metal was about $317 per pound. The quoted price for beryllium metal powder at yearend 1988 and yearend 1989 was $244 per pound and $261 per pound, respectively. In 1990, the Defense Logistics Agency awarded a contract to convert some of the beryl ore contained in the NDS to vacuum hot-pressed beryllium billets. The contract was extended through 1992 for a combined total of 73 t of beryllium metal, valued at about $46 million, recovered from about 2,940 t of NDS beryl ore (Kramer, 1993, 1994). The overall unit value of the NDS metal, about $287 per pound, was comparable to the price being quoted for beryllium metal powder from yearend 1990 to yearend 1994, which ranged from $269 per pound to $295 per pound. Deliveries of the metal to the NDS were completed in the second quarter of 1994.

The beryllium metal purchase and beryl ore conversion came at a time of declining beryllium metal consumption, caused by reduced spending for strategic defense programs. The jump in price in 1995, shown in the graph, reflects a change in the nature of the price quotation, not any single causal event. Beryllium metal currently averages about 10% of annual U.S. beryllium demand compared with about 20% in the early 1990's. With applications primarily in the aerospace and defense sectors, the dissolution of the U.S.S.R. in 1991 contributed most to the decline in beryllium metal demand as defense strategic plans changed. The sole U.S. beryllium metal producer, however, continues to develop purer metal with improved physical properties for its customers.

The major end use for beryllium—in beryllium-copper alloys for springs, connectors, and switches for use in such applications as automobiles, aerospace, and computers—averages about 75% of total annual U.S. consumption of beryllium on a beryllium metal equivalent basis. For comparison purposes with metal, the quoted price for beryllium-copper master alloy (BCMA) has remained unchanged since August 1987 at $160 per pound of contained beryllium. In 1998, the U.S. Department of Defense (DOD) initiated the sale of BCMA from the NDS. From May through November, the DOD sold about 1,190 t of BCMA valued at about $6.71 million (Defense National Stockpile Center, 1998a, b, c). The overall unit price for the BCMA sales was about $2.55 per pound.

References Cited

Cunningham, L.D., 1998, Beryllium—1997 annual review: U.S. Geological Survey Mineral Industry Surveys, July, 7 p.
Eilertsen, D.E., 1958, Beryllium, *in* Minerals Yearbook 1956, v. I: U.S. Bureau of Mines, p. 253-258.

Kramer, D.A., 1990, Beryllium, *in* Minerals Yearbook 1988, v. I: U.S. Bureau of Mines, p. 165-175.
———1993, Beryllium in 1992—Annual review: U.S. Bureau of Mines Mineral Industry Surveys, April, 7 p.
———1994, Beryllium in 1993—Annual review: U.S. Bureau of Mines Mineral Industry Surveys, April, 7 p.
———1994, Beryllium, *in* Minerals Yearbook 1994, v. I: U.S. Bureau of Mines, p. 105-110.
Defense National Stockpile Center, 1998a, Stockpile accepts beryllium copper master alloy offer: Fort Belvoir, VA, Defense National Stockpile Center news release, May 11, 1 p.
———1998b, Stockpile accepts beryllium copper master alloy offer: Fort Belvoir, VA, Defense National Stockpile Center news release, September 18, 1 p.
———1998c, Stockpile accepts beryllium copper master alloy offer: Fort Belvoir, VA, Defense National Stockpile Center news release, November 24, 1 p.
Petkof, Benjamin, 1980, Beryllium, *in* Minerals Yearbook 1978-79, v. I: U.S. Bureau of Mines, p. 111-114.
———1985, Beryllium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 75-82.
Rossman, M.D. , MD, Preuss, O.P., MD, and Powers, M.B., 1991, Beryllium—Biomedical and environmental aspects: Baltimore, MD, Williams & Wilkins, 319 p.

Yearend Average Beryllium Metal Price
(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1947	95.00	1960	70.00	1973	49.00	1986	204.00
1948	95.00	1961	54.00	1974	59.75	1987	229.00
1949	95.00	1962	54.00	1975	59.50	1988	244.00
1950	95.00	1963	54.00	1976	59.50	1989	261.00
1951	95.00	1964	54.00	1977	96.00	1990	269.00
1952	95.00	1965	54.00	1978	103.00	1991	280.00
1953	71.50	1966	54.00	1979	103.00	1992	280.00
1954	71.50	1967	54.00	1980	120.00	1993	295.00
1955	71.50	1968	54.00	1981	148.00	1994	295.00
1956	71.50	1969	60.00	1982	166.00	1995	385.00
1957	71.50	1970	60.00	1983	178.00	1996	385.00
1958	71.50	1971	60.00	1984	178.00	1997	385.00
1959	71.50	1972	60.00	1985	196.00	1998	385.00

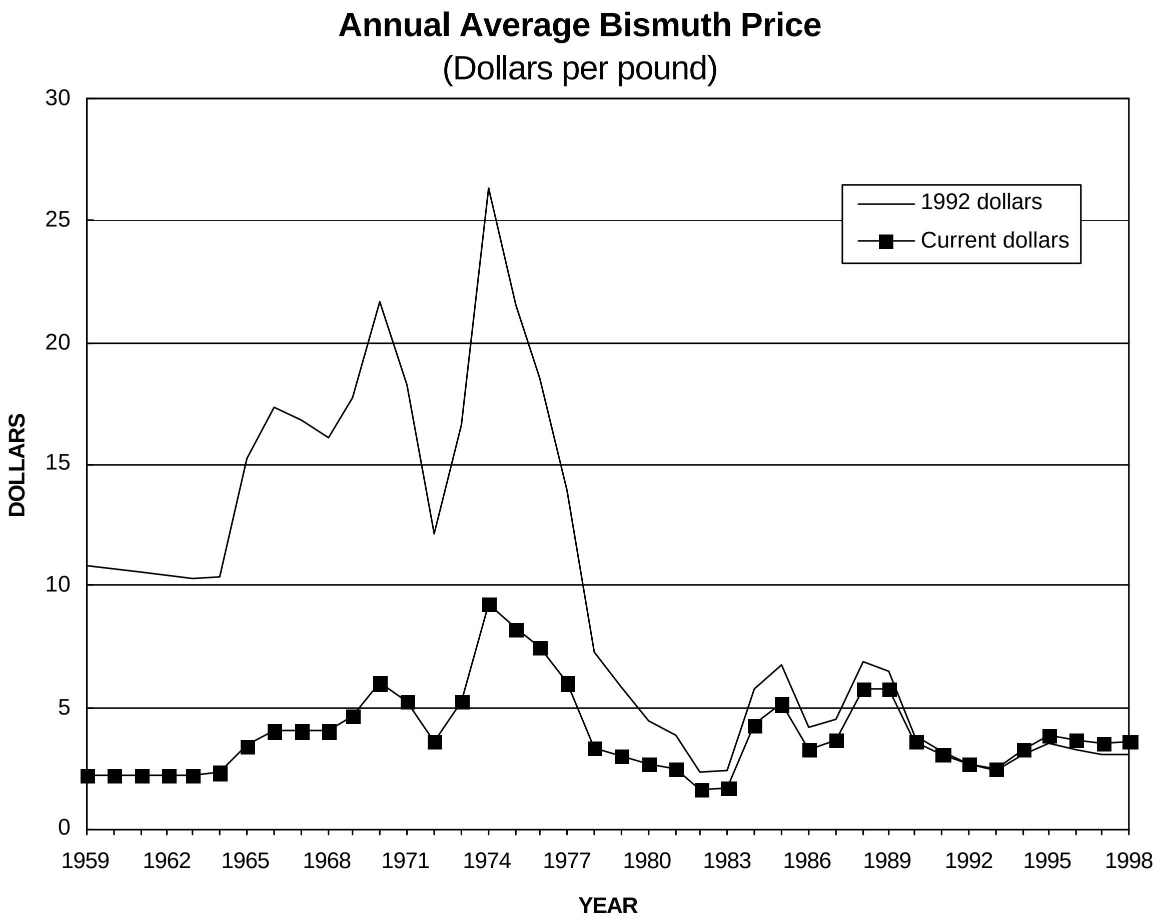
[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:
1947-52, beryllium, technical grade, *in* E&MJ Metal and Mineral Markets.
1953-59, beryllium, lumps and beads, 97% beryllium, *in* American Metal Market (AMM).
1960-68, beryllium, powder or powder blend, 97% beryllium, *in* AMM.
1969-80, beryllium, powder or powder blend, *in* U.S. Bureau of Mines, Minerals Yearbook, origin and/or beryllium content unknown.
1981-85, beryllium, powder blend, 97% beryllium, *in* AMM.
1986-89, beryllium, powder blend, 98.5% beryllium, *provided by* Brush Wellman, Inc.
1990-94, beryllium, powder blend, 98.5% beryllium, *in* AMM.
1995-98, beryllium, powder, 99% beryllium, *in* AMM.

(This page intentionally left blank.)

Bismuth

by Robert D. Brown, Jr.



Significant events affecting bismuth prices since 1958

1959-64	Prices set by producers
1970-74	Major increase in demand for bismuth as a metallurgical additive to aluminum, iron, and steel caused price to reach an all-time high
1975-81	World production grew faster than consumption
1980	Bolivia ceased production, ASARCO Incorporated suspended producer price
1980-82	Economic recessions
1984	Bismuth consumption increased, especially in the United States and Japan
1988	Miners’ strikes cut off all shipments from Peru for several months
1989-90	U.S. consumption decreased, especially for metallurgical additives and chemicals; this, combined with increased imports, large world stocks, impending releases from Government stockpiles, and dealer reaction, caused the price to drop, in spite of bismuth's increasing potential for replacing lead in environmentally sensitive applications
1990	U.S. Department of Defense (DOD), having lowered the goal for bismuth in the National Defense Stockpile (NDS) from 990 to 480 metric tons, began selling the excess bismuth
1992	DOD announced plans to sell all bismuth remaining in the NDS within a 10-year period
1996	Amendments to 1986 Safe Drinking Water Act; U.S. Fish and Wildlife Service gave final approval to Bi97%-Sn shot for waterfowl hunting; Asarco announced impending closure of the Omaha, NE, plant (the sole producer of primary bismuth in the United States)
1997	Omaha plant closed in June, the NDS exhausted its supply of bismuth in November
1998-99	Low prices reduced bismuth to coproduct status with gold, copper, and tungsten at the Tasna Mine in Bolivia and delayed reopening

Demand for bismuth in the United States was small prior to World War II. The chief use was for medicines; bismuth compounds were used to treat such conditions as digestive disorders, venereal diseases, and burns. Minor amounts of bismuth were consumed in fusible alloys for fire sprinkler systems and fuse wire. Bismuth has always been produced mainly as a byproduct of lead refining. The price, which was controlled by the major producers until the mid-1960's, usually reflected the cost of recovery. In World War II, bismuth, considered to be a strategic and critical material, was used for solders, fusible alloys, and medications and in atomic research. To stabilize the market, the producers set the price at $1.25 per pound during the war and at $2.25 per pound from 1950 until 1964 (U.S. Bureau of Mines, 1966).

In the early 1970's, demand for bismuth as a metallurgical additive to aluminum, iron, and steel increased rapidly. This, combined with increased consumption in other categories, caused the producer price to increase dramatically in 1974 to a peak of $12.00 per pound in June. By August, the price dropped back to $9.00 per pound and remained there through the rest of the year. For the complete year 1974, the 21% decrease in domestic demand affected all categories of consumption (Wyche, 1976).

This was followed by 7-year decline in prices owing to increased world production with little growth in consumption. Asarco, the only domestic producer, suspended its list price on October 1, 1980. Until then, the annual average price reported was the Asarco price for 99.99%-pure bismuth. After 1980, the New York dealer price was reported (Carlin, 1981).

In Bolivia, the only country where bismuth was mined as a principal product, it was not possible to make a profit at the lower prices, and production virtually ceased in 1980 (Metal Bulletin, 1982). During the recessions of 1980 and 1981-82, declining domestic consumption and an excess of stocks held by world producers caused the price to drop to a low of $1.30 per pound in January 1983.

In 1984, the price began to climb as consumption increased worldwide, especially in the United States and Japan. In 1988, a series of miners' strikes in Peru, one of the largest producers of bismuth in the world, cut off all shipments for several months (King, 1988; Mining Journal, 1988). This led to the price reaching nearly $7 per pound, even though domestic consumers were able to compensate for this loss by obtaining bismuth elsewhere.

In late 1989, the price of bismuth began to drop owing to lower consumption, increased imports, large world stocks, and dealer reaction to the plan to sell 510 tons of the bismuth in the NDS within 10 years (American Metal Market, 1990). The Defense Logistics Agency (DLA) sold more than 59 tons from the NDS in 1990 and more than 57 tons in 1991. U.S. imports also increased in 1989 and 1990, which further increased the supply of bismuth and helped keep the price near $3.00 per pound. In 1992, the DLA released 91 tons of bismuth from the NDS and announced a new plan to release the remaining 740 tons during a period of 10 years (Jasinski, 1993).

In the early 1990's, research began on the evaluation of bismuth as a nontoxic replacement for lead in such uses as ceramic glazes, fishing sinkers, food-processing equipment (Murray, 1993), free-machining brasses for plumbing applications (Feder, 1991), lubricating greases, and shot for waterfowl hunting (Lowry, 1993). During the middle 1990's, growth in these areas remained slow in spite of direct or indirect Government backing of bismuth for lead replacement. The 1996 Amendments to the 1986 Safe Drinking Water Act require lead-free plumbing for new installations and repairs of facilities providing potable water by August 1998. Also, the U.S. Fish and Wildlife service gave final approval for the use of bismuth-tin shot for waterfowl hunting (U.S. Fish and Wildlife Service, 1997). In 1997, after extended negotiations with local and Nebraska State authorities on environmental remediation, Asarco closed its Omaha smelter, the only site of domestic bismuth production. Also in 1997, the DLA sold all the bismuth remaining in the NDS (American Metal Market, 1997). Thus, the United States became completely dependent on imports for its supply of primary bismuth.

At the end of the decade, total demand increased moderately as consumption for new uses, especially hunting and plumbing applications, began to increase. Supply remained adequate and prices remained low. Owing to low prices for bismuth, the reopening of the Tasna Mine in Bolivia, closed since 1980, was delayed. When production starts, bismuth, copper, gold, and tungsten will be coproducts (Mining Journal, 1999). In the original plan, bismuth was to be the main product (Tice, 1997).

References Cited

American Metal Market, 1990, DLA schedules sale of bismuth: American Metal Market, v. 98, July 23, no. 142, p. 2.

———1997, DLA's bismuth stocks emptied: American Metal Market, v. 105, no. 218, November 10, p. 16.

Carlin, J.F., Jr., 1981, Bismuth, *in* Minerals Yearbook 1980, v. I: U.S. Bureau of Mines, p. 129-132.

Feder, B.J., 1991, A new form of brass, to cut lead in drinking water: New York Times, v. 140, May 15, p. C7.

King, A.G., 1988, Bismuth rise caused by Peru strike: American Metal Market, v. 96, no. 155, August 9, p. 2.

Jasinski, S.M., 1993, Bismuth in 1992—Annual review: U.S. Bureau of Mines Mineral Industry Surveys, 6 p.

Lowry, Ed, 1993, Bismuth shot—The ballistic potential: American Rifleman, v. 141, no. 9, September, p. 54-61.

Metal Bulletin, 1982, Bismuth metal: Metal Bulletin Handbook 1982, v. 2, Statistics, p. 87-89.

Mining Journal, 1988, Peru strike boosts bismuth: [London] Mining Journal, v. 310, no. 7953, January 29, p. 77.

———1999, Minor metals in December: [London] Mining Journal, v. 332, no. 8514, January 15, p. 27.

Murray, C.J., 1993, Bismuth alloy replaces lead, eliminates toxicity: Design News, v. 49, no. 10, May 17, p. 124-125.

Tice, Kelley, 1997, A mine's tale—Taking care of bismuth: American Metal Market, v. 105, no.174, September 9, p. 1-2.
U.S. Bureau of Mines, 1966, Bismuth, *in* Commodity Data Summaries: U.S. Bureau of Mines, p. 16-17.
U.S. Fish and Wildlife Service, 1997, Approval of bismuth-tin shot as non-toxic for waterfowl and coots hunting: Federal Register, v. 62, no. 12, January 31, p. 4873-4876.
Wyche, Charlie, 1976, Bismuth, *in* Minerals Yearbook 1974, v. I: U.S. Bureau of Mines, p. 223-227.

Annual Average Bismuth Price[1]
(Dollars per pound[2])

Year	Price	Year	Price	Year	Price	Year	Price
1906	1.25	1930	1.35	1954	2.25	1978	3.38
1907	1.25	1931	1.25	1955	2.25	1979	3.01
1908	1.75	1932	0.85	1956	2.25	1980	2.64
1909	1.75	1933	1.08	1957	2.25	1981	2.52
1910	1.93	1934	1.20	1958	2.25	1982	1.61
1911	2.13	1935	1.05	1959	2.25	1983	1.72
1912	2.03	1936	1.00	1960	2.25	1984	4.27
1913	2.00	1937	1.00	1961	2.25	1985	5.18
1914	2.88	1938	1.05	1962	2.25	1986	3.25
1915	2.88	1939	1.10	1963	2.25	1987	3.65
1916	3.63	1940	1.25	1964	2.30	1988	5.78
1917	3.43	1941	1.25	1965	3.43	1989	5.76
1918	3.43	1942	1.25	1966	4.00	1990	3.56
1919	3.08	1943	1.25	1967	4.00	1991	3.10
1920	2.55	1944	1.25	1968	4.00	1992	2.66
1921	1.95	1945	1.25	1969	4.63	1993	2.50
1922	1.98	1946	1.44	1970	6.00	1994	3.25
1923	2.50	1947	1.98	1971	5.26	1995	3.85
1924	2.03	1948	2.00	1972	3.63	1996	3.65
1925	2.00	1949	2.00	1973	5.25	1997	3.50
1926	3.03	1950	2.06	1974	9.25	1998	3.60
1927	2.30	1951	2.25	1975	8.25		
1928	1.98	1952	2.25	1976	7.50		
1929	1.70	1953	2.25	1977	6.00		

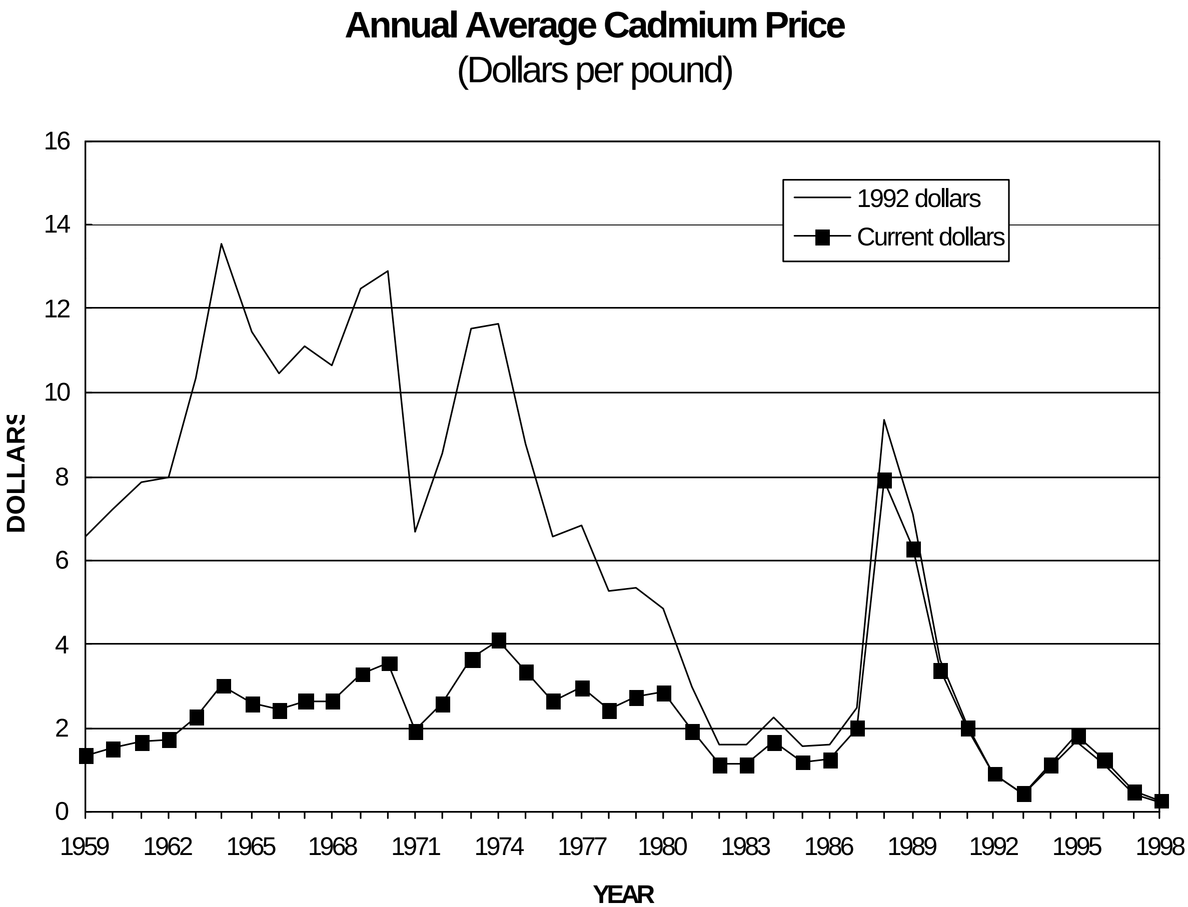
[1]Prices for 99.99%-pure bismuth.
[2]To convert to dollars per kilogram, multiply by 2.20462.

Note:
1906-23, ASARCO Incorporated, producer price, *in* U.S. Geological Survey, Mineral Resources of the United States.
1924-31, ASARCO Incorporated, producer price *in* U.S. Bureau of Mines, Mineral Resources of the United States.
1932-80, ASARCO Incorporated, producer price, *in* U.S. Bureau of Mines, Minerals Yearbook.
1981-93, New York dealer price, *in* Metals Week [through June 14, 1993].
1993-98, New York dealer price, *in* Platt's Metals Week.

(This page intentionally left blank.)

Cadmium

by Jozef Plachy



Significant events affecting cadmium prices since 1958

1961-75	Vietnam War; price trends slowly upward
1971-74	Doubling of price, despite anti-inflation price controls
1973-74	Oil embargo by the Organization of Petroleum Exporting Countries
1980-82	Two recessions (1980 and 1981-82); plummeting price
1982	Lowest cadmium price since end the of World War II
1988	Tight supply of cadmium metal, speculative trading; largest recorded annual increase in cadmium price

Cadmium minerals are not found in commercial quantities. The metal is produced as a byproduct in the recovery of primary zinc from zinc ores and also from some lead or complex copper-lead-zinc ores. The feed material for cadmium production consists of fume and dust that are collected as flue dust in baghouses during the pyro-metallurgical processing of zinc and residues that result from electrolytic zinc production. The availability of cadmium is, in most cases, dependent on the amount of zinc produced. Germany was the only important producer of cadmium until World War I. Production of cadmium in the United States began in 1907. By 1917, the United States had become the world's leading producer and held that position for more than 50 years. During this period, the price of cadmium was dictated by either market forces or, during World War II and the Korean Conflict, Government-imposed regulations. The last of these regulations, enacted during the Korean Conflict, was revoked on May 15, 1952. Since that time, the price of cadmium has been determined primarily by supply and demand.

Following the end of Government regulations, the price of cadmium metal fluctuated widely between 1953 and 1973, reflecting the variation in supply and demand. Domestic prices rose to world price levels in 1973 and increased to $4.09 per pound by 1974, surpassing the European market quotations. During the next few years, the price trended slowly downward despite continuing currency inflation. By 1982, depressed by the recessions of 1980 and 1981-82, the price had dropped to the lowest level since the end of World War II—$1.11 per pound of cadmium metal.

What began as a modest increase in 1986 and 1987 turned into the largest recorded annual increase of cadmium price in 1988. By March of that year, the domestic price for a pound of cadmium metal reached $9.10. The market was so tight in early 1998 that major producers did not have any material to sell on the spot market and would not make any commitments for near-term sales at a specific price. The price increase was attributed to the tight supply of cadmium, heavy speculative trading, and world labor disputes, which disrupted the supply of cadmium metal. The supply squeeze was further affected by the purchases of large quantities of cadmium by the nickel-cadmium battery industry, particularly in Japan. For the first 8 months (after which producers stopped quoting), the price averaged $7.90, a nearly 300% increase from that of the previous year. The price fell precipitously in the following 5 years, dropping to $0.45 in 1993 (U.S. Bureau of Mines, 1993, p. 21-24). Since that year, the price for cadmium has fluctuated between $0.28 and $1.80 per pound of metal. Some industry analysts attribute the volatility of cadmium prices to the fact that the price of the 95% of all cadmium sold under long-term contracts, usually by primary zinc producers, is strongly influenced by the 5% of cadmium sold on the spot market, which is more reflective of supply and demand.

The price for cadmium in the next several years will probably be affected by the proposed ban on cadmium in some of the major European countries, increasingly strict U.S. environmental regulations limiting domestic use of cadmium in all its forms, and an increased supply of primary cadmium from zinc smelting and secondary cadmium from recycling (Organisation for Economic Co-operation and Development, 1997, p. 3-5).

References Cited

Organisation for Economic Co-operation and Development, 1997, OECD workshop on the effective collection and recycling of nickel-cadmium batteries: Lyon, France, Organisation for Economic Co-operation and Development, 30 p.

U.S. Bureau of Mines, 1993, Metal prices in the United States through 1991: U.S. Bureau of Mines, 201 p.

Annual Average Cadmium Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1900	0.65	1925	0.60	1950	2.17	1975	3.36
1901	0.68	1926	0.60	1951	2.55	1976	2.66
1902	0.54	1927	0.60	1952	2.23	1977	2.96
1903	0.53	1928	0.60	1953	2.00	1978	2.45
1904	0.59	1929	0.60	1954	1.70	1979	2.76
1905	0.65	1930	0.60	1955	1.70	1980	2.84
1906	0.76	1931	0.55	1956	1.70	1981	1.93
1907	1.02	1932	0.55	1957	1.70	1982	1.11
1908	0.75	1933	0.55	1958	1.52	1983	1.13
1909	0.52	1934	0.55	1959	1.36	1984	1.69
1910	0.55	1935	0.70	1960	1.52	1985	1.21
1911	0.67	1936	0.98	1961	1.68	1986	1.25
1912	0.76	1937	1.22	1962	1.72	1987	1.99
1913	0.77	1938	0.98	1963	2.26	1988	7.90
1914	0.89	1939	0.64	1964	3.00	1989	6.28
1915	1.19	1940	0.82	1965	2.58	1990	3.38
1916	1.56	1941	0.90	1966	2.42	1991	2.01
1917	1.47	1942	0.90	1967	2.64	1992	0.91
1918	1.48	1943	0.90	1968	2.65	1993	0.45
1919	1.22	1944	0.90	1969	3.27	1994	1.13
1920	1.17	1945	0.90	1970	3.57	1995	1.84
1921	0.98	1946	1.09	1971	1.92	1996	1.24
1922	1.09	1947	1.70	1972	2.56	1997	0.51
1923	0.88	1948	1.83	1973	3.64	1998	0.28
1924	0.70	1949	2.00	1974	4.09		

[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:

1900-66, Producer price for 99.95%-pure cadmium, *in* Engineering & Mining Journal.

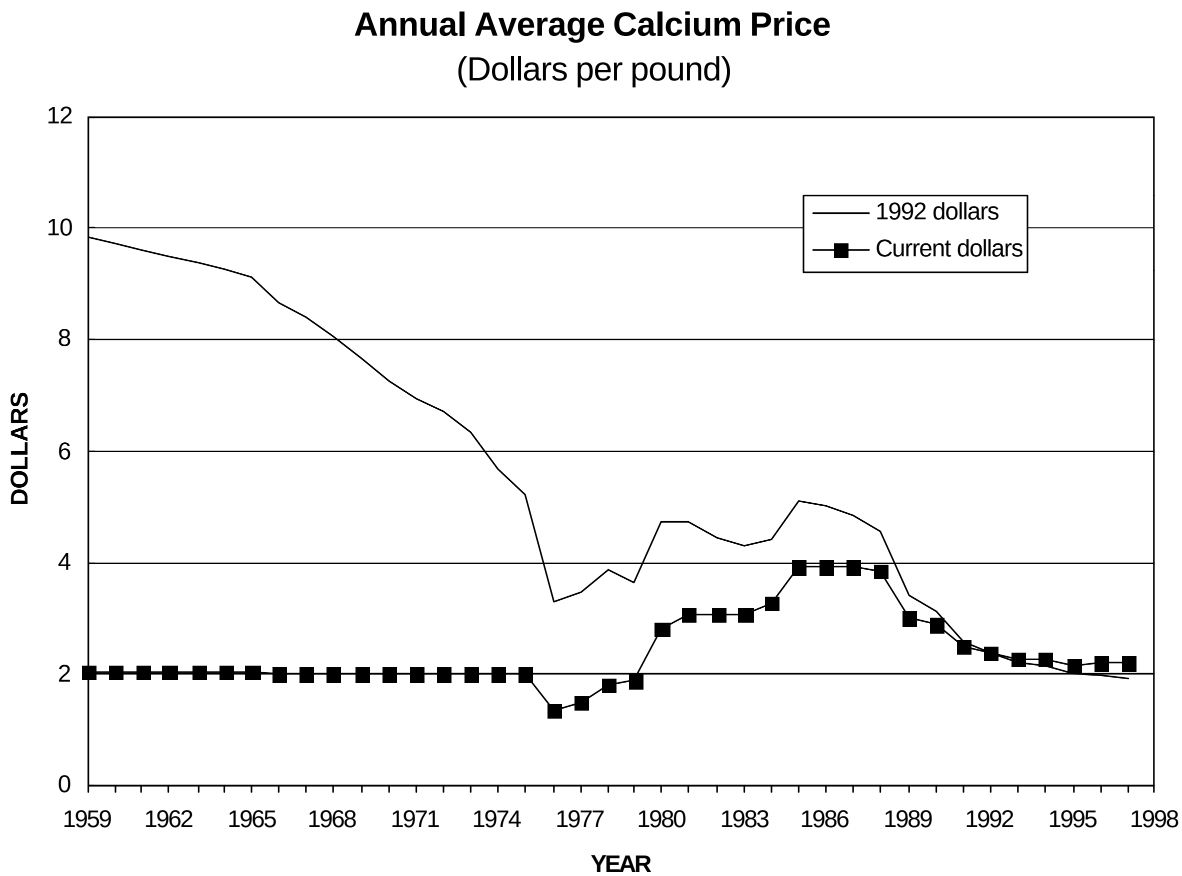
1967-93, Producer price for 99.95%-pure cadmium, *in* Metals Week. Major producers suspended price quotes during the last 4 months of 1988; 1988 price is January to August average.

1994-99, New York dealer price for 99.99%-pure cadmium, *in* Platt's Metals Week.

(This page intentionally left blank.)

Calcium

by M. Michael Miller



Calcium is a soft, light, silvery-white metal. It is a bivalent element of the alkaline-earth group. The metal oxidizes rapidly in the presence of moisture or in dry air at a temperature above 285/ C. Calcium reacts readily with water, forming hydrated lime (calcium hydroxide) and hydrogen. It melts at 845/ C, boils at 1,420/ C, and can be purified by distillation in an inert atmosphere or in a vacuum.

Calcium metal is produced by an aluminothermic reduction process that begins with high-calcium limestone calcined to form calcium oxide. The calcium oxide is blended with finely divided aluminum, and the mixture is compacted into briquets. The briquets are placed in retorts and heated in a furnace at about 1,200/ C under high vacuum. The calcium oxide is reduced to calcium metal gas, which is collected in the water-cooled condenser section of the retort (Hibbins, 1992).

Calcium metal is sold on a contract basis, and the contract price may vary greatly from the published producer price. The published prices change infrequently and serve only as a guide to the prices obtained by producers and dealers. The prices listed in the table are quoted for different quantities (see footnotes) and cannot be directly compared.

Reference Cited

Hibbins, S.G., 1992, Calcium and calcium alloys, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, p. 777-786.

Annual Average Calcium Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1959	2.05	1969	2.00	1979	1.89	1989	3.00
1960	2.05	1970	2.00	1980	2.78	1990	2.89
1961	2.05	1971	2.00	1981	3.05	1991	2.50
1962	2.05	1972	2.00	1982	3.05	1992	2.38
1963	2.05	1973	2.00	1983	3.05	1993	2.25
1964	2.05	1974	2.00	1984	3.25	1994	2.25
1965	2.05	1975	2.00	1985	3.92	1995	2.15
1966	2.00	1976	1.33	1986	3.92	1996	2.20
1967	2.00	1977	1.49	1987	3.92	1997	2.20
1968	2.00	1978	1.80	1988	3.85	1998	NA

NA Not available

[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:

1959-65, metal, 97%- to 98%-pure, cast in slabs and small pieces, in more than 1-metric-ton lots, *in* Engineering & Mining Journal, Metal and Mineral Markets.

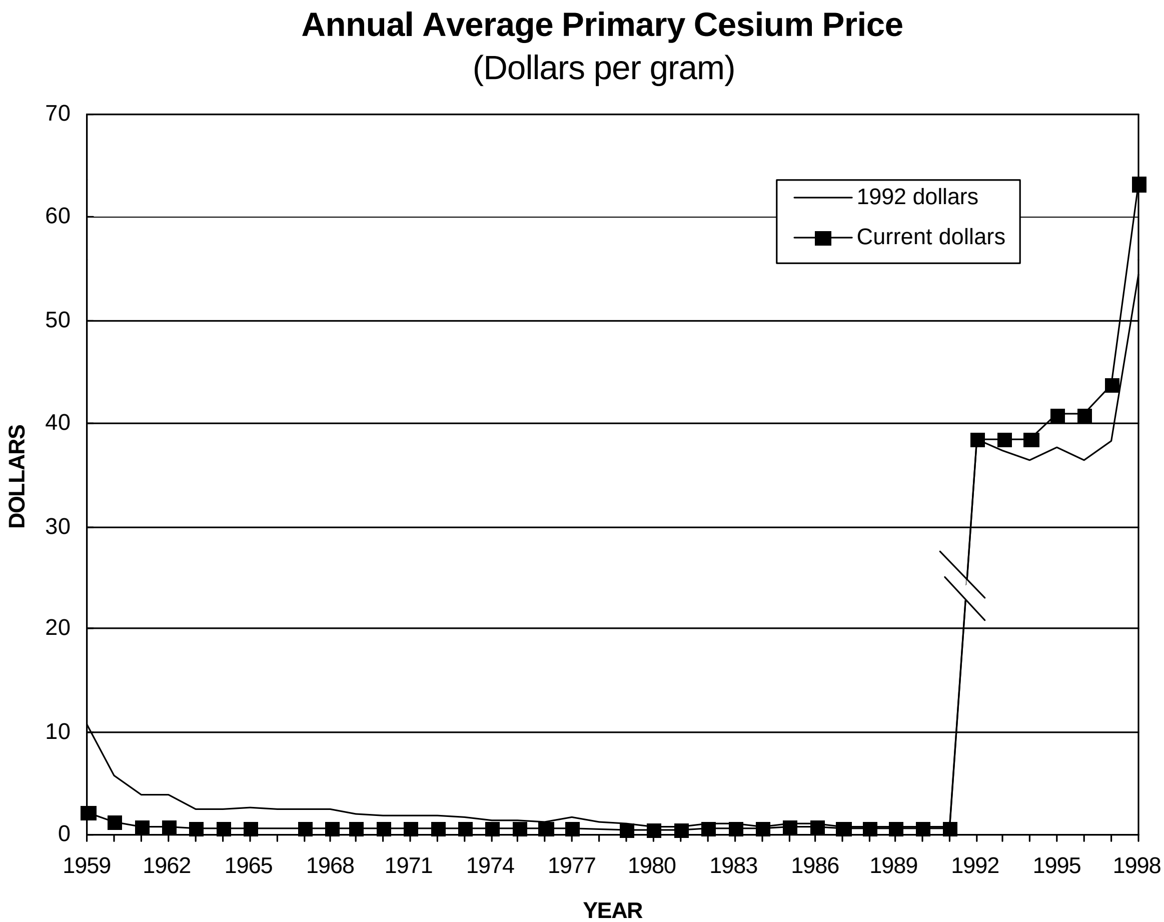
1966-75, U.S. producers price, more than 99%-pure, full crowns, in quantities of less than 100 pounds, *in* Calcium and Calcium Compounds chapters in the U.S. Bureau of Mines Minerals Yearbook.

1976-88, metal, Ca + Mg 99.5%, Mg 0.7%, full crowns, in quantities of more than 20,000 pounds, *in* Metals Week.

1989-97, metal, 98% minimum, *in* Metal Bulletin.

Cesium

by Robert G. Reese, Jr.



Cesium, the most electropositive and least abundant of the five naturally occurring alkali metals, was discovered spectroscopically in 1860 (Perel'man, 1965, p. 1). The first cesium metal was produced in 1881. Because cesium is not mined domestically, the United States is completely dependent on imports. Historically, the most important use for cesium has been in research and development, primarily in chemical and electrical applications.

Owing to the small size of the industry, quoted cesium prices are those of individual companies. The cesium price varies with the purity of the material and inversely with the quantity purchased. Cesium metal has been marketed in purities ranging from 99% to 99.98%.

The annual prices presented in the graph and table may not be comparable from year to year owing to differences in purities, quantity of material purchased, and/or the source of the price. For example, prior to 1960, the prices published in the U.S. Bureau of Mines Minerals Yearbooks were for purchases of less than 1 pound of cesium metal. From 1960 through 1991, the cesium metal prices published in the Yearbooks were for purchases of at least 1 pound of material and are significantly lower than the pre-1960 prices owing to discounts for the larger quantity purchased. The prices for 1992 through 1998 represent the price charged for a 1-gram ampoule of 99.98%-pure cesium metal and are an order of magnitude higher than the 1960 to 1991 prices.

Reference Cited

Perel'man, F.M., 1965, Rubidium and caesium: New York, The Macmillan Co., 144 p.

Annual Average Primary Cesium Price

(Dollars per gram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	2.23	1969	0.52	1979	0.50	1989	0.69
1960	1.19	1970	0.52	1980	0.50	1990	0.69
1961	0.83	1971	0.52	1981	0.50	1991	0.69
1962	0.83	1972	0.52	1982	0.66	1992	38.50
1963	0.52	1973	0.52	1983	0.66	1993	38.50
1964	0.52	1974	0.52	1984	0.66	1994	38.50
1965	0.58	1975	0.52	1985	0.72	1995	40.80
1966	NA	1976	0.52	1986	0.72	1996	40.80
1967	0.58	1977	0.66	1987	0.66	1997	43.70
1968	0.58	1978	NA	1988	0.66	1998	63.30

NA Not available

Note:

The data in the table above were compiled from information in various U.S. Bureau of Mines Minerals Yearbooks, U.S. Bureau of Mines Mineral Commodity Summaries, and U.S. Geological Survey Mineral Commodity Summaries. It is believed that the data in the previously mentioned publications were obtained from the sources listed below.

1959, Average of the prices attributed to American Potash & Chemical Corp. & Penn Rare Metals Co.

1960, 99+%-pure cesium, 10-pound lots.

1961-62, Penn Rare Metals Division, Kawecki Chemical Co., 99.9%-pure cesium, 1- to 9-pound lots.

1963-64, Average of the range of prices for 99+%-pure cesium in American Metal Market.

1965, Average of the range of prices for 99.6%-pure cesium, 1- to 9-pound lots attributed to the Penn Rare Metals Division of Kawecki Chemical Co.

1967-68, Average of the range of prices for 99.5%-pure cesium, 1- to 9-pound lots attributed to the Penn Rare Metals Division of Kawecki Chemical Co.

1969, Average of the range of prices for 99+%-pure cesium.

1970-77, Average of the range of prices for 99+%-pure cesium in American Metal Market.

1979-1981, American Metal Market yearend price for 99+%-pure cesium.

1982-86, KBI Division, Cabot Corp., average of the yearend price for technical- and high-purity-grade cesium.

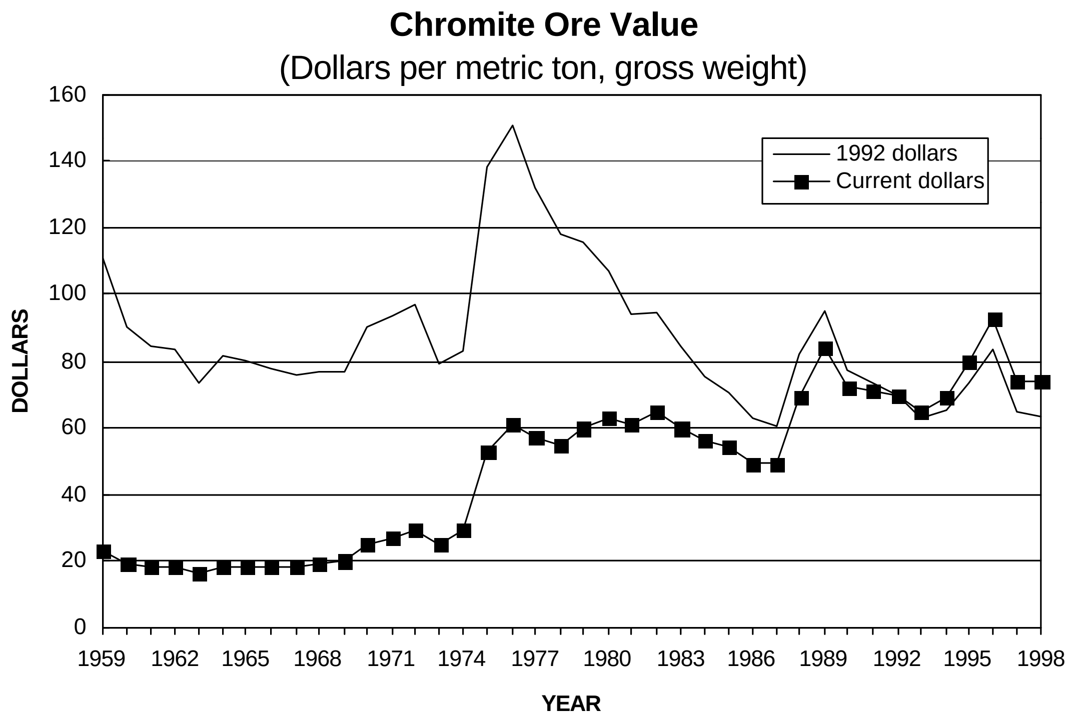
1987-88, KBI Division, Cabot Corp., average of the yearend price for technical- and high-purity-grade cesium in lots of less than 50 pounds.

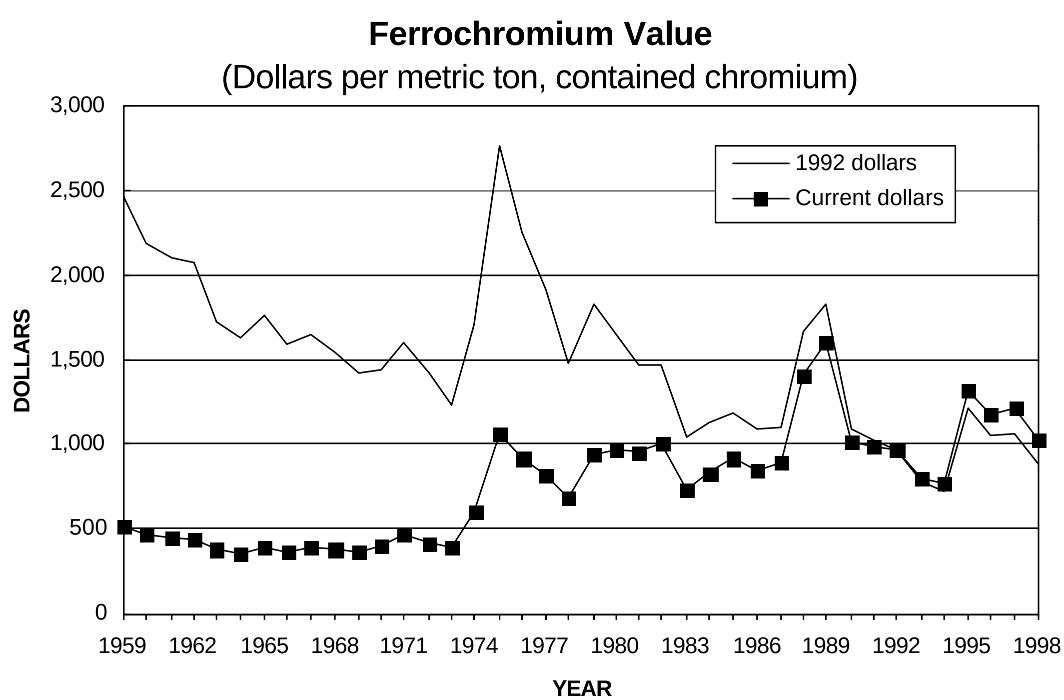
1989-91, KBI Division, Cabot Corp.

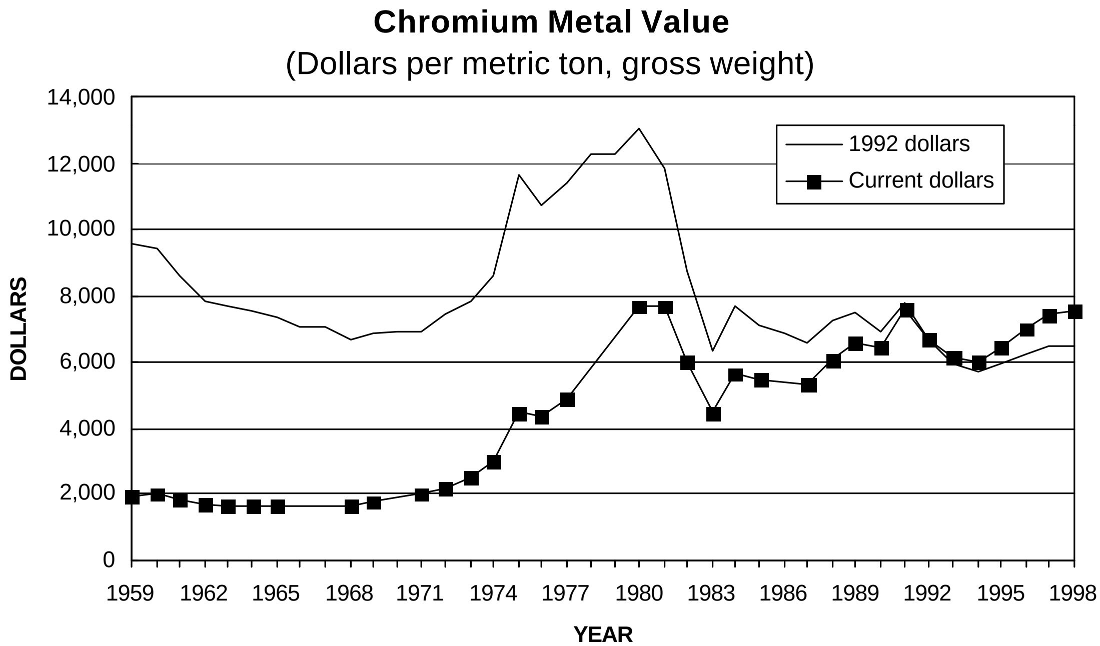
1992-98, Alfa Aesar and other chemical catalogs. Prices for purchases of 99.98%-pure cesium in 1-gram ampoules.

Chromium

by John F. Papp







Significant events affecting chromite ore prices since 1958

1987-89	Increased stainless steel production
1991	Dissolution of the Soviet Union
1997	Start of the Asian financial crisis

Chromium, the chemical element, was discovered in 1797 by Nicolas-Louis Vauquelin, a professor of chemistry at the Paris École des Mines, one of the new European technical universities established to bring science education to the mining industry (Weeks, 1968, p. 271-283). The chromite mineral, comprising primarily chromium, iron, and oxygen, was subsequently found to be useful as a refractory material. Chromite was first exploited for the production of pigments (Gray, 1988) and the manufacture of refractory materials. Today, the major use of chromium is in the metallurgical industry to make stainless steel; substantially less chromium is used in the refractory and chemical industries (Papp, 1994, p. 7, 17). The major chromium commodity materials are chromite ore, ferrochromium, and chromium metal. The major traded chromium commodity is now ferrochromium, which replaced chromite ore. Chromium metal prices apply to a relatively small amount of the chromium commodity materials. To meet the needs of different users of price information, all three price histories have been included.

An understanding of the structure of the chromium industry is important to understanding chromium material price structure. Ferrochromium was originally produced mainly near stainless steel producers but production has since moved to locations in proximity to chromite ore producers. The United States is not a chromite-ore-producing country; it is, however, a major world producer of stainless steel and of chromium chemicals. After World War II, the United States built a stockpile of chromium commodities for national security reasons. After the dissolution of the Soviet Union in 1991, the Federal Government started to sell its stockpile; the price of material was based on negotiated contract. Each month, the Defense Logistics Agency (DLA), the Federal agency responsible for stockpile management, accepted bids on chromium materials that had been authorized for sale by the U.S. Congress (U.S. Department of Defense, 1997). The DLA negotiated a price for the chromium material with the potential purchaser.

Imports of various forms of chromium are important because their value is a good indicator of price. Until the period from 1980 through 1990, the United States imported most of its chromium needs in the form of chromite ore because ferrochromium was domestically produced. As domestic ferrochromium production capacity declined, imported ferrochromium surpassed chromite ore as the major commodity source of chromium for the United States. Markets for chromium metal developed along with the jet engine, many parts of which need alloys that require chromium metal.

The structure of the chromium industry has been changing, as has the role of the United States in that industry. Reported U.S. trade statistics (i.e., amount and value) for chromite ore date back to 1884; ferrochromium, 1910; and chromium metal, 1923. Trade journal prices for chromium metal go back only to 1964. Thus, chromite ore is the only chromium commodity for which the reported historical trade journal price and U.S. import value series is long. Since U.S. import data was first collected, technological changes have resulted in a change in the predominant grade of chromite ore and ferrochromium traded. The United States has been a consumer of a broad range of chromium materials, and to a large degree, prices of chromium-containing materials have been sustained by demand in the United States and other industrialized nations. As a chromium-chemical-manufacturing nation, the United States also imported chromite ore for chemical production. As a steel-producing nation, the United States imported chromite ore for refractory and alloy production. Between about 1970 and 1999, the United States made the transition from producing to importing ferrochromium for its steel industry. As a result, U.S. import statistics included declining amounts of metallurgical grade chromite ore over that time period. The United States is a major alloy- and stainless-steel-producing nation, and chromium ferroalloy imports, including a broad range of grades and sources, reflect that.

Chromite ore and other chromium materials are not traded on commodity or futures exchanges. Thus, the price for chromite ore or any other chromium material is not publicly negotiated or available. After surveying consumers and producers, some trade journals publish a composite price or price range based on their survey. Included among these are American Metal Market, Industrial Minerals, Metal Bulletin, Metals Price Report, Platt's Metals Week, and Ryan's Notes. Although the prices for chromium materials reported in such periodicals might, indeed, represent price in the market being surveyed, no representation of quantity of trade is made. Usually, more than one source and/or grade of material reported by the trade journals may have disparate characteristics. In this situation, price is an average and does not apply to any specific product. A broadly descriptive name like "chromite ore" covers many sources and grades of material. The U.S. import value reported to the U.S. Customs Service, the U.S. Department of the Treasury, and published by the U.S. Bureau of the Census, U.S. Department of Commerce, includes a declared value of the imported material estimated at the point of export. It excludes U.S. import duties, freight, insurance, and other charges incurred in shipping the merchandise to the United States (U.S. Bureau of the Census, 1992, p. 2-6). Chromite ore values are annual weighted-average values based on quantity, content, and customs value of imports as reported in U.S. customs statistics.

Chromite ore is graded by its chromic oxide (Cr_2O_3) content, and its price is reported in trade journals on a gross-weight basis (U.S. dollars per metric ton, gross weight). Commercially traded chromite ore grades range from 35% to 55% Cr_2O_3. Suppose, for example, that a particular chromite ore is graded at 42% to 45% and priced at $100 per metric ton. It contains 42% to 45% chromic oxide and costs $100 per ton, gross weight. To calculate the cost of the chromium contained in this material, remember that chromic oxide is 68.42% chromium. Consequently, 1 ton of this material then contains between 0.287 and 0.308 ton of chromium yielding a unit value of between $325 and $348 per ton of chromium. Ferrochromium typically contains between 50% and 65% chromium, and its price is reported in trade journals in dollars per pound of contained chromium. Chromium metal is typically in excess of 99% pure, and its price is reported in trade journals in dollars per pound, gross weight (Papp, 1995). A wide variety of chromium metal prices are reported in trade journals. The units of chromium material value are similar to those of chromium material price reported in trade journals—dollars per metric ton, gross weight, for chromite ore and chromium metal and dollars per metric ton of contained chromium for ferrochromium. (To convert from dollars per metric ton to dollars per pound, multiply by $4.536x10^{-4}$.)

The unit value of chromium in each of its commodity forms is substantially different. In 1997, the unit value of chromium contained in its commodity forms was, in rounded numbers and in units of dollars per metric ton of contained chromium— chromite ore, $200; ferrochromium, $1,000; and chromium metal, $7,000.

The predominant influence on the price of chromite ore is the relation between supply and demand and general economic conditions. Stocks relative to anticipated consumption also affect material price. When supply does not meet demand or when stocks appear to be insufficient, price is expected to increase. Because stainless steel is the major end use for chromium, world stainless steel production or anticipated production plays a major role in determining chromium demand and is, therefore, a major influence on ferrochromium and chromite ore prices. Strong demand for chromium from the international stainless steel market resulted in price increases from 1987 through 1989. Chromium industry production capacity growth exceeded stainless steel industry chromium demand growth, which continued but at a rate lower than that of ferrochromium production capacity. The result was excess production capacity in the chromium ferroalloy industry that resulted in lower ferrochromium prices. In 1991, the dissolution of the former Soviet Union (FSU) resulted in decreased demand for chromium from those markets and added chromium products from the FSU to world markets. Both of these events exacerbated the downward pressure on ferrochromium prices. In 1997, the Asian financial crisis resulted in a lower world demand for stainless steel that put more downward pressure on ferrochromium prices.

Of the 12.5 million metric tons of 1997 world chromite ore production, 85% went into the ferrochromium industry; 8% to the chemical industry; and 7% to the refractory industry (Toerien, 1997; Papp, 1998, p. 8). Because non-ferrochromium-grade chromite ore is often a byproduct of ferrochromium-grade ore, ferrochromium industry demand is the main driving force of chromite ore production (O'Driscoll, 1998). The relation is indicated by the lead sometimes shown by ferrochromium price over chromite ore price. The annually averaged price data show that price peaks for ferrochromium and chromite ore were coincident in 1982 and 1989, and ferrochromium price led chromite ore price in 1975-76 and 1995-96. In the first two cases, annual averaging hides the price change relation. In the second two cases, increased demand for ferrochromium drove up ferrochromium prices, but the chromite ore price increase lagged by 1 year. The most recent ferrochromium price peaks were in June 1989 and December 1995 (Warburg Dillon Read Securities (South Africa) (Pty) Ltd., 1998, p. 3).

References Cited

Gray, Alan, 1988, Lead chrome pigments, *in* Lewis, P.A., ed., Properties and economics: New York, Wiley-Interscience Publication, Pigments Handbook, v. 1, p. 315-325.

O'Driscoll, Mike, 1998, Chromite supply—A question of ownership: Industrial Minerals, no. 366, March, p. 51.

Papp, J.F., 1994, Chromium life cycle study: U.S. Bureau of Mines Information Circular 9411, 94 p.

———1995, Chromium metal: U.S. Bureau of Mines Information Circular 9430, 64 p.

———1998, Chromium in 1997—Annual review: U.S. Geological Survey Mineral Industry Surveys, September 27, 27 p.

Toerien, G.P., 1997, [Untitled]: Ryan's Notes Ferroalloys Conference, Boca Raton, FL, November 4, 1997, handout, unpaginated.

U.S. Bureau of the Census, 1992, Guide to foreign trade statistics: U.S. Bureau of the Census, 276 p.

U.S. Department of Defense, 1998, Operations under the Strategic and Critical Materials Stock Piling Act during the period October 1996 through September 1997: U.S. Department of Defense Strategic and Critical Materials Report to the Congress, 43 p.

Warburg Dillon Read Securities (South Africa) (Pty) Ltd., 1998, South Africa, Steel & Allied, Samancor: Warburg Dillon Read Securities (South Africa) (Pty) Ltd., 67 p.

Weeks, M.E., and Leichester, H.M., 1968, Discovery of the elements (7th ed.): Journal of Chemical Education, 896 p.

Chromite Ore Value[1]
(Dollars per metric ton, gross weight)

Year	Price	Year	Price	Year	Price	Year	Price
1940	13	1955	23	1970	25	1985	54
1941	12	1956	25	1971	27	1986	49
1942	16	1957	27	1972	29	1987	49
1943	20	1958	25	1973	25	1988	69
1944	21	1959	23	1974	29	1989	84
1945	21	1960	19	1975	53	1990	72
1946	17	1961	18	1976	61	1991	71
1947	19	1962	18	1977	57	1992	70
1948	24	1963	16	1978	55	1993	65
1949	22	1964	18	1979	60	1994	69
1950	20	1965	18	1980	63	1995	80
1951	20	1966	18	1981	61	1996	93
1952	25	1967	18	1982	65	1997	74
1953	28	1968	19	1983	60	1998	74
1954	26	1969	20	1984	56		

[1] Annual weighted-average chromite ore value based on quantity and declared free-on-board value of U.S. imports as reported in U.S. customs statistics, as reported by the U.S. Bureau of the Census, U.S. Department of Commerce. Based on U.S. chromite ore import statistics, 1940 through 1997, average chromic oxide content plus or minus average deviation is 43.8 ± 1.5 percent; and chromium content, 30.0 ± 1.0 percent.

Ferrochromium Value[1]

(Dollars per metric ton, contained chromium)

Year	Price	Year	Price	Year	Price	Year	Price
1947	295	1960	462	1973	392	1986	851
1948	344	1961	449	1974	600	1987	893
1949	352	1962	445	1975	1,061	1988	1,403
1950	363	1963	376	1976	916	1989	1,609
1951	411	1964	360	1977	826	1990	1,017
1952	442	1965	395	1978	686	1991	997
1953	556	1966	367	1979	945	1992	966
1954	NA	1967	394	1980	972	1993	801
1955	NA	1968	382	1981	952	1994	767
1956	484	1969	370	1982	1,008	1995	1,322
1957	516	1970	401	1983	737	1996	1,179
1958	540	1971	464	1984	833	1997	1,212
1959	512	1972	422	1985	914	1998	1,027

NA Not available

[1] Weighted-average ferrochromium value based on content quantity and declared free-on-board value of U.S. imports as reported in U.S. customs statistics, as reported by the U.S. Bureau of the Census, U.S. Department of Commerce. Based on U.S. ferrochromium import statistics, 1947 through 1997, average chromium content plus or minus average deviation is 61.4 ± 3.7 percent.

Chromium Metal Value[1]

(Dollars per metric ton, gross weight)

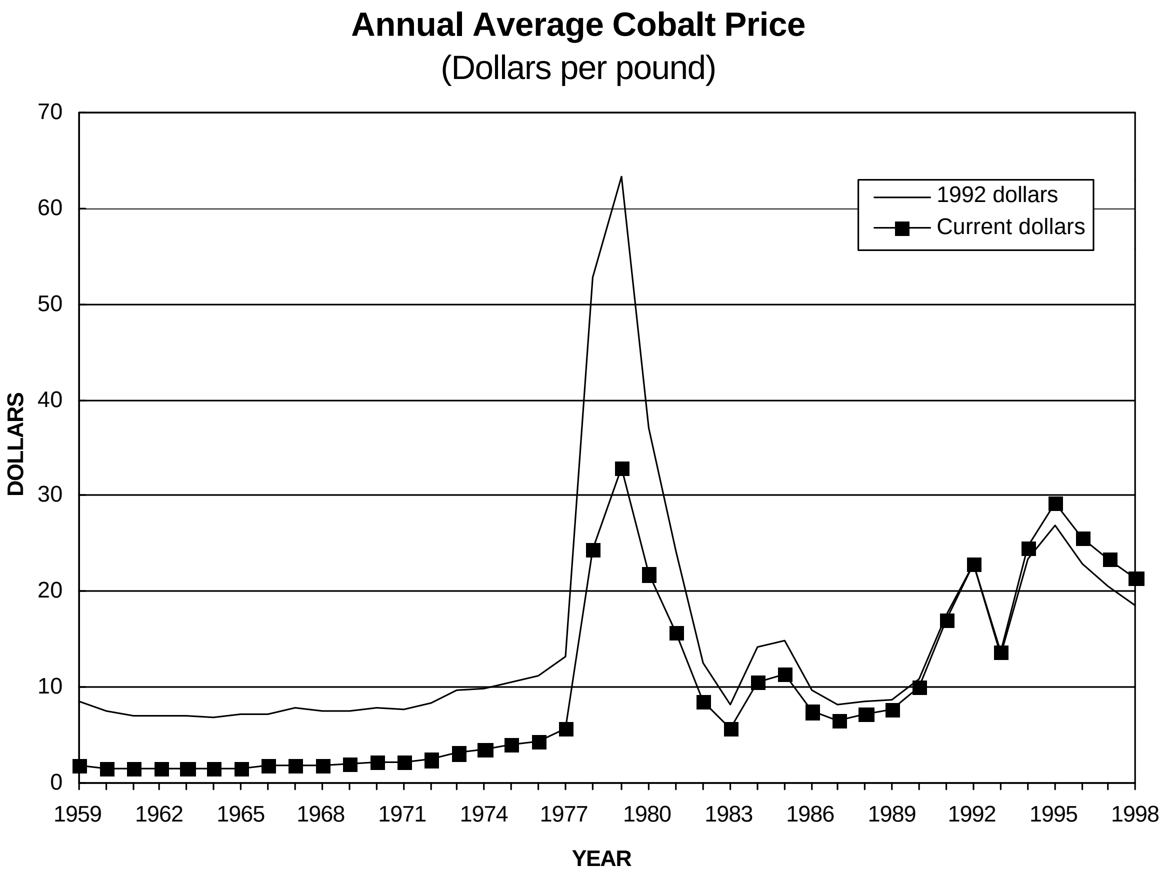
Year	Price	Year	Price	Year	Price	Year	Price
1956	1,852	1967	NA	1978	NA	1989	6,597
1957	2,237	1968	1,656	1979	NA	1990	6,460
1958	2,234	1969	1,800	1980	7,682	1991	7,584
1959	1,993	1970	NA	1981	7,662	1992	6,671
1960	1,998	1971	2,003	1982	6,018	1993	6,137
1961	1,832	1972	2,206	1983	4,491	1994	6,031
1962	1,689	1973	2,491	1984	5,674	1995	6,455
1963	1,677	1974	3,030	1985	5,468	1996	7,018
1964	1,670	1975	4,486	1986	NA	1997	7,419
1965	1,661	1976	4,350	1987	5,320	1998	7,576
1966	NA	1977	4,938	1988	6,097		

NA Not available

[1] Weighted-average chromium metal value based on quantity and declared free-on-board value of U.S. imports as reported in U.S. customs statistics, as reported by the U.S. Bureau of the Census, U.S. Department of Commerce. Chromium metal is typically in excess of 99% pure.

Cobalt

by Kim B. Shedd



Significant events affecting cobalt prices since 1958

1967-1976	Sales of significant quantities of cobalt from U.S. Government stockpile
1978	Strong cobalt demand, Zaire's copper-cobalt mining region invaded, and free market developed
1981-1982	Sharp recession
1984	Zaire and Zambia announce a joint producer price
1990-1991	Recession
1990	Strikes in Zaire and political unrest in Zambia, cave-in at Zaire's Kamoto copper-cobalt mine, and Russia began exporting cobalt to Western markets
1991	Unrest in Zaire and dissolution of the Soviet Union
1992-1993	Economic downturn and decrease in U.S. defense spending
1993-1998	Sales of cobalt from the U.S. Government stockpile
1994	Producer price was changed to a reference price

Cobalt is a strategic and critical metal used in many diverse industrial and military applications. The largest use of cobalt is in superalloys, which are used to make parts for gas turbine aircraft engines. In its metal and/or chemical forms, cobalt is also used to make magnets; corrosion and wear-resistant alloys; high-speed steels; cemented carbides and diamond tools; catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; ground coats for porcelain enamels; pigments; battery electrodes; steel-belted radial tires; and magnetic recording media. Various forms of cobalt metal, including briquettes, cathode (electrolytic cobalt), fines, granules (shot), ingot, powder, and rondelles, have been produced and marketed. Cobalt prices presented in the table for 1969 onward are for cobalt cathode, which is produced by electrowinning. In the electrolytic cell, cobalt metal is deposited on the cathode, usually as a continuous sheet of cobalt metal. Following removal from the cathode, the sheet of cobalt can be broken into small pieces and sold as "broken cathode" or cut into squares and sold as "cut cathode." Current spot prices quoted in Platt's Metals Week are for cathode with a minimum cobalt content of 99.8%.

In addition to general economic conditions and supply/demand fundamentals, the following factors have influenced cobalt prices over time: most cobalt is produced as a byproduct of either copper or nickel, resulting in a certain amount of supply inelasticity; cobalt is produced by a limited number of countries, one of which, the Democratic Republic of the Congo (formerly Zaire, formerly the Belgian Congo), was the world's dominant producer from the 1920's until the 1990's; and cobalt is considered to be a strategic and critical metal, and as a result, purchases for and sales from Government stockpiles have added to demand and supply, respectively.

During much of its history, the price of cobalt metal was set primarily by producers. Before World War II, the leading Belgian, British, Canadian, Finnish, and French producers agreed to control cobalt supply and to maintain a uniform price. Following the War, prices quoted by the Belgian Congo were generally followed by other producers (Young, 1960, p. 8). Beginning in the mid-1980's, Zaire and Zambia cooperated in setting the producer price (Jones, 1986; Cobalt Development Institute, 1987). During times when producers controlled the market, the majority of cobalt sales were directly between producers or their sales agents and consumers. These sales were conducted under medium- or long-term agreements at the producer price or at the producer price minus quality and quantity discounts. In the early 1990's, the African producers lost much of their influence on cobalt prices (Kielty, 1992, p. 2). This was the result of reduced production from Zaire and Zambia at a time when an increasing amount of cobalt was entering the free market. The producer price was renamed the "reference price" in 1994, and since then, most cobalt has been sold at free market prices.

In the free market, sales are between merchants (independent traders) and consumers or merchants and other merchants (intermerchant trading). Cobalt in the free market can originate from producers, either officially or unofficially; from Government stockpile releases; or consumers with excess metal. The volume of free market sales has varied over time and from country to country. Free market prices sometimes change very rapidly. Although they reflect overall supply and demand, they can be strongly influenced by buyer perceptions of short-term availability, and the reasons for sudden changes are not always evident.

Historically, cobalt prices were relatively stable until the late 1970's, when a series of events resulted in concerns over cobalt supply and a rapid increase in prices to more than $40 per pound. The key factors and events leading up to the "cobalt crisis" were as follows: the cessation of cobalt sales from the U.S. Government stockpile in 1976, a drawdown of Zairian producer inventories following 2 years of sales exceeding production, a sharp increase in demand, a reduction in cobalt allocations by the Zairian producer, limited world cobalt production capacity, and an invasion of the copper-cobalt mining region in Zaire (Mining Journal, 1979; Kirk, 1985). Although Zaire's annual production actually exceeded that of the previous year, the "cobalt crisis" had long-term impacts on the cobalt market. For the first time in many years, a strong free market in cobalt developed, and cobalt prices gained the reputation of being unstable.

Following the "crisis," production capacity was increased, recycling and recovery of cobalt from secondary materials also increased, and consumers conserved or substituted cobalt where possible. The recession in the early 1980's added to the reduction in demand and an oversupply situation developed (Kielty, 1988). Beginning in the mid-1980's, Zaire and Zambia worked together to stabilize cobalt prices. They established a joint producer price and limited sales of cobalt to the free market (Kramer and Salak, 1984). In addition, Zaire acted as a "swing producer" by reducing its production and inventories to meet demand (Kielty, 1990, p. 2-3, 10). From late 1986 until mid-1990, Zaire and Zambia were successful in returning stability to cobalt prices.

Free market price stability ended during the second half of 1990. In early 1990, delayed shipments from African producers, planned cutbacks in nickel production by Canadian nickel-cobalt producers, assumptions regarding reduced inventory levels in Zaire, and tightening of cobalt supplies on the free market caused concern over future cobalt availability. In July, the free market cobalt price began to rise following reports of strikes in Zaire and political unrest in Zambia. News of a cave-in at Zaire's Kamoto copper-cobalt mine in late September added to concerns over cobalt availability.

During 1990, Russia began exporting cobalt to Western markets. The breakup of the Soviet Union, a reduction in Russian military production, and an increase in demand for hard currency led to increased exports in 1991. As a result, Russia became a net exporter of cobalt, and Russian cobalt developed into a significant component of Western supply. Most of this cobalt was sold by merchants in the free market.

The free market cobalt price slowly decreased during the first 9 months of 1991. Speculation continued during this period regarding potential supply shortages, but demand was limited by recessionary economic conditions. Political and economic tensions in Zaire continued to increase. The price of cobalt began to rapidly increase following news of renewed unrest in September and October. The cobalt price peaked at more than $30 per pound in late December 1991/early January 1992.

During the next 2 years, the free market cobalt price trended downward to approximately $11 per pound. The decrease during 1992 and 1993 was attributed to the following factors: reduced consumption because of a decrease in U.S. defense spending, a decrease in demand from the commercial aircraft sector, and an economic downturn in the United States, Europe, and Japan; reduced demand because of a drawdown of consumer inventories; and the availability of cobalt on the free market.

Following several years of decline, world refined cobalt production reached a low point in 1993. The U.S. Government began selling excess cobalt from the National Defense Stockpile (NDS) in March of that year. NDS cobalt was available to merchants, as well as to consumers, thus providing more cobalt to the free market. Although cobalt from the NDS and Russia was a lower quality than that typically offered to the market, consumers found ways to take advantage of the availability and lower cost of cobalt from these sources.

Beginning in mid-December 1993 and ending in mid-January 1994, the free market cobalt price more than doubled. This price increase reflected a growing concern over cobalt supply prompted by the following factors: delays by the African producers in announcing their 1994 pricing policy, consumers' reduced inventory levels resulting from buying on an as-needed basis, press reports that the copper-cobalt mining region in Zaire had declared autonomy from the rest of the country, expectations for reduced production in 1994, and merchants' reports of reduced supplies of Russian cobalt. The magnitude and speed of the price increase, however, suggested market manipulation (Kielty, 1994).

During 1994 and 1995, the supply of and demand for cobalt increased. World production increased, cobalt from Russia and the NDS continued to contribute to supply, and the amount of cobalt recovered from intermediate materials and recycled from scrap increased. Economic conditions improved, and world demand increased. The free market cobalt price was high and unstable, between $20 and $30 per pound, during most of this 2-year period. The overall trend in free market prices was upward, reaching more than $32 per pound by December 1995. High cobalt prices, combined with forecasts for large increases in nickel demand, resulted in the initiation of a significant number of projects that could produce cobalt within 3 to 6 years either as a byproduct of nickel or copper mining or from the processing of cobalt-bearing intermediate materials stockpiled during past copper production.

World cobalt production continued to increase in 1996. Demand remained strong, but the free market cobalt price decreased to approximately $21.50 per pound by yearend. Market sentiment shifted from concern about availability to forecasts of potential oversupply as future production increased at a faster rate than demand.

During 1997, world production was approximately equal to that of 1996, and demand remained strong. The free market cobalt price fluctuated between approximately $19 and $26 per pound. In 1998, the cobalt price declined significantly. It gradually decreased from a high of approximately $26 per pound in January to approximately $24 per pound in early June, and then rapidly decreased to approximately $10 to $11 per pound by yearend. The decrease in price suggests that plenty of cobalt was available to meet demand. Total sales and shipments of cobalt from the NDS were higher in 1998 than those of 1997, and on the basis of data from the first 6 months of 1998, world production was higher than that of the previous year. In addition, the following were cited as possible contributing factors to the decreasing prices: weak demand, particularly from the superalloy sector; reduced demand because of poor economic conditions in Asia and elsewhere; consumers buying only as needed, drawing down inventories, and delaying purchases while waiting for the price to bottom out; producers offering cobalt at low prices to reduce their inventories and/or to gain market share; and merchants pushing down prices to buy cheaper cobalt at a later date and/or to gain market share.

In 1999, three new projects in Australia are expected to begin producing cobalt as a byproduct of nickel. Plans for additional new cobalt production are underway or being considered at various projects in Africa, North America, and Oceania. This increase in production from more diverse sources is anticipated to put downward pressure on cobalt prices.

References Cited

Cobalt Development Institute, 1987, Statistics: Cobalt News, March, p. 9-10.

Jones, Monique, 1986, Cobalt market—1985 review: Cobalt News, March, p. 6-10.

Kielty, Edward, 1988, Cobalt—More stable times, *in* Metals Week nickel, moly, cobalt conference, Tucson, AZ, October 26-28, 1988, Proceedings: New York, Metals Week, 13 p.

———1990, What next for cobalt?—1991—A year to manage change, *in* Metals Week Conference, Tucson, AZ, October 25-26, 1990, Proceedings: New York, Metals Week, 26 p.

———1992, Cobalt review and outlook, *in* Metals Week Ferroalloys Conference, Tucson, AZ, November 5-6, 1992, Proceedings: New York, Metals Week, 22 p.

———1994, Cobalt—An unpredictable market: Engineering and Mining Journal, v. 195, no. 3, p. 28-30.

Kirk, W.S., 1985, A third pricing phase—Stability?: American Metal Market, v. 93, no. 163, August 23, p. 9, 12.

Kramer, David, and Salak, John, 1984, Cobalt $11.70/lb.—Zaire, Zambia: American Metal Market, v. 92, no. 52, March 15, p. 1, 16.

Mining Journal, 1979, Cobalt, *in* Mining annual review 1979: Mining Journal, 1979, p. 80-81.

Young, R.S., 1960, Cobalt—Its chemistry, metallurgy, and uses: New York, Reinhold Publishing Corp., 424 p.

Annual Average Cobalt Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1937	1.29	1953	2.43	1969	1.92	1985	11.43
1938	1.36	1954	2.60	1970	2.20	1986	7.49
1939	1.40	1955	2.60	1971	2.20	1987	6.56
1940	1.50	1956	2.58	1972	2.45	1988	7.09
1941	1.50	1957	2.03	1973	3.04	1989	7.64
1942	1.50	1958	2.00	1974	3.47	1990	10.09
1943	1.50	1959	1.77	1975	3.98	1991	16.92
1944	1.50	1960	1.54	1976	4.47	1992	22.93
1945	1.50	1961	1.50	1977	5.62	1993	13.79
1946	1.50	1962	1.50	1978	24.52	1994	24.66
1947	1.58	1963	1.50	1979	32.83	1995	29.21
1948	1.65	1964	1.50	1980	21.82	1996	25.50
1949	1.76	1965	1.63	1981	15.67	1997	23.34
1950	1.80	1966	1.65	1982	8.56	1998	21.43
1951	2.18	1967	1.85	1983	5.76		
1952	2.40	1968	1.85	1984	10.44		

[1]To convert to dollars per kilogram, multiply by 2.20462.

Note: Annual average prices were derived from price changes reported in the following sources.

1937-77, contract or producer price, domestic quotation for cobalt metal, *in* U.S. Bureau of Mines Minerals Yearbook; origins of prices are unknown.

1978, free market price, cobalt metal, *in* Engineering and Mining Journal, v. 180, no. 3, 1979, p. 138.

1979, free market price, cobalt metal, *in* Engineering and Mining Journal, v. 181, no. 3, 1980, p. 112.

1980, European free market price, 99.5% cobalt metal, *in* Metal Bulletin Handbook, 1981, p. 73.

1981, European free market price, 99.5% cobalt metal, *in* Metal Bulletin Handbook, 1982, p. 51, and U.S. spot price, 99.5 % cobalt cathode, *in* Metals Week.

1982-92, U.S. spot price, 99.5% cobalt cathode, *in* Metals Week.

1993, U.S. spot price, 99.8% cobalt cathode, *in* Metals Week.

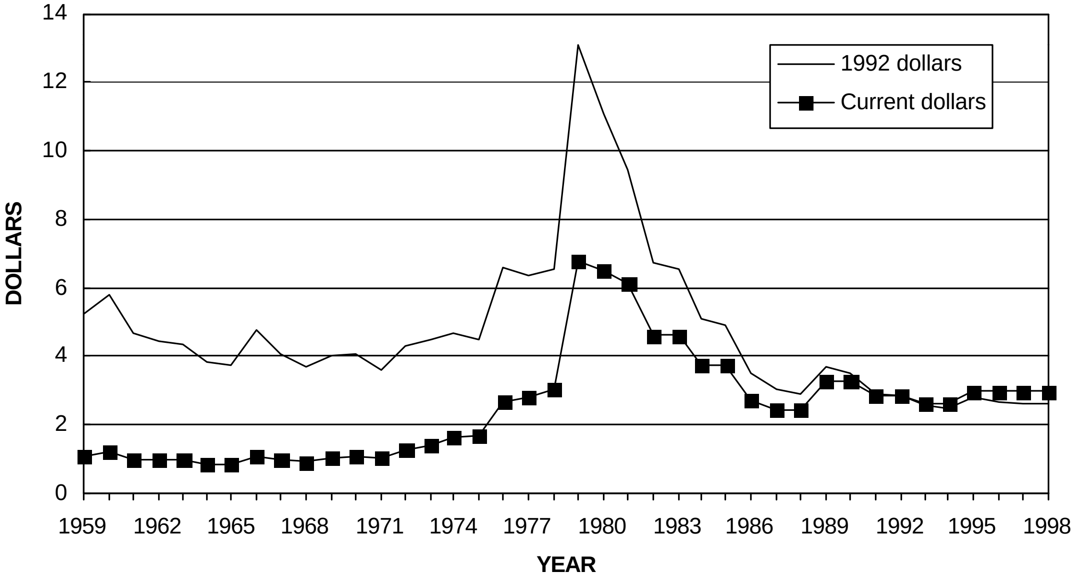
1994-98, U.S. spot price, 99.8% cobalt cathode, *in* Platt’s Metals Week.

Columbium (Niobium)

by Larry D. Cunningham

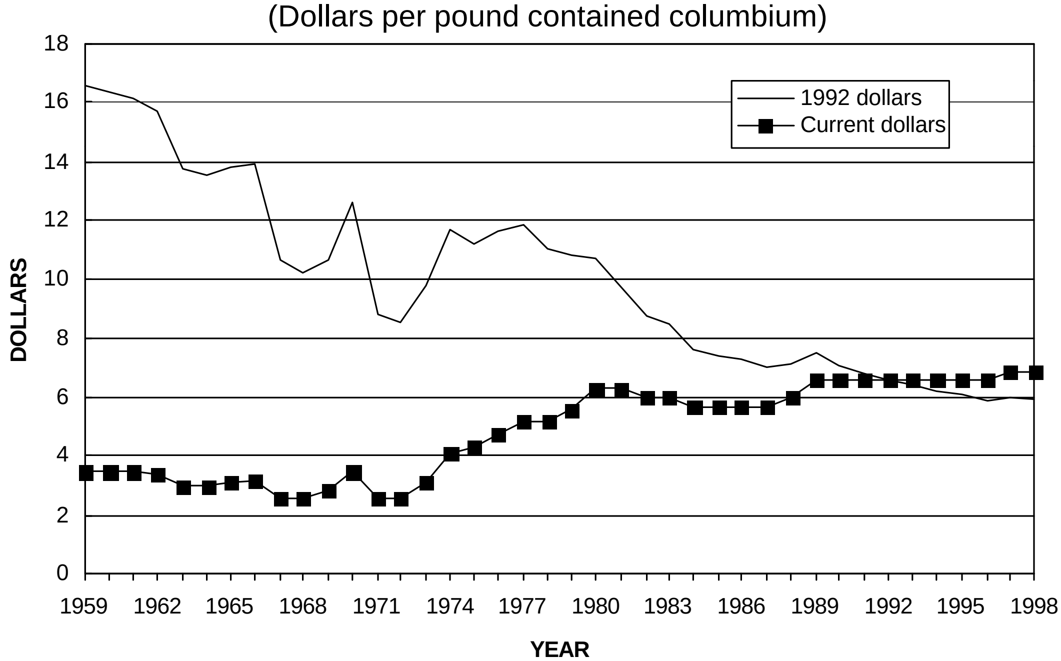
Yearend Average Columbium (Niobium) Concentrate Price

(Dollars per pound contained columbium pentoxide)



Yearend Average Ferrocolumbium (Ferroniobium) Price

(Dollars per pound contained columbium)



Significant events affecting columbium prices since 1958

1960-70	Development of pyrochlore deposits in Brazil and Canada
1970-79	Increased demand
1980	Columbium oxide produced from pyrochlore-based feed material
1981	Exports of Brazilian pyrochlore ceased
1994	Production of ferrocolumbium began in Canada
1997-98	Sales of ferrocolumbium from the National Defense Stockpile (NDS)
1998	Expansion of ferrocolumbium production capacity in Brazil

Columbium is a refractory metal that conducts heat and electricity well and is characterized by a high melting point, resistance to corrosion, and ease of fabrication. Columbium, in the form of ferrocolumbium, is used worldwide mostly as an alloying element in steels and in superalloys. Little commercial application was found for columbium until the 1930's, when metallurgists began using it in the form of ferrocolumbium in steel and as columbium carbide in high-speed cutting tools (Cunningham, 1985a). Acceptable substitutes, such as molybdenum, tantalum, titanium, tungsten, and vanadium, are available for some columbium applications, but substitution may lower performance and/or cost-effectiveness.

The columbium price is driven by the availability of columbium mineral feed materials, recycling being an insignificant source of supply. Thus, the events affecting the supply of columbium mineral concentrates are discussed herein. A price table and graph, however, are included for standard-grade ferrocolumbium, the dominant form in which columbium is consumed. In 1979, the increase in demand for "high-purity" ferrocolumbium in superalloys was significant. This increased columbium demand affected the prices for high-purity ferrocolumbium and for columbite, but had no real impact on the price for standard ferrocolumbium. The feed material for production of high-purity ferrocolumbium was columbite, and standard ferrocolumbium was produced from pyrochlore. In 1998, the price for columbium contained in concentrate was $4.29 per pound compared with $6.88 per pound for columbium contained in standard ferrocolumbium.

Brazil and Canada are the major producers of columbium mineral concentrates and converters of the material to ferrocolumbium. The U.S. columbium-mining industry has not been significant since 1959. The United States satisfies its columbium requirements primarily by importing ferrocolumbium and columbium oxide from Brazil, ferrocolumbium from Canada, and lesser amounts of columbium concentrates for processing from various countries. Many of the applications for columbium are either directly or indirectly defense related because of its use in the aerospace, communications, energy, and transportation industries. Thus, columbium is classified as critical and strategic, and, over the years, various columbium materials have been purchased for the NDS.

A significant activity during the 1950's was the U.S. Government's worldwide program for the purchase of about 6,800 metric tons (t) of combined columbium and tantalum oxides contained in columbium-tantalum ores and concentrates. The purchase program was terminated in 1959 (Cunningham, 1985a, b). The program, which was initiated to encourage increased production of columbium-tantalum ores and concentrates of domestic and foreign origin, largely governed the market price for columbium ores and concentrates. It also resulted in the discovery of large low-grade domestic and foreign deposits of columbium minerals. The program, however, was less successful in developing domestic columbium mineral production. The low grade of the discoveries precluded their development at current or expected future prices. Termination of the program was followed by lower market prices, resulting in reduced production worldwide. Marginal producers, who could not operate profitably at lower prices, halted production.

Reshaping of columbium supply and demand began in the 1960's. Discovery of the strengthening effect of small amounts of columbium in structural carbon steel eventually led to a widespread and growing use for columbium in high-strength low-alloy steels. Until the mid-1960's, the world's needs for columbium were provided for mostly by columbite concentrates mined in Nigeria; the Nigerian columbite was produced as a byproduct of tin mining. Development of pyrochlore deposits in Brazil and Canada during this period, however, greatly increased columbium availability (Cunningham, 1985a; Miller, Fantel, and Buckingham, 1986, p. 8; Crockett and Sutphin, 1993, p. 4-5). Pyrochlore deposits are mined primarily for columbium, and columbite and tantalite are recovered mostly as a byproduct/coproduct of other minerals, principally tin. The shift in columbium supply from Nigeria to Brazil and Canada did not have an adverse impact on the columbium price, which changed little or not at all during the 1960's owing to the readily available supplies of pyrochlore.

During the 1970's, increased demand, mostly in the form of ferrocolumbium for steelmaking, continued to be met by the large quantities of pyrochlore concentrates produced in Brazil and Canada. Pyrochlore became the standard material for the manufacture of ferrocolumbium for steelmaking.

Columbite-tantalite remained as the source material for the production of columbium oxide used in high-purity columbium products. As demand increased in the 1970's, prices began to escalate for columbium concentrates and columbium products. With continued strong demand for columbium in the manufacture of steels and especially high-purity columbium products, the price for columbium concentrates peaked in 1979.

In 1980, an important change in columbium supply took place when plants that produced columbium oxide from pyrochlore-based feed materials were established in Brazil and the United States, which resulted in lower prices for columbium oxide and high-purity columbium products (Jones, 1981). This change greatly diminished the need for columbite ores. Until 1980, columbium oxide had been produced mostly from columbite- and tantalite-based materials. Columbium concentrate prices fell during most of the 1980's owing to the large quantities of pyrochlore produced in Brazil and Canada and the columbium products produced from this feed material, especially in Brazil.

Brazil's production of columbium concentrates, mostly pyrochlore, accounts for more than 85% of total world production of columbium. Pyrochlore concentrates, however, have not been exported from Brazil since 1981. Pyrochlore concentrates produced in Brazil are processed locally, and some of the upgraded columbium products are consumed domestically, with the majority of the products exported. As the dominant columbium producer/supplier, Brazil has maintained a marketing strategy of stable supply and moderate price changes.

A significant change took place in the columbium industry in late 1994. The sole Canadian columbium concentrate producer began ferrocolumbium production at its columbium mine in Quebec (Teck Corp., 1994, p. 13, 32). The plant converts basically all pyrochlore concentrates produced at the mine to ferrocolumbium. Prior to commissioning of the plant, columbium concentrates produced at the mine were shipped mostly to the United States, Europe, and Japan for conversion to ferrocolumbium.

In 1997, the U.S. Department of Defense initiated the sale of ferrocolumbium from the NDS. From March 1997 through December 1998, the Defense Logistics Agency sold about 211 t of columbium contained in ferrocolumbium valued at about $2.98 million (Cunningham, 1998a, b, p. 1; Defense National Stockpile Center, 1998a, b). The overall average unit price for the sales, about $6.40 per pound of contained columbium, was somewhat less than that quoted for ferrocolumbium, $6.88 per pound of contained columbium.

In 1998, the leading Brazilian columbium producer initiated plans to raise its ferrocolumbium production capacity by about 50% by 2000. The expansion is aimed at maintaining the stability of world supply and pricing of ferrocolumbium in response to growing international demand (Metal Bulletin, 1998).

For most of the 1990's, the price for columbium remained stable as the demand for and supply of columbium continued to increase.

References Cited

Crockett, R.N., and Sutphin, D.M., 1993, International Strategic Minerals Inventory summary report—Niobium (columbium) and tantalum: U.S. Geological Survey Circular 930-M, 36 p.

Cunningham, L.D., 1985a, Columbium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 185-196.

———1985b, Tantalum, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 811-822.

———1998a, Columbium (niobium), *in* Mineral Commodity Summaries 1998: U.S. Geological Survey, p. 50-51.

———1998b, Columbium (niobium) and tantalum in 1997—Annual review: U.S. Geological Survey Mineral Industry Surveys, August, 12 p.

Defense National Stockpile Center, 1998a, Stockpile accepts ferrocolumbium offers: Fort Belvoir, VA, Defense National Stockpile Center news release, November 13, 1 p.

———1998b, Stockpile accepts ferrocolumbium offers: Fort Belvoir, VA, Defense National Stockpile Center news release, December 10, 1 p.

Jones, T.S., 1981, Columbium and tantalum, *in* Minerals Yearbook 1980, v. I: U.S. Bureau of Mines, p. 249-260.

Metal Bulletin, 1998, CBMM expands to maintain ferro-niobium stability: Metal Bulletin, no. 8311, September 21, p. 11.

Miller, F.W., Fantel, R.J., and Buckingham, D.A., 1986, Columbium availability—Market economy countries—A minerals availability appraisal: U.S. Bureau of Mines Information Circular 9085, 20 p.

Teck Corp., 1994, Teck Corp. annual report 1994: Vancouver, British Columbia, Canada, Teck Corp., 60 p.

Yearend Average Columbium (Niobium) Concentrate Price

(Dollars per pound contained columbium pentoxide[1])

Year	Price	Year	Price	Year	Price	Year	Price
1940	0.35	1955	3.40	1970	1.12	1985	3.75
1941	0.35	1956	3.40	1971	1.04	1986	2.75
1942	0.53	1957	3.40	1972	1.29	1987	2.43
1943	0.25	1958	3.40	1973	1.42	1988	2.43
1944	0.25	1959	1.08	1974	1.64	1989	3.25
1945	0.60	1960	1.22	1975	1.71	1990	3.25
1946	0.54	1961	1.00	1976	2.69	1991	2.83
1947	0.65	1962	0.95	1977	2.76	1992	2.83
1948	0.73	1963	0.95	1978	3.03	1993	2.60
1949	1.13	1964	0.85	1979	6.78	1994	2.60
1950	2.55	1965	0.85	1980	6.50	1995	3.00
1951	2.56	1966	1.11	1981	6.13	1996	3.00
1952	3.40	1967	0.97	1982	4.63	1997	3.00
1953	3.40	1968	0.92	1983	4.63	1998	3.00
1954	3.40	1969	1.05	1984	3.75		

[1] To convert to dollars per kilogram, multiply by 2.20462.

Sources: Metal Bulletin (1946-51), U.S. Government purchase (1952-58), E&MJ Metal and Mineral Markets (1959-66), Metals Week (1967-90), and Metal Bulletin (1991-98). Prices before 1946 were published by the U.S. Bureau of Mines; origins are unknown.

Yearend Average Ferrocolumbium (Ferroniobium) Price[1]

(Dollars per pound contained columbium[2])

Year	Price	Year	Price	Year	Price	Year	Price
1940	2.30	1955	6.90	1970	3.49	1985	5.66
1941	2.30	1956	6.90	1971	2.55	1986	5.66
1942	2.28	1957	4.90	1972	2.55	1987	5.66
1943	2.28	1958	3.73	1973	3.10	1988	6.00
1944	2.28	1959	3.45	1974	4.12	1989	6.58
1945	2.28	1960	3.45	1975	4.30	1990	6.58
1946	2.28	1961	3.45	1976	4.73	1991	6.58
1947	2.55	1962	3.40	1977	5.12	1992	6.58
1948	2.90	1963	3.00	1978	5.12	1993	6.58
1949	2.90	1964	3.00	1979	5.58	1994	6.58
1950	4.90	1965	3.10	1980	6.29	1995	6.58
1951	4.90	1966	3.21	1981	6.29	1996	6.58
1952	4.90	1967	2.53	1982	6.00	1997	6.88
1953	6.40	1968	2.53	1983	6.00	1998	6.88
1954	12.00	1969	2.79	1984	5.66		

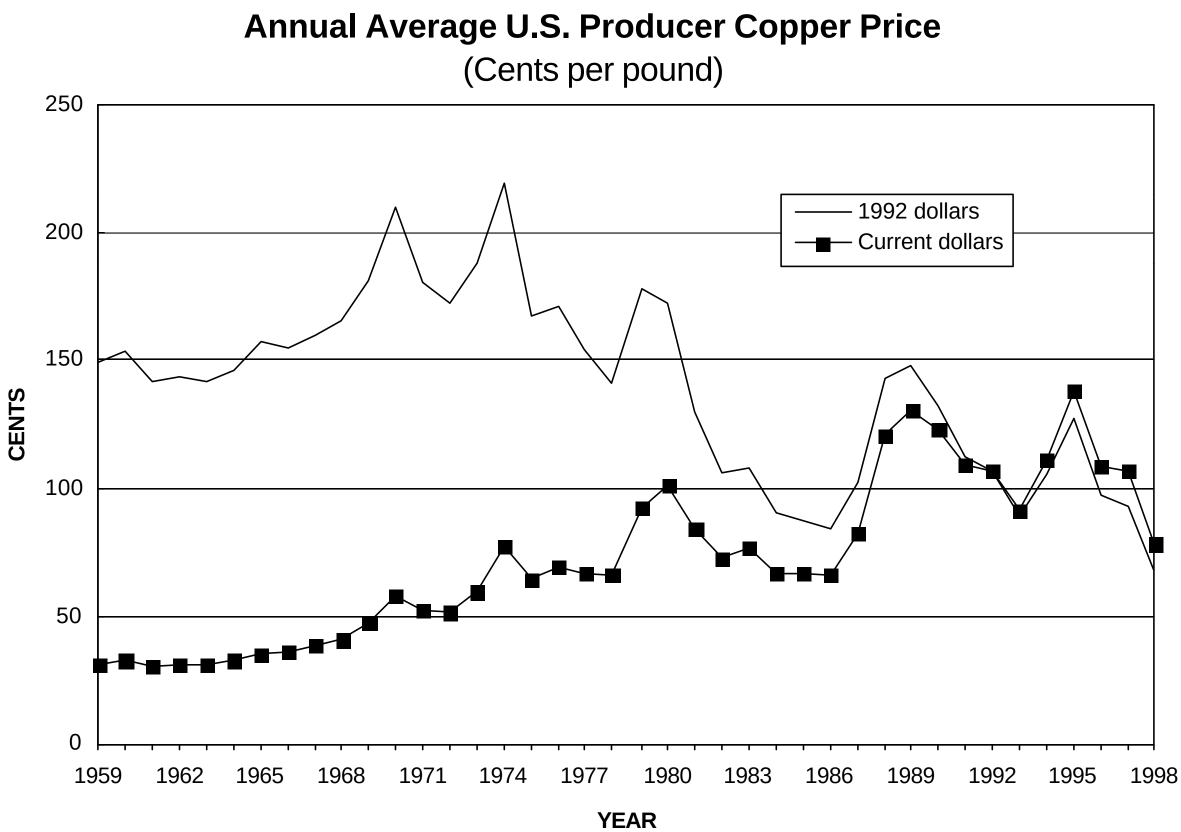
[1] Standard (steelmaking) grade, 65% contained columbium (1997-98).

[2] To convert to dollars per kilogram, multiply by 2.20462.

Sources: Mostly E&MJ Metal and Mineral Markets (1940-66), Metals Week (1967-92), Platt's Metals Week (1993-96), and American Metal Market (1997-98).

Copper

by Daniel Edelstein



Significant events affecting copper prices since 1958

1959-60	6-month labor strikes cause tight supplies, 17% U.S. consumption growth in 1959 and export growth in 1960
1961-62	Record high production rates balanced by strong consumption
1963	Voluntary production cutbacks reduce oversupply and help stabilize prices
1964-66	Vietnam War begins, accompanied by strong demand growth and stockpile releases
1967-68	Longest, most severe strikes to date; Government stockpile releases, set aside programs, export controls, and production stimulus programs initiated to meet defense needs; formation of the Intergovernmental Council of Copper Exporting Countries (CIPEC)
1970-73	Continued high wartime demand; easing of export controls and set-asides; two-tier pricing generates Government concern; price controls limit rise; nationalization of U.S-owned Chilean properties; the Organization of Petroleum Exporting Countries (OPEC) oil embargo begins
1974	End of price controls and strong demand cause first-half price rise before second-half economic reversal; last stockpile release, 229,000 metric tons; fixed exchange rates abandoned
1975-77	Demand drops precipitously owing to recession, copper inventories rise to record levels, price volatility
1978-80	Record copper consumption and lower stock levels; rising precious metals prices; 5-month labor strike; beginning of Commodity Exchange, Inc. (COMEX)-based pricing
1981	Large growth in domestic and world production; rising inventories
1982-84	Recession; inventory buildup; U.S. production sharply curtailed; expansion of COMEX-based pricing
1985-86	Draw down of high copper inventories; cutback in capacity at U.S. mines; cost-cutting and efficiency moves
1987-89	Historically low inventories; growing world consumption; prices peak at $1.68 in December 1988

1990-92	Global supply constraints balance recession; dissolution of the Soviet Union and political turmoil in Africa; precarious supply/demand balance leads to price volatility
1993	Stagnant world demand and rising inventories; London Metal Exchange (LME) intervention in market causes sharp price drop in September
1994-95	Strong global demand growth, sharp inventory decline, record high annual price, LME opens U.S. warehouses
1996	Sumitomo Corp. reveals huge trading losses and prices plummet at midyear despite global inventory decline
1997-98	Asian economic crises and rapid expansion of global capacity combine to generate large global surplus

Historically, wirebar was the dominant form of copper traded, and the price for refined copper wirebar was the "bellwether" price for copper. By the middle 1970's, however, technology had changed to continuous casting and drawing of wire rod directly from refined cathode, thus bypassing the need to cast wirebar. Even though more than 50% of primary copper produced in the United States is traded as rod by integrated mine producers, the high-grade copper cathode price is used as the "base" price for most transactions (Jolly, 1991, p. 46).

About 70% of domestic primary refined copper is produced from a multistage process, beginning with the mining and concentrating of ores, and followed by smelting and electrolytic refining to produce a high-grade cathode. The other 30% is produced from acid leaching of copper ores and wastes and solvent extraction and electrowinning of refined copper from the pregnant solution. Though most domestic producers have a high degree of vertical integration, copper products from each stage of processing have their own independent markets and are traded globally. Each product has its own pricing procedure that is linked, for the most part, to its copper content and the market price for refined copper. For example, copper concentrates, which contain between 20% and 35% copper, are purchased on the basis of the refined copper market value of their recoverable copper content, with charges taken for smelting and refining. Penalties may be assessed by the smelter/refiner for unwanted contaminants or low grade, and credits may be given for recoverable byproducts. Even though the smelting and refining charges are driven by processing cost factors, they may fluctuate significantly according to the market balance for concentrates. Similarly, prices for copper scrap are discounted from the refined value of the recoverable copper content to allow for processing costs and profit. Though the discount from refined must be sufficient to account for processing costs, market conditions for each type of scrap will affect their prices.

Until the late 1970's, domestic copper prices were generally referenced to the U.S. producer price. The traditional U.S. producer price, which normally included a charge for delivery and insurance, was based on annually negotiated sales contracts, with prices changing at least quarterly. The producer price system offered stability and served the interests of both the producer and the consumer. Producer prices tended to be above commodity exchange prices during weak markets and below the exchange prices during high demand periods. During periods of tight supply, U.S. mills, most of which were producer-owned subsidiaries, were given allocations assuring them of reasonably priced supplies (Jolly, 1991, p. 46). Although the producer pricing provided stability for contract purchases, it created a two-tiered price structure, where spot purchases and exchange prices were significantly different from producer prices. During the peak demand period of the Vietnam War, 1964-69, the average LME spot price was $0.575 per pound, compared with only $0.38 for the domestic producer price.

Beginning with the nationalization of foreign production in Africa and Chile in the 1960's and early 1970's, the US. producers' influence on domestic and world markets weakened, and domestic producer pricing became more market sensitive, changing frequently to track global prices. Periods of surplus supply, which occurred from the mid-1970's to the mid-1980's also contributed to the decreased influence of U.S. producer prices on world markets as surplus supplies flowed to the exchanges. As a result, U.S. producers abandoned classic producer pricing, some in 1978 and others in the early 1980's, and changed to a COMEX-based pricing system. Using the first-position COMEX price as a base, producers now quote premiums that may include transportation and insurance costs (Jolly, 1991). The current producer price quoted reflects a weighted average of the delivered price of copper to domestic consumers by domestic producers. Since the adoption of COMEX-based pricing, the producer margin has averaged almost $0.05 per pound, generally increasing at times of low prices and decreasing during high prices. During the high-price period from 1994 to 1997, the producer premium averaged less than 4 cents per pound, and contrary to historical trend, remained at that level although prices fell in 1998.

While the traditional producer prices provided a buffer to price shifts, speculative influence on a COMEX-based pricing system can result in price volatility, especially during tight markets, such as from late 1987 through 1989 and 1995 through 1997. Periods of stock surpluses, such as from 1975 to 1987, and the current market tend to create greater price stability. In response to the greater volatility of COMEX-based pricing, producers and consumers have increasingly used futures markets to hedge their sales and purchases.

Strike periods that occur with expiration of labor contracts have a significant effect on copper prices. The two 6-month strikes in 1946 and 1959, the 9-month strike in 1967-68, and the 5-month strike in 1980, were of particular significance. The 1967-68 strike had the most severe effect because it coincided with a period of high international demand occasioned by the Vietnam war and an unusually high period of worldwide economic growth. Government releases of stockpile material were used to alleviate shortages during each of these incidents, with the exception of the 1980 strike, which took place during a period of high commercial inventories and low Government stocks (Jolly, 1991, p. 47). Because more than 65% of world capacity comprises mines with outputs that are larger than 100,000 tons per year of copper, disruptions to production at any given large mine can affect prices. For example, from 1989 to 1991, a series of events tempered what might have otherwise been a modest oversupply period. These events included political insurgencies and labor strikes at foreign producers that closed a 180,000-ton-per-year mine in Papua New Guinea and severely reduced production in Zaire. The oversupply was further tempered by a smelter bottleneck that developed in late 1991 (Jolly, 1991, p. 47).

Governments' interventions in economic policies or directly in copper markets have had significant effects on copper prices. The U.S. Government has taken action during periods of war and national emergency to control prices and levy tariffs, to impose export quotas, to provide price supports, lend monies for expansion and exploration, to guarantee production purchases, and to buy and sell for the national stockpile. Most of these strategies , including the use of price controls (1971-74) were applied most recently during the Vietnam War. Beginning in the middle 1960's with the nationalization of copper mines in Chile, the Democratic Republic of the Congo (formerly Zaire) and Zambia, the world's private copper-mining industry (principally American) lost a significant share of its net equity and influence in copper and its ability to modulate production at times of surplus. In 1978 and 1983, which were periods of depressed copper prices, the U.S. industry unsuccessfully filed suit with the International Trade Commission to restrict imports of "low-priced" copper. Currency devaluations by copper-exporting counties also served to lower their costs to and maintain production levels. In 1967, the Inter-governmental CIPEC was formed. Its attempt to intervene in the depressed copper market in 1975 by limiting production of member countries to 90% of normal production and by reducing CIPEC-country copper exports by 15% was not fully observed and was unsuccessful in stimulating a price rise (Mikesell, 1979, p. 187-215).

Although the price of copper has been influenced by business cycles, government policy, and technological changes, production costs and the balance between supply and demand have ultimately been the principal determinants. The above influences, combined with the large capital investment and long lead times required to develop new mines, have, in recent decades, resulted in a highly cyclical copper industry. World mine production reached a peak in 1974 at the height of a major economic recession; this followed capacity growth stimulated by the high-demand war years. The resulting oversupply kept prices depressed for 4 years. Strong growth in consumption in the latter part of the 1970's led to tight supplies, high prices, and expansions in global capacity. When a sharp economic recession began in 1981, world mine production and capacity were again reaching peak levels. The resulting oversupply depressed prices for 5 years and resulted in the initial shutdown of about one-third of U.S. mine production. The large surplus and low prices discouraged new production and set the stage for the tight supplies and high prices that ensued from 1987 to 1992. There had been a 3-year shortfall in global production while overhanging inventories were worked off. The rise in price during 1987 was delayed by changing business practices, such as a shift to just-in-time inventories, and the expectations of new capacity. Large capital investments, particularly in the United States, had greatly increased worker productivity and allowed producers to regain profitability at the prevailing low prices.

World copper inventories began to rise in 1990 with the onset of a global recession and, except for a dip in 1992, continued to rise through most of 1993. Though relatively high by historical standards, copper prices declined as copper inventories rose. In 1992, a short-lived dip in inventories that was attributed to a bottleneck in smelter capacity caused prices to spike upward for several months before resuming their downward trend. Despite rising LME inventories, a second spike in prices occurred in mid-1993; a spot shortage of copper developed that was attributed to market control by several large market participants. Prices plummeted in September when the LME intervened to limit price backwardation (forward prices selling at a discount to spot prices).

Prices rose precipitously in 1994 following a strong growth in world demand, which had stagnated during the preceding 3 years, and development of a supply deficit. Beginning in 1994, numerous factors combined to stimulate a surge in new capacity development: a rapid growth in world demand fueled by the United States and Asia; changing political/investment climates, including increased government stability and privatization efforts, particularly in South America, made foreign investment more attractive; environmental restrictions made investment in North America less attractive; and companies sought to protect themselves from future downturns by investing in lower cost production. An anticipated surplus in production was delayed, in part, by higher-than-expected consumption and by production disruptions, including political strife in Africa, that reduced expected output. In June 1996, copper prices plummeted from the high level of the previous 18 months, the producer price falling to \$0.94, following revelations by Sumitomo that it had lost several billion dollars on unauthorized copper trades and speculation by industry that Sumitomo held large unreported copper inventories (Platt's Metals Week, 1996). Following the sharp drop in prices, however, an increasingly tight copper supply caused prices to rise, recovering to $1.20 per pound. With the onset of the Asian economic crises in 1997, demand failed to keep pace with production increases and an anticipated global copper surplus developed. The constant dollar copper price in 1998 fell to the lowest level since the Great Depression of the 1930's.

References Cited

Jolly, J.L., 1991, Copper, *in* Metal prices in the United States through 1991: U.S. Bureau of Mines, p. 45-52.

Mikesell, R.F., 1979, The world copper industry: Baltimore, MD, Johns Hopkins University Press, 393 p.

Platt's Metals Week, 1996, Sumitomo copper position raises market anxiety: Platt's Metals Week, v. 67, no. 25, June 7, p. 1.

Annual Average U.S. Producer Copper Price
(Cents per pound[1])

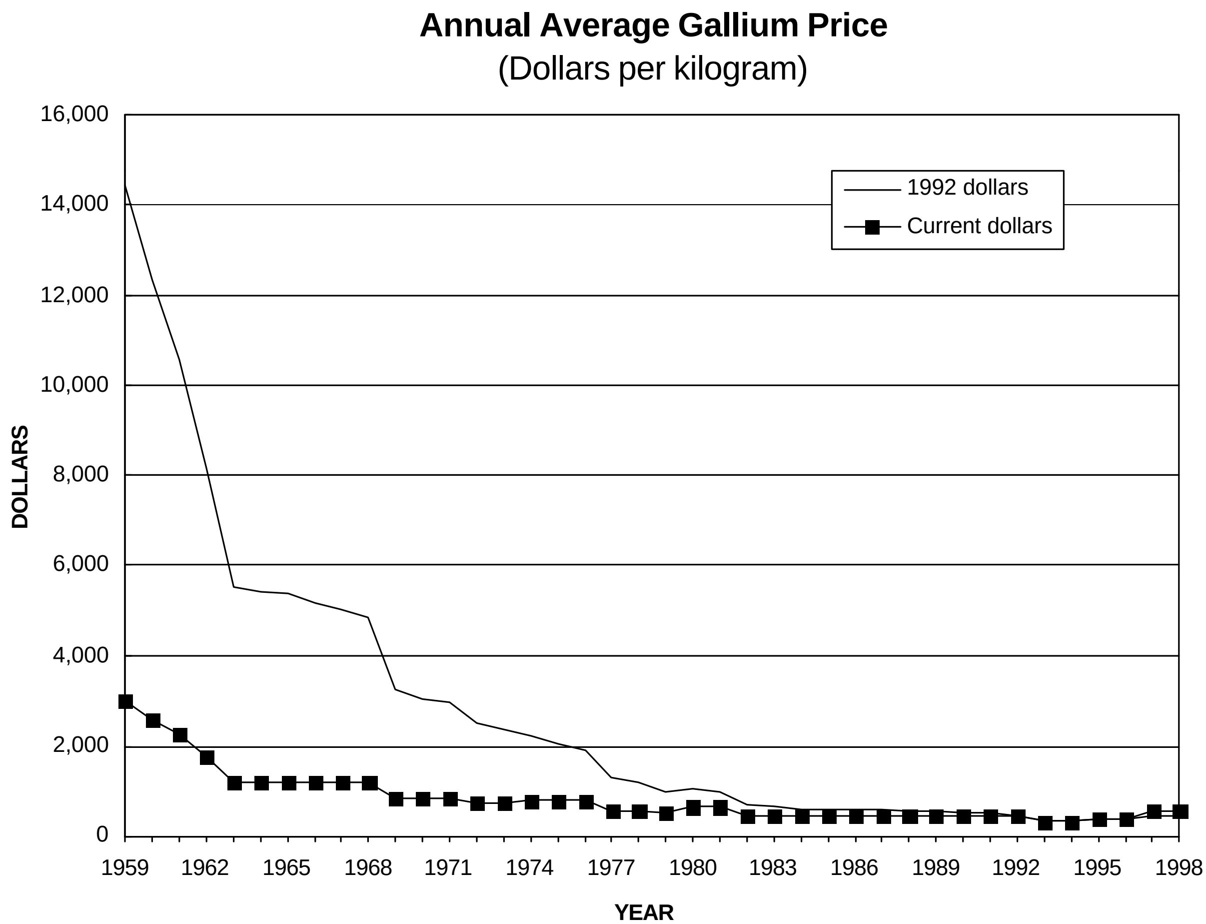
Year	Price	Year	Price	Year	Price	Year	Price
1850	22	1888	16.8	1926	14.05	1964	32.35
1851	17	1889	13.5	1927	13.05	1965	35.36
1852	22	1890	15.6	1928	14.81	1966	36.00
1853	22	1891	12.8	1929	18.35	1967	38.10
1854	22	1892	11.6	1930	13.23	1968	41.17
1855	27	1893	10.8	1931	8.37	1969	47.43
1856	27	1894	9.5	1932	5.79	1970	58.07
1857	25	1895	10.7	1933	7.28	1971	52.09
1858	23	1896	10.8	1934	8.66	1972	51.44
1859	22	1897	11.29	1935	8.88	1973	59.49
1860	23	1898	12.03	1936	9.71	1974	77.27
1861	22	1899	16.70	1937	13.39	1975	64.16
1862	22	1900	16.19	1938	10.22	1976	69.59
1863	34	1901	16.10	1939	11.20	1977	66.77
1864	47	1902	11.63	1940	11.53	1978	65.81
1865	39.2	1903	13.20	1941	12.00	1979	92.19
1866	34.2	1904	12.80	1942	12.00	1980	101.31
1867	25.4	1905	15.60	1943	12.00	1981	84.21
1868	23.0	1906	19.30	1944	12.00	1982	72.80
1869	24.2	1907	20.00	1945	12.00	1983	76.53
1870	21.2	1908	13.20	1946	14.04	1984	66.85
1871	24.1	1909	13.11	1947	21.27	1985	66.97
1872	35.6	1910	12.88	1948	22.32	1986	66.05
1873	28.0	1911	12.55	1949	19.50	1987	82.50
1874	22.0	1912	16.48	1950	21.58	1988	120.51
1875	22.7	1913	15.52	1951	24.50	1989	130.95
1876	21.0	1914	13.31	1952	24.50	1990	123.16
1877	19.0	1915	17.47	1953	29.05	1991	109.33
1878	16.6	1916	28.46	1954	29.94	1992	107.42
1879	18.6	1917	29.19	1955	37.51	1993	91.56
1880	21.4	1918	24.68	1956	42.00	1994	111.05
1881	19.2	1919	18.19	1957	30.17	1995	138.33
1882	19.1	1920	17.50	1958	26.31	1996	109.04
1883	16.5	1921	12.65	1959	30.99	1997	106.92
1884	13.0	1922	13.56	1960	32.34	1998	78.64
1885	10.8	1923	14.75	1961	30.32		
1886	11.1	1924	13.28	1962	31.00		
1887	13.8	1925	14.30	1963	31.00		

[1] To convert to cents per kilogram, multiply by 2.20462.

Note:
1850-96, New York price for Lake copper (99.9%-pure copper), *in* Loughlin, G.F., Prefatory note on the report on gold, silver, copper, lead, and zinc, Mineral Resources of the United States 1922, Part I, U.S. Geological Survey, 1925, p. 127a.
1897-98, New York price for Lake copper (99.9%-pure copper), *in* Engineering and Mining Journal.
1899-1908, Electrolytic (99.9%-pure copper) refinery price in New York, *in* Engineering and Mining Journal.
1909-22, Electrolytic (99.9%-pure copper) domestic f.o.b. refinery, *in* American Metal Market.
1923-72, Electrolytic (99.9%-pure copper) domestic delivered to Connecticut price, *in* American Metal Market.
1973-77, U.S. producer electrolytic (99.9%-pure copper) wirebar, *in* Metals Week.
1978-98, U.S. producer cathode (99.99%-pure copper), *in* Metals Week (1978-92) and Platt's Metals Week (1993-98).

Gallium

by Deborah A. Kramer



Significant events affecting gallium prices since 1958

1960-63	Technologic improvements in gallium recovery and purification techniques
1966-73	U.S. gallium demand increases significantly because of widespread use of light-emitting diodes (LED's)

Prices shown in the above graph are for gallium of 99.9999% purity. This grade has been used since the 1960's in gallium-arsenide-based optoelectronic devices, including LED's, laser diodes, and solar cells. From 1936 to 1960, prices for 99.9%-pure gallium were quoted at $3,000 per kilogram; this grade of metal, however, had very limited uses in commercial applications. Most of its consumption was for experimental purposes; small quantities were used as a specialized mirror coating, in high-temperature thermometers, and in low-melting-point alloys. Consequently, there was little relation between prices prior to 1960 and those after that time when commercial applications were developed.

Gallium is recovered primarily as a byproduct from the refining of bauxite to alumina. As a byproduct metal, price trends for gallium are not significantly influenced by macroeconomic factors; rather, they are driven by gallium supply and demand relations. The large drop in prices in the early 1960's was principally because of technologic improvements in gallium recovery and purification processes. Commercial gallium extraction techniques were introduced in the late 1950's (Beja, 1951; de la Breteque, 1957). As these processes were improved, the availability of gallium became greater, but the demand did not increase.

Introduction of the gallium-arsenide-based LED changed the consumption pattern of gallium from that of a laboratory curiosity to a metal with some consumer applications. LED's, used in consumer applications, such as displays in digital watches and hand-held calculators, were responsible for large annual increases in demand from 1966 to 1973. To capture the LED market, gallium prices continued to drop throughout this period.

Research and development of gallium arsenide's semiconducting properties, which were begun in the mid-1960's, has continued through 1998 as potential applications for the material continue to be evaluated (Brodsky, 1990). Gallium-arsenide-based integrated circuits have been developed and have made inroads into low-volume applications, such as sophisticated military warfare systems and supercomputers. Because these are low-volume applications and the quantity of gallium used per unit produced is small, gallium's raw material cost is not a significant factor in the item's final cost. The demand for gallium, therefore, has not increased to a level that cannot be met by existing supplies, and there has been no incentive to increase gallium's price. Although gallium prices have decreased as its uses have grown, it is still used in small quantities compared with many other metals and only in specialized applications where its properties are crucial.

Most gallium prices are directly negotiated between the producer and consumer, with larger volume consumers able to negotiate lower prices. Producer-quoted prices, therefore, may not represent actual selling prices; in most cases, they provide an indication of the trend of gallium prices.

References Cited

Beja, Maurice, 1951, Method of extracting gallium oxide from aluminous substances: U.S. Patent 2,574,008, 5 p.

Brodsky, M.H., 1990, Progress in gallium arsenide semiconductors: Scientific American, v. 262, no. 2, p. 68-75.

de la Breteque, Pierre, 1957, Method of recovering gallium from an alkali aluminate lye: U.S. Patent 2,793,179, 6 p.

Annual Average Gallium Price[1]
(Dollars per kilogram)

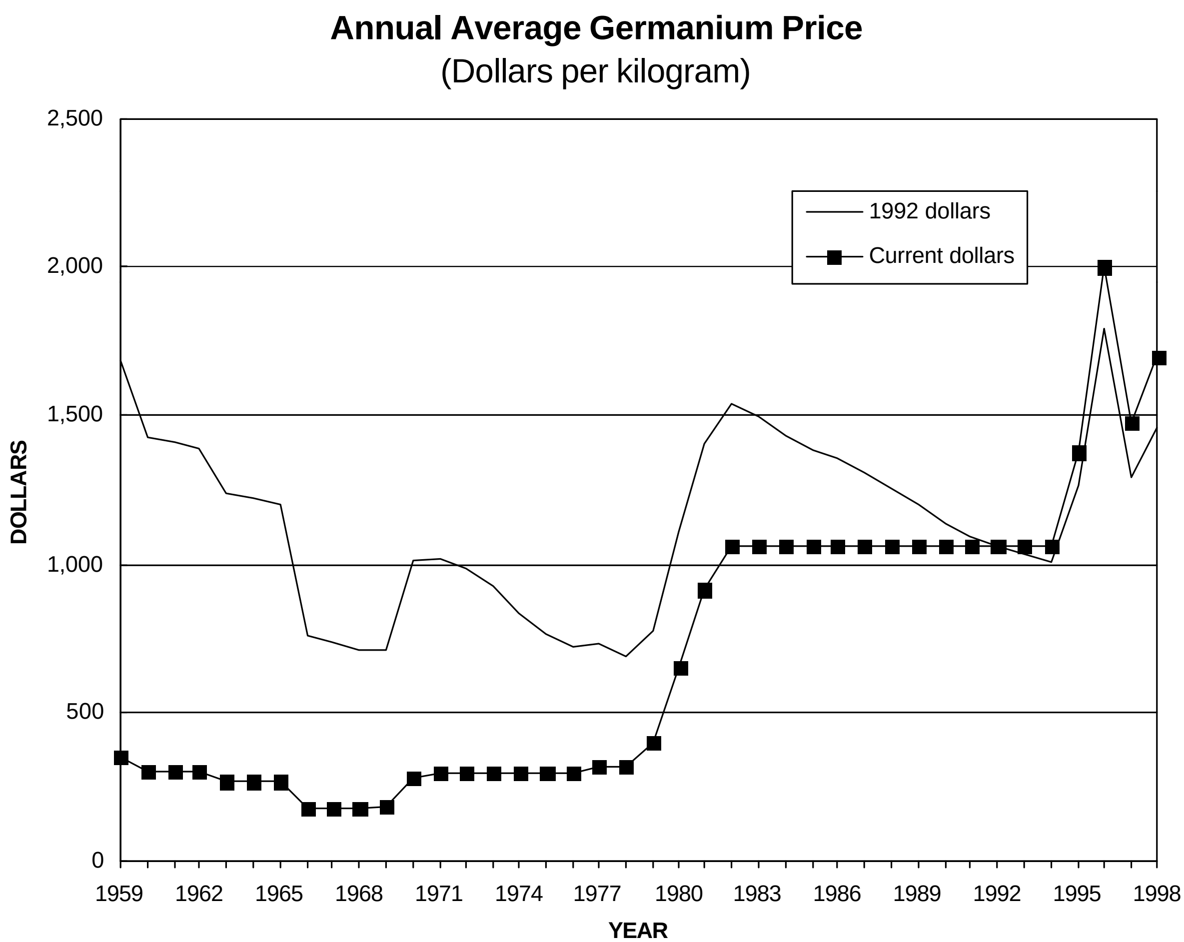
Year	Price	Year	Price	Year	Price	Year	Price
1959	3,000	1969	850	1979	510	1989	475
1960	2,600	1970	850	1980	630	1990	475
1961	2,250	1971	850	1981	630	1991	475
1962	1,750	1972	750	1982	470	1992	475
1963	1,200	1973	750	1983	470	1993	330
1964	1,200	1974	775	1984	445	1994	325
1965	1,200	1975	775	1985	475	1995	390
1966	1,200	1976	775	1986	475	1996	390
1967	1,200	1977	550	1987	475	1997	550
1968	1,200	1978	550	1988	475	1998	550

[1] 99.9999%-pure gallium metal.

Source: American Metal Market.

Germanium

by Robert D. Brown, Jr.



Significant events affecting germanium prices since 1958

1979-82	Increased demand, tight supply
1984	National Defense Stockpile (NDS) authorization, goal 30,000 kilograms
1987	New authorized NDS goal of 146,000 kilograms
1991	NDS goal lowered to 68,000 kilograms
1996	Increased demand, production shortages
1997	NDS stockpile sales begin

Germanium was discovered by Clemens Winkler in 1886, although its existence had been predicted by D.I. Mendeleev in his periodic table of elements in 1869. Germanium is a hard, grayish-white element; has a metallic luster; has the same crystal structure as diamond; and is brittle, like glass. It is a semiconductor, with electrical properties between those of a metal and an insulator. Germanium and its compounds remained almost entirely items of interest for research until World War II, although the use of germanium dioxide in treating anemia was reported in 1922 (Gregory, 1942).

With the invention and development of the crystal diode and the transistor, in the 1940's, germanium became an important industrial material (Bardeen and Brattain, 1948). Prior to 1945, the amount of germanium produced was very small, a few hundred pounds per year. From 1945 to 1949, the demand for electronic uses resulted in substantial growth of the germanium industry and higher prices for the metal.

After 1953, germanium prices started to decline progressively and, by 1966, bottomed out at $175 per kilogram of metal, the lowest price ever quoted. This price prevailed for the next 2 years, rose in 1969, and rose again in 1970 because of inflationary trends in the market. Prices remained constant at $293 per kilogram from 1971 through 1976.

The invention and development of the germanium transistor opened the door for countless applications of solid-state electronics. From 1950 through the early 1970’s, this area provided an excellent market for germanium. In the 1970’s, demand for germanium in transistors, diodes, and rectifiers declined, owing mainly to the increasing use of electronic-grade silicon as a replacement. The reduced demand for germanium in the electronic field was offset, however, by a dramatic increases in demand in fiber optics communication networks (Roskill's Letter from Japan, 1997), in infrared night vision systems (Metal Bulletin 1975), and as a polymerization catalyst (Metal Bulletin, 1995). These end uses represented 77% of worldwide germanium consumption for 1998.

Increased demand and tight supply caused dramatic increases in both domestic and foreign prices for germanium metal beginning in 1979. By December 1981, the domestic germanium metal quoted price was set at $1,060 per kilogram and remained there for 13 years. During most of this period, the free market price remained lower than the published producer price for germanium metal, owing to the development of a worldwide excess of supply relative to demand.

Germanium was designated a strategic and critical material and was included in the National Defense Stockpile (NDS) in 1984 with an initial goal of 30,000 kilograms of germanium metal. In 1987, a new NDS goal of 146,000 kilograms was established on the basis of U.S. Department of Defense estimates for actual emergency conditions of mobilization. In 1991, the goal was adjusted downwards to 68,000 kilograms. In 1995, the Defense Logistics Agency, which manages the NDS, made plans to sell germanium from the stockpile at the rate of 4,000 kilograms per year, through 2005. The release rate was increased to 6,000 kilograms per year in 1997, the first year of actual sales, and to 8,000 kilograms per year in 1998 (U.S. Department of Defense, 1998). Yearend 1998 inventory was 54,300 kilograms (Defense Logistics Agency, oral commun., 1999).

Starting in 1995, the producer price rose again and fluctuated around $1,500 per kilogram. It reached $2,000 per kilogram in 1996. The higher price levels were due to increased demand and shortages in production. The gradual releases of germanium from the U.S., Russian, and Ukrainian stockpiles with the lowering of world military tensions tended to stabilize prices.

Historically, the supply of germanium has been more than adequate to meet demand, and throughout its relatively short industrial existence, germanium has remained a “high-tech” material.

References Cited

Bardeen, John, and Brattain, W.H., 1948, The transistor—A semiconductor triode: Physics Review, v. 74, Series 2, July 15, p. 230-31.

Gregory, T.C., 1942, Germanium, *in* The condensed chemical dictionary: New York, Reinhold, p. 320.

Metal Bulletin, 1975, Minor, precious metals—Germanium: Metal Bulletin, no. 5971, March 4, p. 21.

———1995, Germanium dioxide prices continue to firm: Metal Bulletin, no. 7982, May 25, p. 7.

Roskill’s Letter From Japan, 1997, Germanium—Growth in demand led by the use of high-purity germanium tetrachloride in optical fibres: Roskill’s Letter From Japan, no. 256, August, p. 2-6.

U.S. Department of Defense, 1998, Strategic and critical materials report to the Congress: U.S. Department of Defense, January 13, 43 p.

Annual Average Germanium Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1945	441	1959	350	1973	293	1987	1,060
1946	397	1960	300	1974	293	1988	1,060
1947	397	1961	300	1975	293	1989	1,060
1948	507	1962	300	1976	293	1990	1,060
1949	727	1963	270	1977	314	1991	1,060
1950	397	1964	270	1978	319	1992	1,060
1951	397	1965	270	1979	398	1993	1,060
1952	484	1966	175	1980	653	1994	1,060
1953	720	1967	175	1981	911	1995	1,375
1954	650	1968	175	1982	1,060	1996	2,000
1955	650	1969	185	1983	1,060	1997	1,475
1956	535	1970	280	1984	1,060	1998	1,700
1957	445	1971	293	1985	1,060		
1958	445	1972	293	1986	1,060		

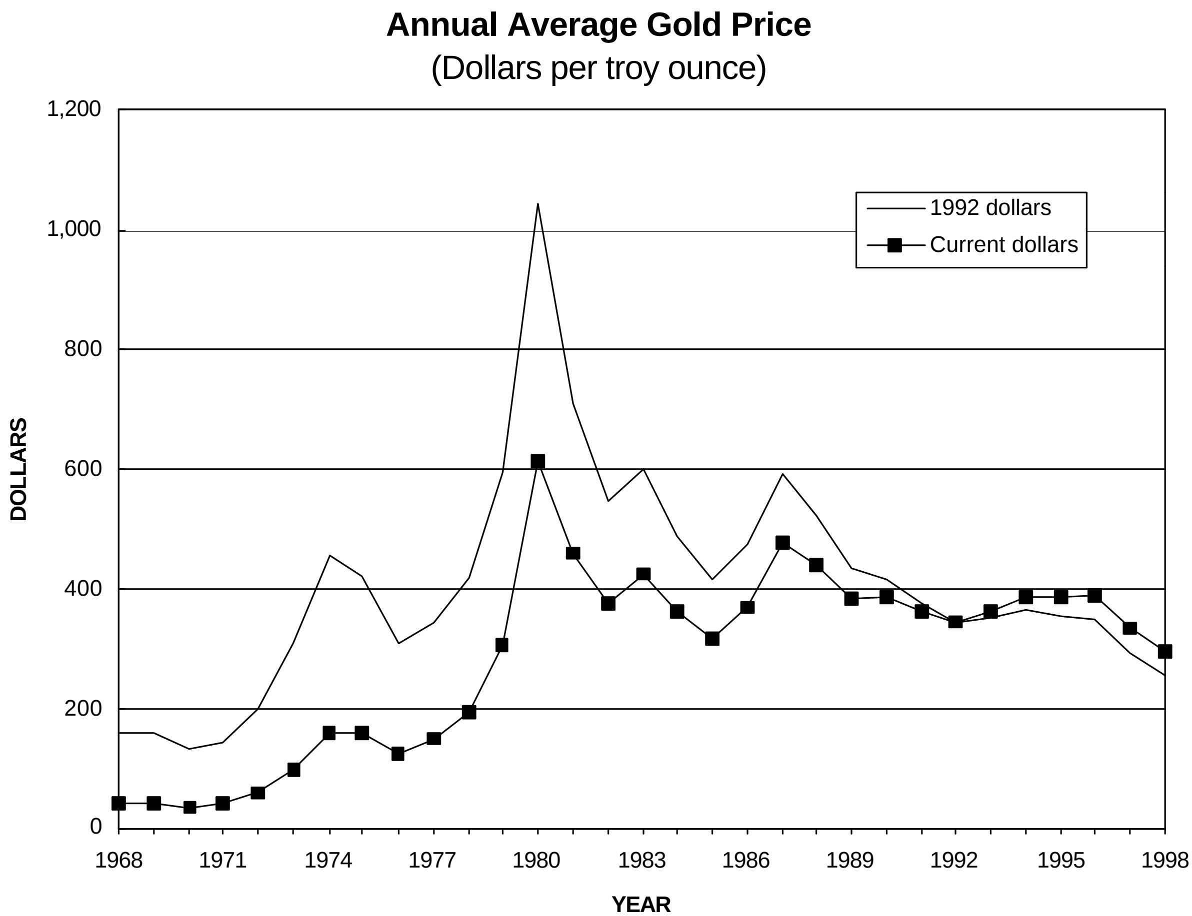
Note:
1945-57, Domestic price for 99.9%-pure germanium, *in* E & MJ Metal and Mineral Markets.
1957-66, Domestic price for zone-refined germanium (99.9999% pure), *in* E & MJ Metal and Mineral Markets.
1967-81, Domestic price for zone-refined germanium (99.9999% pure), *in* Metals Week.
1982-93, U.S. producer price for zone-refined germanium (99.9999% pure), *in* Metals Week [through June 14, 1993].
1993-94, U.S. producer price for zone-refined germanium (99.9999% pure), *in* Platt's Metals Week.
1995-98, U.S. producer price quotes for zone-refined germanium (99.9999% pure), *in* U.S. Geological Survey, Minerals Yearbook.

(This page intentionally left blank.)

Au

Gold

by Earle B. Amey



Significant events affecting U.S. gold prices since 1958

1961	The London gold pool was established in which U.S. central banks and seven other nations agreed to buy and sell gold to support the $35 per troy ounce price that had been established on January 31, 1934
1968	The London gold pool sustained enormous losses and was discontinued; the two-tier gold price was established, one tier was for official monetary transactions, the other for open-market transactions
1969-70	Mild U.S. recession
1971	President suspends convertibility of dollar into gold, dollar devalued by 7.9%
1972	Official U.S. gold price increased to $38 per ounce
1973	Official U.S. gold price increased to $42.22, dollar devalued, two-tier gold price terminated, Organization of Petroleum Exporting Countries (OPEC) oil embargo begins
1974	U.S. citizens allowed to hold gold bullion and coins for the first time in 40 years
1975	U.S. Treasury begins public sales of gold stocks
1976	International Monetary Fund (IMF) begins 5-year gold sales program, IMF auctions and lower inflation outlook drive gold prices down
1977	Hiatus in U.S. Treasury gold sales
1978	U.S. Treasury resumes selling gold, Middle Eastern investors increase gold purchases
1979	Soviet Union invades Afghanistan; political upheaval in Iran, taking of U.S. hostages

1980	Gold price peaks at an historic daily high of $850 per ounce on January 21, IMF completes 5-year gold sales program
1982-88	Fluctuating world currency exchange rates, increasing concern about U.S. trade and budget deficits and banking problems, and Third World debt
1989-91	Conflict in the Persian Gulf and the breaking up of the Soviet Union, erosion of gold's role as a safe haven for investors, generally weak economic growth worldwide
1992-96	Gold price remains relatively stable
1997-98	Central banks of several countries sell large shares of gold holdings to meet common-currency criteria for European Union or to demonetize; bank failures or insolvencies in East and Southeast Asian countries

The price of a fine suit of men's clothes can be used to show anyone who is not familiar with the price history of gold just how very cheap gold is today. With an ounce of gold, a man could buy a fine suit of clothes in the time of Shakespeare, in that of Beethoven and Jefferson, and in the Depression of the 1930's. In fact, this statement was still true in the 1980's, but not in the late 1990's. The suit standard now implies a gold price of perhaps $1,000 per troy ounce. Today, a really good man's suit can easily cost 4 ounces of gold, and that is without a vest, which once was standard (Forbes, 1998).

Increases in gold price have had a good basis of precedent in history. During the period from 1344 to 1717, the price for gold almost quadrupled, reaching the equivalent of $20.67 per ounce. That price was maintained for more than 200 years until the enactment of the Gold Reserve Act, which increased it to $35 per ounce, on January 30, 1934. Pressure for still another increase in price gathered momentum less than 15 years later. Prices as high as $105 per ounce had been proposed, and world trade brought prices up to $70 per ounce. (Colorado School of Mines, 1959).

In November 1961, the London gold pool, in which central banks of the United States and seven other nations agreed to buy and sell gold to support the $35-per-ounce price, was established (Ryan and McBreen, 1963, p. 607). On March 17, 1968, the governors of the member central banks announced that they would no longer buy and sell gold in the private market, but would sell gold to each other for $35 per ounce. Thus, a two-tier market was established—an official market and a private market—in which the price was determined by supply and demand (Ryan, 1970, p. 535).

Following the establishment of the two-tier price system, a fixed price of $35 per ounce for official monetary transactions and a floating market price for private transactions, the U.S. Government asked Engelhard Minerals and Chemicals Corp. (known today as Engelhard Corp.), to quote a daily price. Engelhard initiated a buying quotation—the lowest price at which it could obtain sufficient gold of 99.95% purity to meet its requirements. A selling quotation $0.60 above the buying price, later reduced to $0.40, was also established (Ryan, 1970, p. 535). Thus, the basis for the average domestic market price for gold shown in the table was established.

On August 15, 1971, the President announced the suspension of convertibility of dollars into gold (West, 1973, p. 540). Following provisions of Public Law 92-268, the Par Value Modification Act, enacted March 31, 1972, the official price of gold was increased to $38 per ounce on May 8, 1972 (West, 1975, p. 557).

Following amendments to the Par Value Modification Act contained in Public Law 93-110, enacted on September 21, 1973, the dollar's par value was devalued by 10%, to 0.829848 Special Drawing Rights (a unit of account in the IMF). This fixed the official price of gold at $42.22 per ounce effective at 12:01 a.m., October 18, 1973. That price remains unchanged. The two-tier pricing system was terminated on November 13, 1973 (West, 1975, p.560).

Following provisions of Public Law 93-373, enacted August 14, 1974, the President was given the authority to repeal the prohibition on the holding of gold by private citizens, and effective December 31, 1974, the prohibition was repealed (West, 1976, p. 603).

Gold occupies a unique position among the world's commodities; it is an internationally traded commodity and a long-established, universally acceptable storehouse of value, considered by many people worldwide to be superior to fiat paper currencies with fleeting longevity or fluctuating unpredictable value. It has been said many times that gold is "forever"; its high intrinsic and monetary value usually dictates that, in time, most of it will be recycled to serve again. Because of its historically high value, much of the gold mined throughout history is still in circulation in one form or another (Lucas, 1993, p. 505).

As a consequence of the dual roles played by gold, as commodity and as money, its price cannot be viewed as one would view the price of other goods or services in a free market. Gold also cannot be viewed strictly from the standpoint of the U.S. market alone because international political and economic events that may influence the market for gold as a commodity may be outweighed by developments perceived to favor gold as a medium of exchange.

During 1969 and 1970 the United States experienced a mild recession, while the Republic of South Africa was permitted to sell gold to the IMF at $35 per ounce or less to meet its foreign exchange needs (Hoyt, 1970, p. 521).

By December 1971, the U.S. dollar had been devalued by 7.9% per exchange agreements reached during the Smithsonian Accords in Washington, DC (West, 1973, p. 539-540). Affected by previous year's devaluation, the official U.S. gold price was raised to $38 per ounce on May 8, 1972; speculative buying was encouraged by monetary policy changes made by the European Economic Community and by restricted supplies of newly mined gold (West, 1974, p. 567).

In 1973, the gold market was influenced by a weakening and devaluation of the U.S. dollar, lowered confidence in currency values, higher inflation rates, unsettled world trade, and, for the third consecutive year, lower mine production. The official U.S. gold price was increased to $42.22 per ounce on September 21. An embargo was begun on petroleum shipments to the United States by OPEC in mid-October. The two-tier gold price system, begun in 1968, was terminated (West, 1975, p. 557).

The OPEC embargo contributed to rising oil prices, worldwide inflation, and general economic uncertainty in 1974. Gold prices rose on speculation near yearend, pending the yearend removal of restrictions on U.S. citizens holding gold. The gold price trend was reversed in December by the U.S. Treasury's announcement that it would offer 2 million ounces of Treasury gold for public sale beginning on January 6, 1975 (West, 1976, p. 603). Investor and speculator interest was diminished by the announcement by the IMF that it would sell 25 million ounces of gold on the open market beginning in 1976. The Treasury, however, was able to sell 1.25 million ounces from its gold stock during 1975 (West, 1977, p. 669).

Monthly IMF auctions were begun in midyear 1976 to provide capital for low-interest loans to developing countries. The IMF planned to sell a total of one-sixth of its gold stocks, or 25 million ounces, over a 5-year period, and planned to restore an equal portion to member countries. In addition, a reduced inflation outlook drove prices down until October when the low gold price and renewed anxiety about the economy served to reverse price trends. The Treasury gold stock was down at yearend owing to its use in Bicentennial medals, which were made by the Bureau of the Mint and sold by the American Revolution Bicentennial Administration (West and Butterman, 1978, p. 591).

The world economy was stagnant in 1977. Limited success in controlling inflation led to higher gold prices, which benefitted the IMF auctions that continued throughout the year. There was a hiatus in Treasury sales (Butterman, 1980, p. 428).

IMF auctions continued during 1978, and the Treasury resumed gold stock selling (Butterman, 1980, p. 428). Middle-East oil-producing countries and investors began purchasing gold with their eroding dollar assets.

Economic conditions worsened during the next 3 years. Negative political events in Iran, Afghanistan, and elsewhere propelled the price of gold to an historic high of $850 per ounce by January 21, 1980. The IMF completed its 5-year auction program in May 1980. The Treasury sold no more gold in 1980 or 1981 (Lucas, 1981, p. 347). After the U.S. hostages were released by Iran on January 20, 1981, political tension was lessened, which led to less hoarding and reduced gold prices. The Japanese began to invest in the gold market.

Although the United States' strict monetary policy contributed to a recession and high interest rates in 1982, the advent of computer trading contributed to short-term volatility in the gold price (Lucas, 1983, p. 370). Lingering effects of the world economic recession on the mineral industry led to profit taking during the first part of 1983. Speculative gold trading to midyear strengthened price but was followed by profit taking (Lucas, 1984, p. 385). Oil prices weakened, while gold supplies from mines and official sources increased.

In 1984, the price declined, owing to increasing strength of the U.S. dollar and investor selling. Weakened price and a favorable market outlook contributed to increases in demand for gold-bearing fabricated products (Lucas, 1985, p. 423). The U.S. dollar weakened in the first quarter of 1985 against major European currencies and the Japanese yen. It continued weakening in 1986, which encouraged gold investment (Lucas, 1988, p. 441) as oil prices declined sharply.

By 1987, there was a sharp reversal in world stock markets with a continued weakness of the U.S. dollar combined with growing concern regarding U.S. budget and trade deficits and increasing U.S. private and Third World debt. Stability of the international monetary arrangements was questioned. Volatile investment markets generated increased gold-trading activity (Lucas, 1988, p. 441). During 1988, gold prices declined in response to a variety of factors, such as the withdrawal of the U.S.S.R. from Afghanistan, which gave investors the perception that political stability was at hand; weakening oil prices combined with an increase in interest rates by the U.S. Federal Reserve led to reduced inflationary expectations, increasing U.S. dollar strength, as well as improved U.S. trade results (Lucas, 1989, p. 64-65).

Official sector gold sales increased in 1989 as central banks adopted a more aggressive policy of gold management (Lucas, 1991, p. 468). In addition, a change of attitude developed toward gold, aided by concerns about the security of bonds and other financial assets and a setback in the U.S. stock markets in mid-October (Gold Fields Mineral Services Limited, 1990, p. 8).

The rise in Japanese interest rates in 1990 provided alternate investment havens. The U.S.S.R. was reported to have sold significant amounts of gold for hard currency. The Chinese sold out of equity swap agreements that were negotiated in mid-1989. The gold price drifted down as a result of the Persian Gulf War and the recession (Gold Fields Mineral Services Limited, 1991, p. 8-9).

The brief multination conflict that started in 1991 in the Persian Gulf did little to affect the perception of moderating political stability generally or to influence the price of gold for any sustained period of time. The collapse and restructuring of the U.S.S.R., however, did much to reduce investor interest in gold (Gold Fields Mineral Services Limited, 1992, p. 5).

The end of the 1992 bear market encouraged a return of European and U.S. investor confidence. In 1993, the high gold price, which particularly affected the local currencies of the Middle East and Asia, resulted in reduced hoarding of coins and large amounts of gold scrap being off-loaded into the market (Roskill Information Services Ltd., 1995, p. i).

During 1994, the gold market held onto the gains achieved during the previous year, but the U.S. dollar price lacked direction and volatility. Hoarding of gold continued to be reduced, as investors deserted the market (Roskill Information Services Ltd., 1995, p. i).

The average dollar price of gold remained almost unchanged between 1994 and 1996. Late in the fourth quarter of 1996, the Dutch Government provided a key catalyst by selling one-third of its reserves (Gold Fields Mineral Services Limited, 1997, p. 5). Fears that other central banks might sell their gold reserves followed (CRU International Ltd., 1996, p. 19).

During 1997 and 1998, central banks of several countries sold large shares of gold holdings to meet common-currency criteria for the European Union or to demonetize. Bank failures or insolvencies in East and Southeast Asian countries created uncertainty in investment circles. The price of gold returned to the low levels of 1979 (Gold Fields Mineral Services Limited, 1998, p. 5).

References Cited

Butterman, W.C., 1980, Gold, *in* Minerals Yearbook 1977, v. I: U.S. Bureau of Mines, p. 427-445.

———1980, Gold, *in* Minerals Yearbook 1978-79, v. I: U.S Bureau of Mines, p. 377-399.

Colorado School of Mines, 1959, The price for gold: Colorado School of Mines Mineral Industries Bulletin, v. 2, no. 6, November, p. 10.

CRU International Ltd., 1996, Gold: CRU International Ltd. Quarterly Market Service, November, 60 p.

Forbes, 1998, Gold miners versus haberdashers: Forbes, May 4, v. 161, no. 9, p. 50-51.

Gold Fields Mineral Services Limited, 1990, Gold 1990: [London], Gold Fields Mineral Services Limited, 64 p.

———1991, Gold 1991: [London], Gold Fields Mineral Services Limited, 64 p.

———1992, Gold 1992: [London], Gold Fields Mineral Services Limited, 64 p.

———1997, Gold 1997: [London], Gold Fields Mineral Services Limited, 71 p.

———1998, Gold 1998: [London], Gold Fields Mineral Services Limited, 63 p.

Hoyt, C.D., 1970, Gold, *in* Minerals Yearbook 1969, v. I: U.S. Bureau of Mines, p. 521-538.

Lucas, J.M., 1981, Gold, *in* Minerals Yearbook 1980, v. I: U.S. Bureau of Mines, p. 347-373.

———1983, Gold, *in* Minerals Yearbook 1982, v. I: U.S. Bureau of Mines, p. 369-396.

———1984, Gold, *in* Minerals Yearbook 1983, v. I: U.S. Bureau of Mines, p. 385-411.

———1985, Gold, *in* Minerals Yearbook 1984, v. I: U.S. Bureau of Mines, p. 405-435.

———1988, Gold, *in* Minerals Yearbook 1986, v. I: U.S. Bureau of Mines, p. 421-458.

———1988, Gold: U.S. Bureau of Mines Mineral Commodity Summaries 1987, p. 62-63.

———1989, Gold: U.S. Bureau of Mines Mineral Commodity Summaries 1989, p. 64-65.

———1991, Gold, *in* Minerals Yearbook 1989, v. I: U.S. Bureau of Mines, p. 455-482.

———1993, Gold, *in* Minerals Yearbook 1990, v. I: U.S. Bureau of Mines, p. 495-522.

Roskill Information Services Ltd., 1995, Gold—Market update, analysis, and outlook: Roskill Information Services Ltd., 145 p., 3 apps., unpaginated.

Ryan, J.P., 1970, Gold, *in* Minerals Yearbook 1968, v. I: U.S. Bureau of Mines, p. 529-549.

Ryan, J.P., and McBreen, K.M., 1963, Gold, *in* Minerals Yearbook 1961, v. I: U.S. Bureau of Mines, p. 597-618.

West, J.M., 1973, Gold, *in* Minerals Yearbook 1971, v. I: U.S. Bureau of Mines, p. 539-560.

———1974, Gold, *in* Minerals Yearbook 1972, v. I: U.S. Bureau of Mines, p. 567-588.

———1975, Gold, *in* Minerals Yearbook 1973, v. I: U.S. Bureau of Mines, p. 557-581.

———1976, Gold, *in* Minerals Yearbook 1974, v. I: U.S. Bureau of Mines, p. 603-626.

———1977, Gold, *in* Minerals Yearbook 1975, v. I: U.S. Bureau of Mines, p. 669-696.

West, J.M., and Butterman, W.C., 1978, Gold, *in* Minerals Yearbook 1976, v. I: U.S. Bureau of Mines, p. 591-615.

Annual Average Gold Price[1]

(Dollars per troy ounce[2])

Year	Price	Year	Price	Year	Price	Year	Price
1968	40.06	1976	125.32	1984	360.66	1992	344.97
1969	41.51	1977	148.31	1985	317.66	1993	360.91
1970	36.41	1978	193.55	1986	368.24	1994	385.41
1971	41.25	1979	307.50	1987	477.95	1995	385.50
1972	58.60	1980	612.56	1988	438.31	1996	389.08
1973	97.81	1981	459.64	1989	382.58	1997	332.38
1974	159.74	1982	375.91	1990	384.93	1998	295.14
1975	161.49	1983	424.00	1991	363.29		

[1] Domestic market price, 99.95%-pure gold.

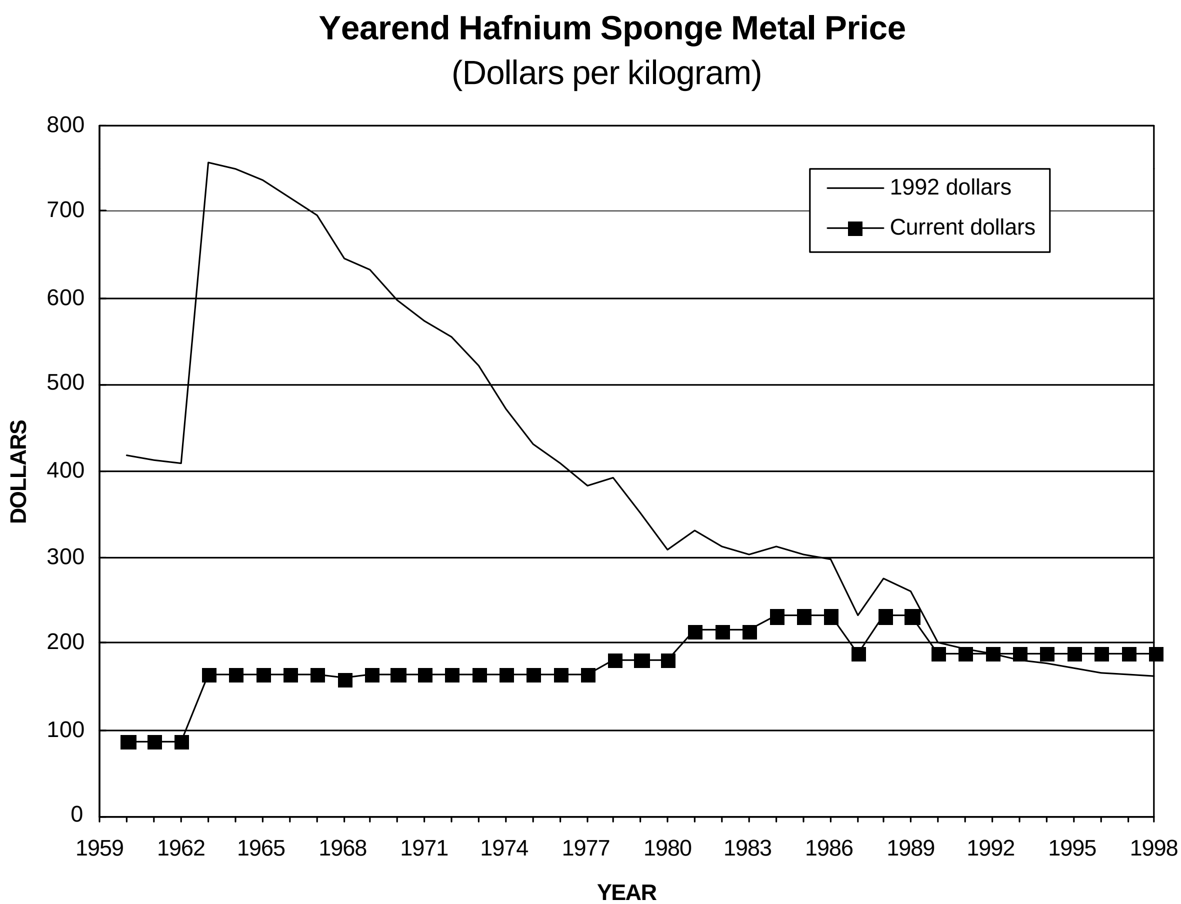
[2] To convert to dollars per kilogram, multiply by 32.1507.

Source: Engelhard Corp., published in Metals Week [through June 14, 1993] and Platt's Metal Week.

(This page intentionally left blank.)

Hafnium

by James B. Hedrick



Significant events affecting hafnium prices

1950	The decision to use hafnium-free zirconium in nuclear reactors
1951	The decision to use hafnium in nuclear reactor control rods
1979-81	Economic recession high inflation

In 1923, hafnium was discovered when Dirk Coster and George Charles von Hevesey separated it from zirconium. Anton Eduard van Arkel and Jan Hendrik de Boer first produced metal 2 years later by using the crystal bar process—hafnium tetrachloride passed over a tungsten filament (van Arkel and de Boer, 1925). Hafnium and zirconium occur together in the ore mineral zircon. Until the 1940's, fractional crystallization of zirconium-hafnium compounds was used to produce limited quantities of hafnium oxide and metal powder. In 1948, hafnium metal powder was quoted at $32 per gram ($32,000 per kilogram). Because of the high costs associated with this technique, a more-economical means was sought. Development of improved methods to separate the two elements began in the 1940's. In 1949, the price of hafnium metal powder dropped to $22 per gram ($22,000 per kilogram). That same year, Carbide & Chemicals Corp., Oak Ridge, TN, developed a liquid-liquid solvent extraction technique to remove hafnium from zirconium; technology that had grown out of the Manhattan Project (Powell, 1961). Commercial production of hafnium arose from the need to produce hafnium-free zirconium metal for use in nuclear reactors. In 1950, a decision was made to use zirconium in the prototype land-based *Nautilus* nuclear reactor for future use in submarines (Wilson and Staehle, 1960, p. 1). In 1951, hafnium was selected as the material to be used in the reactor's control rods.

Hafnium was an expensive laboratory metal in 1945 when development work on an improved magnesium-reduction process (Kroll process) began at the U.S. Bureau of Mines' (USBM) Northwest Electrodevelopment Experiment Station in Albany, OR (Etherington, Dalzell, and Lillie, 1955, p. 2). A pilot plant to produce zirconium metal by using the Kroll process began operating in 1947 and was expanded in 1949, 1950, and twice in 1951 (Kroll, 1937; Kroll, Schlechten, and Yerkes, 1946; Kroll, Schlechten, and others, 1947; Kroll, Anderson, and others, 1948). It was not until 1951, however, that the USBM facility produced several kilograms of hafnium metal grading 28% hafnium and the balance zirconium. By yearend 1951, the USBM produced 3,916 kilograms (8,634 pounds) of hafnium oxide that was used to produce 1,395 kilograms (3,075 pounds) of hafnium sponge (Smith and Stephens, 1960, p. 84).

Hafnium's commercial availability coincided with the expiration of U.S. Department of Defense contracts for nuclear reactors in 1962. The price remained stable at about $165 per kilogram ($75 per pound) for 15 years, and the continued availability of the metal resulted from the growth and development of the commercial nuclear industry.

U.S. demand for hafnium declined in the 1990's as no new orders for nuclear reactors were placed. Demand is primarily for replacement parts and control rods in existing nuclear reactors and as an alloying agent in certain superalloys.

References Cited

Etherington, H., Dalzell, R.C., and Lillie, D.W., 1955, Zirconium and its applications to nuclear reactors, chap. 1 *of* Lustman, B., and Kerze, F., Jr., eds., The metallurgy of zirconium: New York, McGraw-Hill, p. 1-18.

Kroll, W.J., 1937, The formation of titanium and zirconium: Zeitschrift für Anorganishe und Allgemeine Chemie, v. 234, p. 42-50.

Kroll, W.J., Schlechten, A.W., and Yerkes, L.A., 1946, Ductile zirconium from zircon sand: Transcripts of the Electrochemistry Society, v. 89, p. 365-376.

Kroll, W.J., Schlechten, A.W., Carmody, W.R., Yerkes, L.A., Holmes, H.P., and Gilbert, H.L., 1947, Recent progress in the metallurgy of malleable zirconium: Transcripts of the Electrochemistry Society, v. 92, p. 99-113.

Kroll, W.J., Anderson, C.T., Holmes, H.P., Yerkes, L.A., and Gilbert, H.L., 1948, Large scale laboratory production of ductile zirconium: Transcripts of the Electrochemistry Society, v. 94, p. 1-20.

Powell, J.E., 1961, Separation of rare earths by ion exchange, chap. 5 *of* Spedding, F.H., and Daane, A.H., eds., The rare earths: New York, John Wiley & Sons, p. 55-73.

Smith, E.W., and Stephens, W.W., 1960, Hafnium reduction process, chap. 3 *of* Thomas, D.E., and Hayes, E.T., eds., The metallurgy of hafnium: U.S. Atomic Energy Commission, p. 83-106.

van Arkel, A.E., and de Boer, J.H., 1925, Preparation of pure titanium, zirconium, hafnium, and thorium metal: Zeitschrift für Anorganische und Allgemeine Chemie, v. 148, p. 345-350.

Wilson, W.H., and Staehle, R.W., 1960, History of hafnium, chap. 1 *of* Thomas, D.E., and Hayes, E.T., eds., The metallurgy of hafnium: U.S. Atomic Energy Commission, p. 1-8.

Yearend Hafnium Sponge Metal Price
(Dollars per kilogram[1])

Year	Price	Year	Price	Year	Price	Year	Price
1959	NA	1969	165.35	1979	181.88	1989	231.49
1960	88.18	1970	165.35	1980	181.88	1990	187.39
1961	88.18	1971	165.35	1981	214.95	1991	187.39
1962	88.18	1972	165.35	1982	214.95	1992	187.39
1963	165.35	1973	165.35	1983	214.95	1993	187.39
1964	165.35	1974	165.35	1984	231.49	1994	187.39
1965	165.35	1975	165.35	1985	231.49	1995	187.39
1966	165.35	1976	165.35	1986	231.49	1996	187.39
1967	165.35	1977	165.35	1987	187.39	1997	187.39
1968	159.84	1978	181.88	1988	231.49	1998	187.39

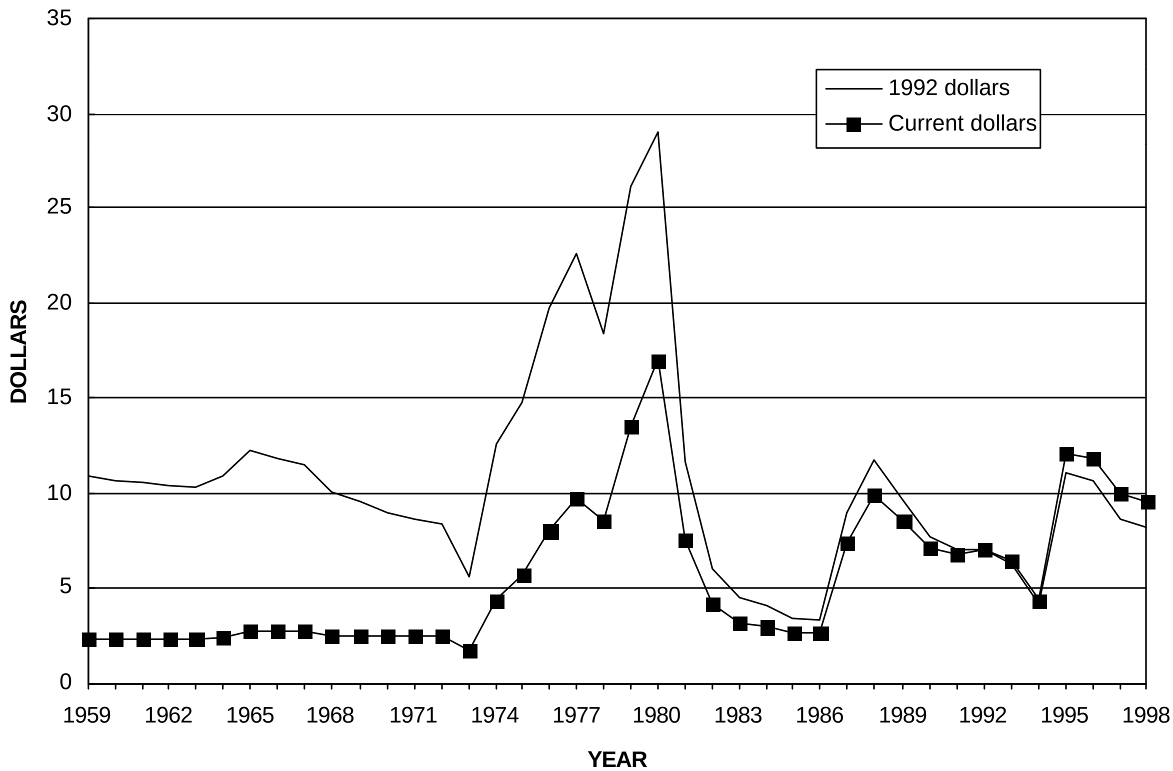
NA Not available
[1] Prices are an average of a range, converted from pounds.

Source: American Metal Market.

Indium

by Robert D. Brown, Jr

Annual Average Indium Price
(Dollars per troy ounce)



Significant events affecting indium prices since 1958

1973-80	Period of high demand, significant increase for nuclear control rods
1979	Lower demand after nuclear powerplant accident at Three Mile Island
1980-82	Economic recessions
1985	Development of indium phosphide semiconductors and indium-tin-oxide thin films
1989	Indium added to National Defense Stockpile (NDS) acquisition plan
1992-94	NDS acquisition of indium
1995	Steady price increase owing to tight supply and strong demand
1996	Steady price decline owing to greater supply and significant recycling
1997	Release of more than half of NDS holdings
1997-98	Reduced demand owing to decrease in production of liquid crystal displays (LCD's) and to shift to more-efficient thin-film technology

Indium is produced mainly from residues generated during zinc ore processing. Prior to 1940, indium was used almost entirely for experimental purposes, although domestic production had begun in 1926. Because of its rarity, about the same as that of silver (Weeks, 1973, p. 242) and lack of industrial applications, indium was sold only in small quantities during this period. The first commercial application came in 1933, when small amounts of indium were added to certain gold dental alloys. The Indium Corporation of America (ICA) was founded in 1934 and became the major domestic producer.

From 1940 through 1945, prices were usually determined through individual negotiations between the producer and consumer (Ludwick, 1959, p. 9).

The first large-scale application for indium was as a coating for bearings in high-performance aircraft engines during World War II (Slattery, 1995, p. 157). Indium increased hardness and helped prevent seizure and corrosion of the bearings. After the war, production gradually increased as new uses were found in fusible alloys, solders, and electronics. A producer price for indium was first established by the ICA in 1945, and it remained at the same level through 1963.

During the period from 1973 through 1980, demand increased, especially for use in nuclear control rods, and easily accessible supplies of raw materials gradually decreased. The ICA depleted its source of feedstock in Bolivia and then obtained source material from Europe. The inability to meet demand was the major factor in the price reaching $20 per troy ounce during 1980, when the annual average price was $17. To increase supply, world producers expanded production capacities.

Orders for nuclear control rods dropped when the rate of nuclear power expansion decreased in the United States following the Three Mile Island accident in 1979. Increased production led to an oversupply during the recessions of the early 1980's. By 1982, the price had plummeted to less than $3 per troy ounce (annual average was $3.19). In 1988, in response to growing demand, especially in the Japanese electronics industry, it climbed to nearly $10 per troy ounce.

In the middle and late 1980's, the development of indium phosphide semiconductors and indium-tin-oxide thin films for LCD's aroused much interest. By 1992, the thin-film application had become the largest end use (Jasinski, 1993).

In 1989, indium was included in the list of materials to be added to the NDS (Schmitt, 1989). The original stockpile goal was 42 metric tons; this was reduced to 7.7 tons in 1992. During that same year, the Defense Logistics Agency, manager of the NDS, began purchasing indium. The NDS had acquired its highest level, 1.56 tons of indium, by 1994. According to the NDS Annual Materials Plan for 1996, indium was to be eliminated from the stockpile, but sales would be limited to 1.1 metric tons per year (American Metal Market, 1997). Slightly more than this amount was sold in 1997, leaving the inventory at 0.44 ton, which was sold in December 1998.

In 1995, a tight supply situation with strong demand forced the price to increase steadily to a $16.25 per troy ounce high. The following year, increased supply and the implementation of an efficient recycling process forced prices back down to a $6.53 per troy ounce low (Roskill Information Services Ltd., 1996, p. 34). This dramatic rise-and-fall is hidden in the annual average statistics, which indicate a drop of only $0.20 from 1995 to 1996.

In 1998, indium demand slackened owing to the second successive year of somewhat lower LCD production and the introduction of a new thin-film coating technology that requires only one-third as much indium per unit as the older process (Roskill Information Services Ltd., 1998, p. 2). After fluctuating moderately in 1997, the price was quite steady in 1998.

References Cited

American Metal Market, 1997, DLA planning sale of indium: American Metal Market, v. 105, no. 35, February 20, p. 12.

Jasinski, S.M., 1993, Indium, *in* Mineral Commodity Summaries 1993: U.S. Bureau of Mines, p. 84-85.

Ludwick, M.T., 1959, Indium, discovery, occurrence, development, and characteristics: Utica, NY, Indium Corporation of America, 770 p.

Roskill Information Services Ltd., 1996, The economics of indium: London, Roskill Information Services Ltd., 111 p.

——1998, Indium—Prices may fall: Roskill's Letter from Japan, no. 270, October, p. 2.

Schmitt, Bill, 1989, Pentagon report urges stockpiling of indium, rhodium, and ruthenium: American Metal Market, v. 97, no. 78, April 21, p. 1.

Slattery, J.A., 1995, Indium and indium compounds, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley, v. 14, p. 155-160.

Weeks, R.A., 1973, Gallium, germanium, and indium, *in* Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 237-246.

Annual Average Indium Price[1]
(Dollars per troy ounce[2])

Year	Price	Year	Price	Year	Price	Year	Price
1936	30.00	1952	2.25	1968	2.50	1984	3.00
1937	30.00	1953	2.25	1970	2.50	1985	2.63
1938	30.00	1954	2.25	1970	2.50	1986	2.61
1939	30.00	1955	2.25	1971	2.50	1987	7.30
1940	23.00	1956	2.25	1972	2.50	1988	9.92
1941	12.50	1957	2.25	1973	1.77	1989	8.55
1942	22.50	1958	2.25	1974	4.42	1990	7.15
1943	12.50	1959	2.25	1975	5.67	1991	6.78
1944	8.75	1960	2.25	1976	8.03	1992	7.01
1945	4.88	1961	2.25	1977	9.77	1993	6.43
1946	2.25	1962	2.25	1978	8.56	1994	4.44
1947	2.25	1963	2.25	1979	13.48	1995	12.06
1948	2.25	1964	2.40	1980	17.00	1996	11.86
1949	2.25	1965	2.75	1981	7.53	1997	9.93
1950	2.25	1966	2.75	1982	4.18	1998	9.52
1951	2.25	1967	2.75	1983	3.19		

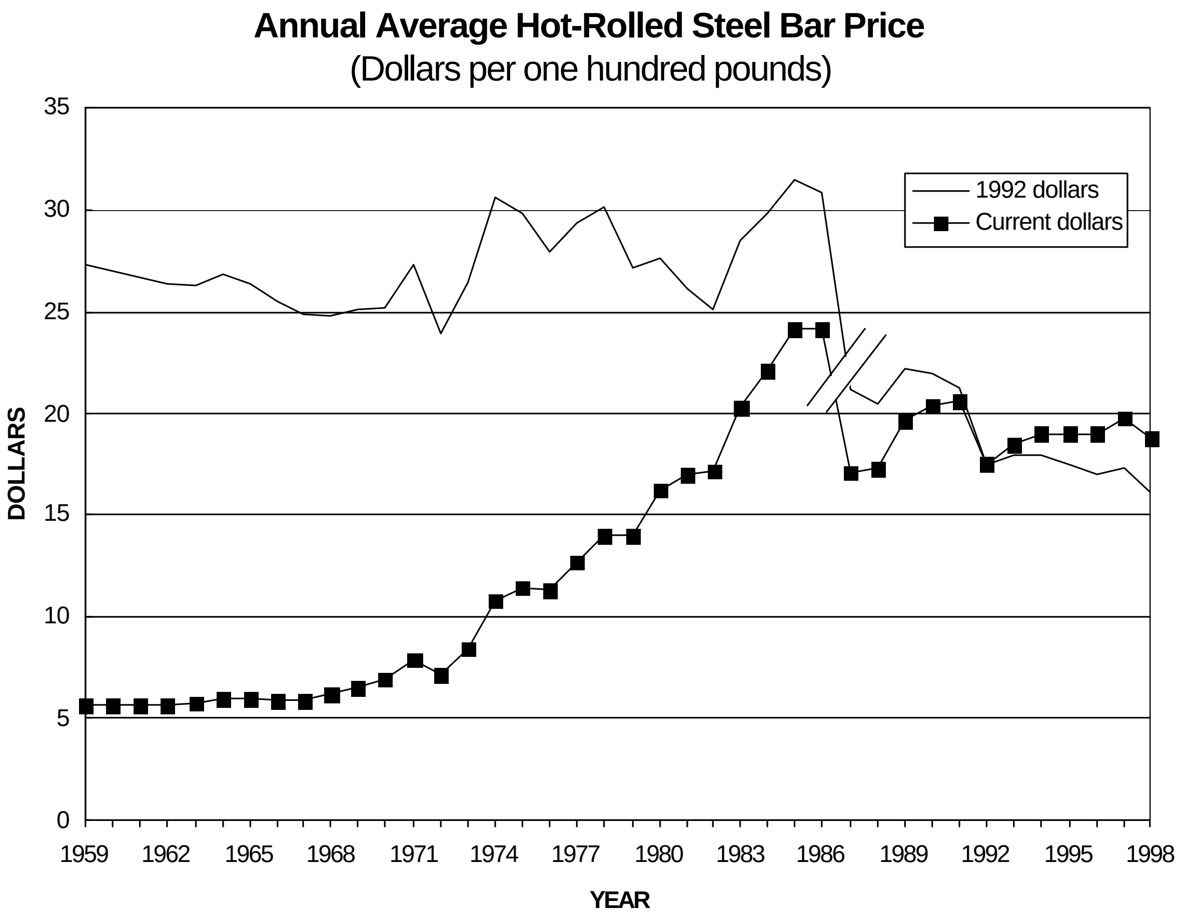
[1] 99.97%-pure indium.
[2] To convert to dollars per kilogram, multiply by 32.1507.

Note:
1936-66, Indium Corporation of America, producer price.
1967-93, U.S. producer price, *in* Metals Week (through June 14, 1993).
1993-98, U.S. producer price, *in* Platt's Metals Week.

(This page intentionally left blank.)

Iron and Steel

by Michael Fenton



Significant events affecting steel prices since 1958

1965	The rise of scrap-based minimills and continuous casters begins
1970	Beginning of energy crisis
1971-74	Price controls in effect
1973	Peak raw steel and pig iron production and peak scrap consumption by steel mills; export restrictions imposed
1974	Peak scrap consumption (steel mills + ferrous foundries)
1989	First thin-slab continuous caster for flat-rolled steel products begins operating at minimill facility
1990	U.S. exports and imports of ferrous scrap reach record highs
1997	Start of the Asian financial crisis

Of the metallic elements, iron is the most useful and most abundant, as well as the cheapest. The term "iron" refers to alloys that contain too much carbon to be formable by forging or rolling. The term "steel" refers to an alloy of iron that is malleable in some temperature ranges and contains manganese, carbon, and often other alloying elements. Hundreds of individual alloy specifications known as "grades" have been developed to produce combinations of strength, ductility, hardness, toughness, magnetic permeability, and corrosion resistance to meet the need of modern consumers. The ability of steel to be permanently deformed by plastic working allows it to be formed into many shapes and sizes

(Lankford and others, 1985, p. 773). Principal methods of hot and cold steel working are hammering, pressing, piercing, extrusion, rolling, drawing, and forging.

Steel products are priced by a system of "base prices" and "extras". In general, each producer specifies a base price for each product form that it manufactures. For example, a producer of carbon steel cold-rolled sheets would specify a base price for that product. In addition, the producer specifies completely the range of thickness, width, and other properties that are covered by the base price. If a customer's requirements are for material thicker, thinner, wider, or narrower than the base range, an extra charge is added. Extras are also added for such requirements as cut-length (as opposed to sheets in coil form), special drawing quality, small orders (e.g., less than 20,000 pounds of a single item), and other requirements, depending upon the product form.

The cost of transportation from the producer to the customer is a significant consideration. As a result, a producer often will adjust his price to match a customer's delivered price from a more proximate producer. When such an adjustment is made, the customer's cost is the same, regardless of the location of the shipping mill; the result for the steel producer is a lower realized price when shipping to a customer located closer to another producing mill.

Steel prices are usually quoted by weight. For many products, however, there is a provision for calculating the weight of a shipment so that a customer is required to pay only for the theoretical weight of the product rather than the actual weight, which normally is more than the theoretical weight because of allowable manufacturing variations. Discounts from the quoted price are often available. In recent years, discounts of as much as 25% have been described for some products at times.

Price indices of groups of steel products have been reported by the major trade publications to show at a glance the overall movement of steel prices since 1897 (American Metal Market) and 1926 (Iron Age). For the purpose of this publication, hot-rolled carbon steel bar was selected because it has been produced continuously since the adoption of the Bessemer steelmaking process in 1875; its historical price series is indicative of prices for the range of steel products; and its price does not incorporate the cost of extensive processing after hot rolling.

For the entire period of this review, except during World War I, prices of hot-rolled carbon steel bar fluctuated within a narrow $8.00 range, in constant dollar terms. During World War I, steep price increases brought about price controls, which were also imposed on the industry during World War II (Campbell, 1948). During the 1960's, prices in current dollars, increased very slowly, but the energy crisis of 1970 started a period of rapid price escalation as energy costs of steel companies increased rapidly and inflation dominated the economy. Wages of steel industry workers were automatically increased because of inflation protection clauses in their union contracts. Price increases were necessary to keep pace with rapidly escalating costs. From 1971-through 1974, price controls were instituted in an attempt to halt price inflation, but were abandoned when they proved ineffective and administratively infeasible.

During the early 1970's, a new approach to steelmaking gained prominence that caused record highs in steel production (1973) and scrap consumption (1974). Small steel plants were erected to produce simple products such as hot-rolled bars of steel. The first plants began production in 1965. These new plants, called minimills, did not have blast furnaces to process iron ore, but instead modern electric furnaces and continuous casters were used to melt ferrous scrap and cast the raw steel into products at the lowest possible cost. Competition with blast-furnace-based steel mills increased as thin-slab continuous casting equipment was adopted, first in 1989, to produce products at thinner gauges with ever improving quality at increasingly lower costs (American Metal Market, 1997; 33 Metal Producing, 1998). Minimills have been able to capture a significant share of the market by setting prices that the previously dominant steel companies were unable to match.

One of the relatively simple products that the minimill companies have come to dominate is hot-rolled steel bar. Discounts from the quoted prices have been widely available, and this was especially true during the late 1970's and early 1980's as minimill companies gained dominance of the market for hot-rolled steel bar. In 1984, the major steel mills stopped revising their quoted prices. In 1987, American Metal Market discontinued the publication of the major mill price and began to report the quoted prices of the minimills, which were more representative of market transaction prices. This change was marked by the 29 percent drop in the quoted price, to $17.12.

The first half of the 1990's were years of increasing domestic demand for steel products and increasing domestic capacity to satisfy this demand. U.S. exports and imports of ferrous scrap reached record highs in 1990, but there was still a trade deficit. By 1997, the American Iron and Steel Institute (AISI) reported an indirect steel-trade surplus of 1.1 million metric tons, the first surplus since AISI began tracking the measurement in 1984 and perhaps since the late 1970's (American Iron and Steel Institute, 1998). This surplus confirmed that U.S. manufacturers were among the world's most competitive producers of high-quality, steel-containing goods in 1997.

Despite rising domestic steel mill capacity, imports of semifinished steel increased significantly in 1993; these imports were needed to make up for the domestic shortage of hot metal capacity in order to satisfy the U.S. market demand for finished steel mill products. Domestic producers were also unable to keep up with demand for finished steel products. An unfavorable currency exchange rate made foreign steel prices much more competitive.

A financial crisis began in Asia in 1997 when Thailand devalued its currency (Garino, 1999). Prospering economies in China, Hong Kong, Indonesia, Japan, the Republic of

Korea, Malaysia, Singapore, Taiwan, and Thailand were seriously weakened. Steel consumption began to decline in these countries as they imported less steel and canceled some new steel production projects. Generally, significant production decreases were not feasible because sales were needed to repay loans granted by the International Monetary Fund to support the economies of these countries (Becker, 1998). Throughout 1998, the United States was the recipient of large quantities of inexpensive semifinished steel imports. Declining prices adversely affected domestic steel producers, who filed antidumping law suits and appealed for the implementation of steel import quotas. The combination of weak steel demand in the Pacific Basin, a strong dollar, and falling world export prices may continue to cause importation of low-priced steel into the United States to the detriment of domestic steelmakers.

References Cited

American Iron and Steel Institute, 1998, AISI issues report on 1997 U.S. indirect steel trade—First surplus achieved in 14 years of tracking: Washington, D.C., American Iron and Steel Institute press release, April 15, 2 p.

American Metal Market, 1997, Minis playing hot band hand: American Metal Market, v. 105, no. 27, February 7, p. 1.

Becker, George, 1998, Steel import woes have deep roots: American Metal Market, v. 106, no. 208, October 29, p. 10.

Campbell, R.F., 1948, The history of basic metals price control in World War II: New York, Columbia University Press, 263 p.

Garino, R.J., 1999, Bull or bear, place your bets: Scrap, v. 56, no. 1, January/February, p. 44.

Lankford, W.T., Jr., Samways, N.L., Craven, R.F., McGannon, H.E., ed., 1985, The making, shaping and treating of steel: Pittsburgh, PA, Herbick & Held, 1572 p.

33 Metal Producing, 1998, Mini-mills moving up: 33 Metal Producing, v. 36, no. 1, January, p. 34.

Annual Average Hot-Rolled Steel Bar Price
(Dollars per one hundred pounds[1])

Year	Price	Year	Price	Year	Price	Year	Price
1897	0.99	1923	2.33	1949	3.35	1975	11.43
1898	0.95	1924	2.20	1950	3.47	1976	11.32
1899	1.95	1925	2.04	1951	3.70	1977	12.68
1900	1.61	1926	1.99	1952	3.78	1978	14.01
1901	1.44	1927	1.84	1953	4.05	1979	14.01
1902	1.58	1928	1.87	1954	4.22	1980	16.20
1903	1.56	1929	1.92	1955	4.47	1981	16.95
1904	1.33	1930	1.73	1956	4.81	1982	17.23
1905	1.48	1931	1.63	1957	5.25	1983	20.25
1906	1.51	1932	1.58	1958	5.35	1984	22.08
1907	1.60	1933	1.64	1959	5.68	1985	24.10
1908	1.48	1934	1.81	1960	5.68	1986	24.10
1909	1.31	1935	1.80	1961	5.68	1987	17.12
1910	1.43	1936	1.92	1962	5.68	1988	17.25
1911	1.26	1937	2.40	1963	5.74	1989	19.60
1912	1.25	1938	2.35	1964	5.93	1990	20.43
1913	1.38	1939	2.19	1965	5.93	1991	20.60
1914	1.15	1940	2.15	1966	5.89	1992	17.48
1915	1.31	1941	2.15	1967	5.92	1993	18.44
1916	2.48	1942	2.15	1968	6.14	1994	18.95
1917	3.49	1943	2.15	1969	6.56	1995	18.95
1918	2.89	1944	2.15	1970	6.98	1996	18.95
1919	2.43	1945	2.21	1971	7.89	1997	19.75
1920	2.99	1946	2.47	1972	7.13	1998	18.75
1921	1.89	1947	2.72	1973	8.38		
1922	1.70	1948	3.09	1974	10.78		

[1] To convert to dollars per metric ton, multiply by 22.0462.

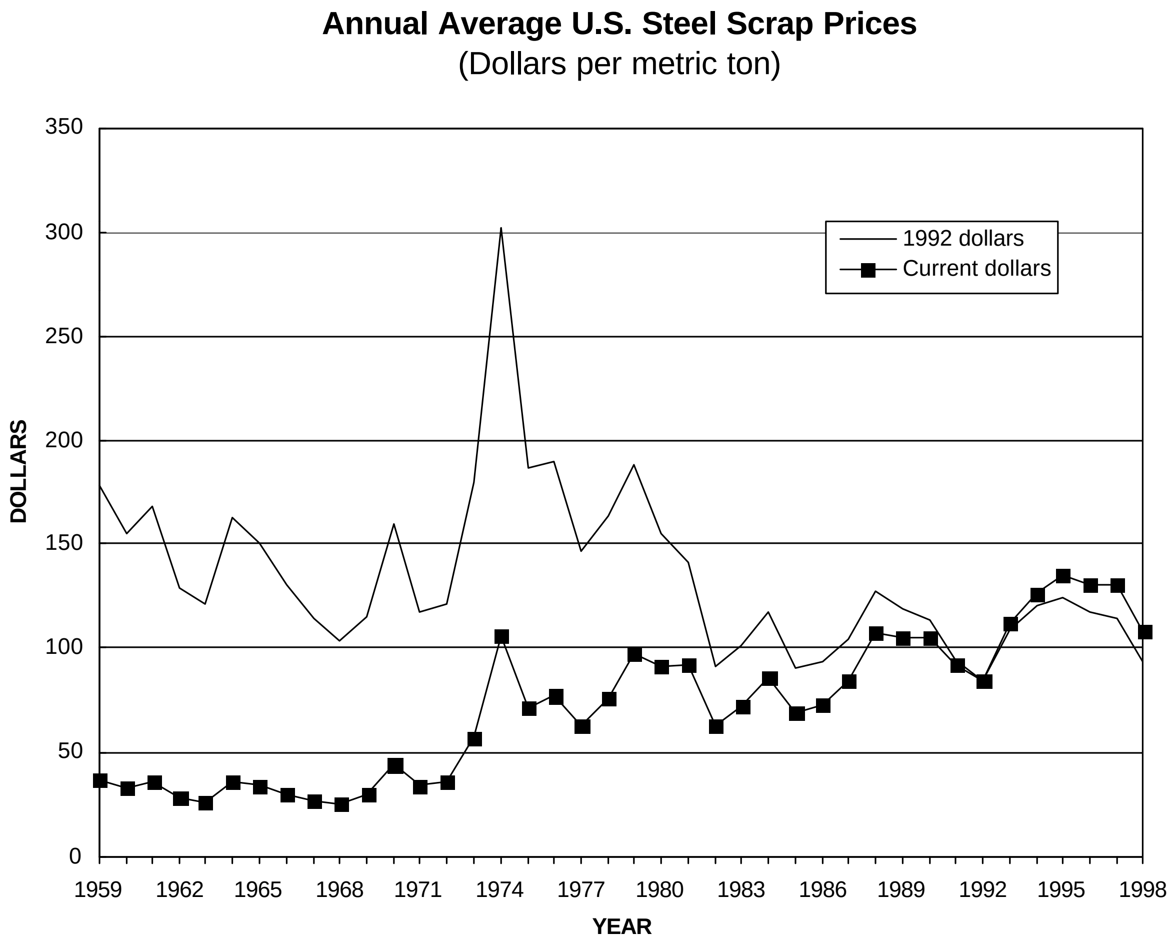
Note:
1897-February 1987, hot-rolled carbon steel bars merchant, Pittsburgh base, dollars per cwt., *in* American Metal Market.
March 1987-1998, hot-rolled carbon SBQ (special bar quality) 1000 series, *in* American Metal Market.

(This page intentionally left blank.)

Fe

Iron and Steel Scrap

by Michael Fenton



Significant events affecting steel scrap prices since 1958

1965	The rise of scrap-based minimills and continuous casters begins
1973	Peak raw steel and pig iron production and peak scrap consumption by steel mills, price controls and export restrictions imposed
1974	Peak scrap consumption (steel mills + ferrous foundries), export restrictions imposed
1989	First thin-slab continuous caster for flat-rolled steel products begins operating at minimill facility
1990	U.S. exports and imports of ferrous scrap reach record highs
	Asian financial crisis begins

Iron and steel (ferrous) scrap is generated within steel mills and foundries (home scrap) or industrial plants (prompt or industrial scrap) while fabricating new iron and steel products and objects discarded because of obsolescence (obsolete scrap). Ferrous scrap recycling is a complex industry that is dependent on the vigor of the two major consumers of scrap—steel mills and ferrous foundries. Thousands of scrap facilities employ tens of thousands of people to collect, process, and distribute scrap in several regional U.S. markets and the international export market.

In a free-market economy when Government price controls are not in effect, scrap prices react quickly to changes in supply and, especially, demand. When demand for steel mill and foundry products is low, demand for scrap is low, and prices fall. Dealers cannot influence sales of scrap if mills and foundries do not need it to charge their furnaces. Dealers can hold back some scrap from mills and foundries when prices are below their costs to purchase and process it. Scrap generated by industrial plants, however, must be disposed of each month to the highest bidder to make room for more scrap. Prices are also influenced by technological changes in steel mills and foundries, processing and upgrading to desired physical and chemical qualities, the use of scrap substitutes, environmental controls and other Government laws and regulations, and export demand. Scrap metal prices quoted in major trade publications, such as American Metal Market, have been considered by many economists to be an excellent barometer of current industrial demand. Of particular interest is the No. 1 Heavy Melting Steel (No. 1) composite price of three citiesCChicago, IL, Philadelphia, PA, and Pittsburgh, PACwhich has been recorded by American Metal Market since 1907.

During the past 90 years, the price of No. 1 responded to supply-and-demand forces in a free-market economic environment, and price fluctuations were sometimes dramatic from year to year. The Great Depression (1929-33) was a time of declining manufacturing activity with all-time record lows in demand and prices for scrap from 1931 to 1933. During World Wars I and II, demand increased to the point that the Government adopted price controls to halt scrap price inflation (Campbell, 1948). The price of No. 1 nearly tripled as a result of high demand during World War II. The Government also adopted price controls during the Korean conflict.

During the early 1970's, a new approach to steelmaking gained prominence, which caused record highs in steel production (1973) and scrap consumption (1974). New, comparatively smaller steel plants were built to produce simple products, such as hot-rolled bars of steel. These new plants, called minimills, did not have blast furnaces to process iron ore; instead, modern electric furnaces and continuous casters were used to melt ferrous scrap and to cast the raw steel into products at the lowest possible cost (Iron and Steelmaker, 1998). Minimills have been able to capture a significant share of the market by setting prices that the previously dominant steel companies were unable to match. By 1990, U.S. exports and imports of ferrous scrap to feed minimills built in the United States and abroad reached record highs.

Ferrous scrap prices declined significantly during 1991 as domestic and world demand for scrap decreased. Domestic demand began to increase during 1992, and world demand remained weak. The period from 1993 to the first half of 1997 was one of strengthening demand for ferrous scrap and rising prices. Developing countries in Asia, Eastern Europe, and Latin America experienced significant economic growth. Minimill capacity increased worldwide, and integrated steel mills increased efficiency and scrap usage.

A financial crisis began in Asia in 1997 when Thailand devalued its currency. Prospering economies in China, Hong Kong, Indonesia, Japan, the Republic of Korea, Malaysia, Singapore, Taiwan, and Thailand were seriously weakened. Asian ferrous scrap purchases decreased, and prices of scrap declined, which adversely affected the domestic scrap industry (Gavaghan, 1998).

By the end of 1998, prices had stabilized at a level about $40 per ton below the price level of the first half of the year.

References Cited

Campbell, R.F., 1948, The history of basic metals price control in World War II: New York, Columbia University Press, 263 p.

Gavaghan, B.P., 1998, World steel industry faces uncertain economic future: Iron and Steelmaker, v. 25, no.12, December, p. 25-26.

Iron and Steelmaker, 1998, I&SM continuous caster roundup: Iron and Steelmaker, v. 25, no. 11, p. 14-31.

Annual Average U.S. Steel Scrap Price[1]
(Dollars per metric ton)

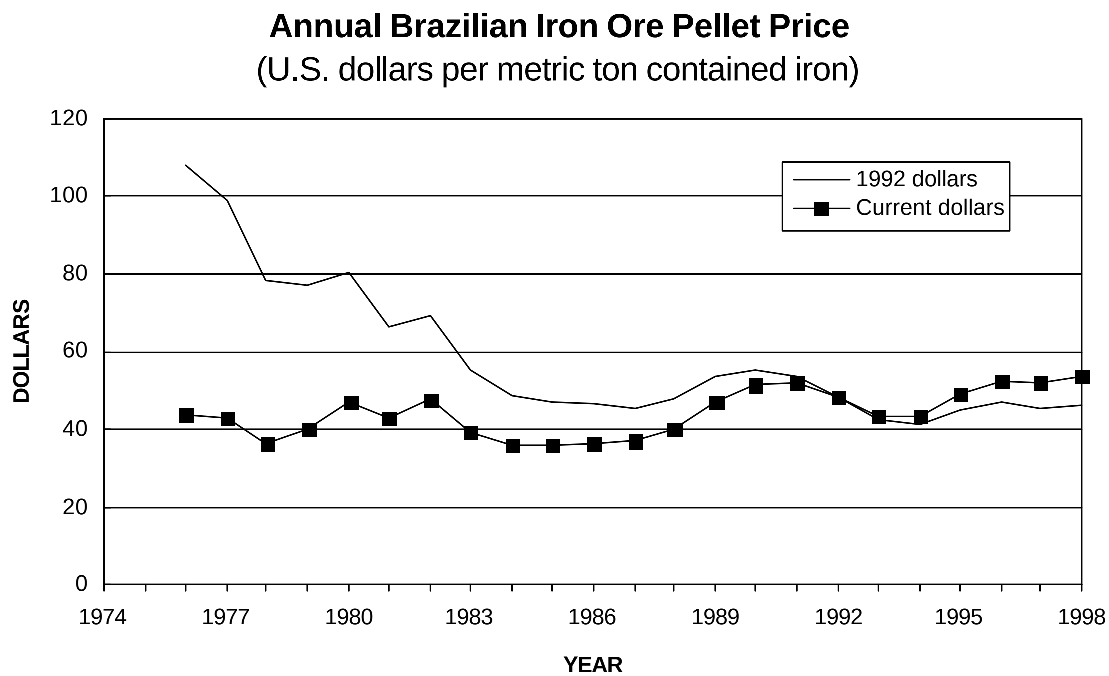
Year	Price	Year	Price	Year	Price	Year	Price
1907	16.27	1930	13.25	1953	39.27	1976	76.74
1908	13.40	1931	9.58	1954	28.29	1977	63.05
1909	15.49	1932	7.29	1955	39.12	1978	75.92
1910	14.48	1933	9.20	1956	52.61	1979	97.41
1911	12.20	1934	10.74	1957	46.36	1980	91.42
1912	13.08	1935	11.52	1958	37.21	1981	91.86
1913	11.94	1936	14.48	1959	37.09	1982	62.72
1914	10.33	1937	17.63	1960	32.68	1983	71.76
1915	12.07	1938	13.21	1961	35.80	1984	86.52
1916	17.13	1939	15.95	1962	27.89	1985	68.93
1917	28.62	1940	18.22	1963	26.47	1986	73.00
1918	28.11	1941	19.12	1964	35.92	1987	84.41
1919	18.05	1942	18.87	1965	33.73	1988	107.26
1920	23.57	1943	18.87	1966	30.18	1989	105.61
1921	12.46	1944	18.33	1967	27.19	1990	105.46
1922	15.58	1945	18.84	1968	25.53	1991	91.79
1923	18.89	1946	19.83	1969	30.08	1992	84.67
1924	16.91	1947	35.08	1970	44.24	1993	112.44
1925	16.91	1948	40.89	1971	33.92	1994	126.82
1926	15.33	1949	27.06	1972	36.05	1995	135.03
1927	13.94	1950	34.78	1973	56.76	1996	130.60
1928	14.13	1951	42.46	1974	106.13	1997	130.45
1929	15.97	1952	41.23	1975	71.37	1998	108.30

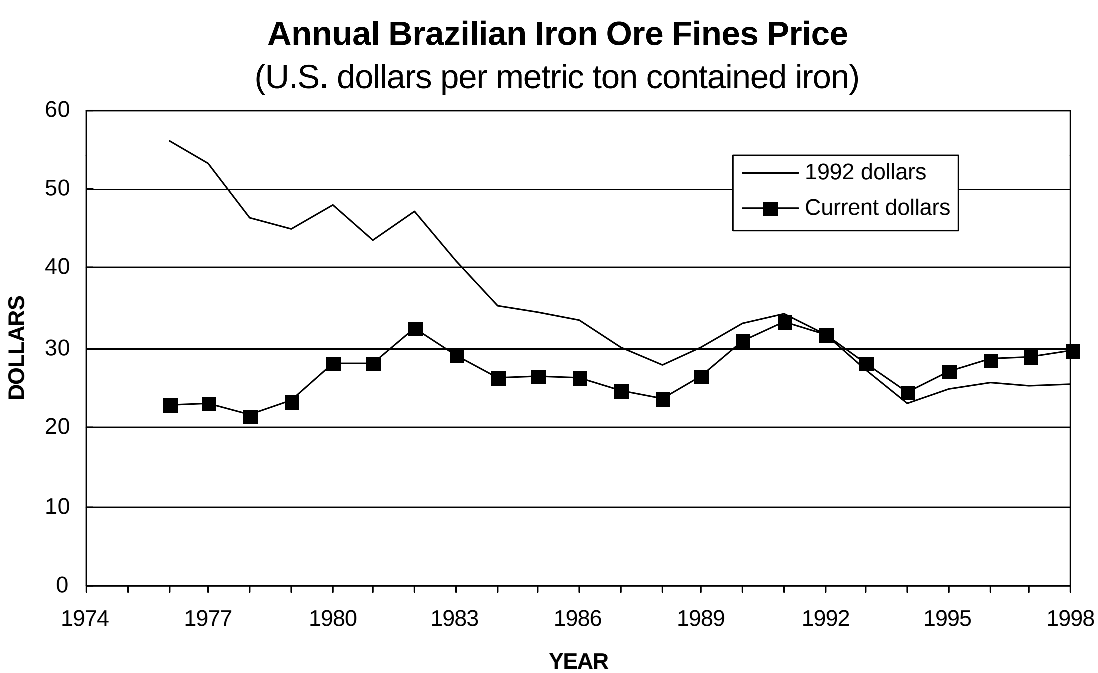
[1] Composite price of No. 1 Heavy Melting Steel scrap at Chicago, IL, Philadelphia, PA, and Pittsburgh, PA, (three-city average). As defined by the Institute of Scrap Recycling Industries, Inc., No. 1 Heavy Melting Steel is wrought iron and/or steel scrap ¼ inch and more in thickness. Individual pieces not more than 60 x 24 inches (changing box size) are prepared in a manner to ensure compact charging.

Source: American Metal Market.

Iron Ore

by William S. Kirk





Significant events affecting iron ore prices since 1958

1973-75	Organization of Petroleum Exporting Countries (OPEC) oil embargo and sharp recession
1981-82	Sharp recession
1997	Beginning of the Asian financial crisis

Iron ore is used to make iron and steel. Iron is the most useful, abundant, and cheapest of the metallic elements. In metallurgical terms, “iron” refers to alloys that contain too much carbon to be formable by forging or rolling. The term “steel” refers to an alloy of iron that is malleable at some temperature ranges and contains carbon, manganese, and often some other alloying elements. Steel is made by using the blast furnace/basic oxygen furnace (BF/BOF) process or the electric arc furnace (EAF) process. The BF/BOF process first makes iron by smelting iron ore in a blast furnace and then using that iron to make steel in a BOF. In the EAF process, iron and steel scrap and often direct reduced iron are melted to produce steel.

Almost all (98%) iron ore is used to make iron and steel so its price is determined by what steelmakers are willing to pay for it and that is based on how the ore behaves in the iron-making process—whether it raises or lowers the costs of producing steel. The behavior of iron ore in the iron-making process is determined by its chemical composition and by its structure or form, both of which affect blast furnace productivity. The chemical constituents that affect the productivity of a blast furnace are iron content, levels of the undesirable substances silica and alumina, moisture and impurities, and levels of the desirable substances limestone and dolomite.

The forms that affect blast furnace productivity—fines (fine ores), lump, and pellets—are also the primary market products. Minor quantities of iron ore concentrate are also sold. Fines are defined as iron ore with the majority of individual particles measuring less than 4.75 millimeters (3/16 inch) diameter. Conversely, lump is iron ore with the majority of individual particles measuring more than 4.75 millimeters diameter. Fines and lump are produced from the same ore and are separated by screening and sorting. Neither product is concentrated. Pellets, the third product type (form), begin as a fined-grained concentrate. A binder, often clay, is added to the concentrate, which is then rolled into balls. The balls then pass through a furnace where they are indurated and become pellets, usually measuring from 9.55 to 16.0 millimeters (3/8-5/8 inch).

Although fines and lump ores cost about the same to produce, fines fetch lower prices than lump because they must be sintered by the steel mill before they can be charged to the blast furnace. This is done to improve permeability of the furnace burden and to prevent loss of fines up the stack. Pellets can be charged directly into the blast furnace as can lump ore, but the latter can decrepitate in the furnace, thereby lowering its value to the steel mill operator. Pellets are usually the most desirable form of iron ore because they contribute the most to the productivity of the blast furnace. Lump ore is the next most desirable ore in terms of blast furnace productivity. The least desirable form is fines, which must be agglomerated (sintered), usually by the steelmaker, before being charged to the blast furnace.

If the chemistry and structure of an iron ore are favorable, then iron- and steel-making costs are reduced, and the steelmaker is willing to pay a higher per-unit price for this ore than for one with less favorable properties. Although an ore with a high iron content and good structure is desirable for increasing productivity in a blast furnace, preference may be given to a lower quality ore if the price is low enough to compensate for its less favorable characteristics. No such flexibility occurs in direct reduction, where ore-quality parameters are very stringent. The direct reduction process uses pellets and lump with chemical characteristics that have historically supported a price premium over blast furnace grades. Fines-based direct reduction processes are now under development.

A steelmaker’s preference for pellets over fines is reflected in the prices. From 1976 through 1998, the average price for Brazilian fines was $27.03 per metric ton; and the average for Brazilian pellets was $44.31 per metric ton. Although iron ore prices rose during the 1976 to 1998 period, when adjusted for inflation, they fell considerably. The price for fines in constant dollars declined by 53.2% and the price for pellets in constant dollars dropped by 56.2%. The inflation adjustment factor used was the Consumer Price Index for All Urban Consumers (CPI) from the U.S. Bureau of Labor Statistics. The CPI was rebased to 1992.

Another factor that affects which form of iron ore used is steel demand. When demand is low, European and Japanese steelmakers switch to fines because they do not have to be concerned with productivity targets. In a tight market, more pellets and lump are consumed.

Until the 1980’s, there were two international iron ore price structures, each related to a specific geographic area: North America and the other market economy countries (Franz, Stenberg, and Strongman, 1986). In North America, more than three-quarters of iron ore production capacity was owned directly by its consumers, the integrated steel companies. These equity ownership conditions led to stable “cost-plus” pricing, meaning the iron ore producers were paid what it cost them to produce the ore, plus royalty and management fees. Prior to this, there was very little need to be competitive (Marcus, Kirsis, and Kakela,1996). Demand was high, and the North American iron ore industry was growing, as it had for 25 years. Pellet capacity expanded steadily from its first commercialization in 1955 to a peak capacity of 127 million metric tons in 1980.

In 1982, major structural changes occurred in the domestic iron ore industry, one of which was the development of a U.S. spot market for pellets. Most spot sales are individually negotiated, one-time contracts made directly between buyer and seller. The spot market led to the beginning of price competition and a winding down of the Lower Lakes pricing system, which had served the iron ore industry for 100 years. Previously, only annual sales, multiyear contracts, or equity ownership transactions existed. The North American iron ore industry had to cut capacity and lower prices to make domestic ore competitive with imported material. This meant that the industry had to lower production costs to stay in business, which was done by greatly improving labor productivity, reducing wages, negotiating lower cost power contracts and royalty agreements, pressing suppliers to reduce prices for materials, lobbying legislators for tax breaks, and paying off debt. The results were dramatic. Domestic mines cut costs by 30%, reduced capacity by one-third, and lowered prices by 42%. Domestic producers are continuing their efforts to reduce costs. The spot market has persisted and, with the reduction of steel mill ownership of iron ore mines to about 63%, has grown stronger.

Exported iron ore is traded in the seaborne market, and prices are determined by market forces. Two iron ore price lists, one for prices of ore to Europe and the other for prices to Japan are widely published. All iron ore is priced in U.S. dollars, which facilitates comparison. The unit pricing system is used with iron ore to accommodate variations in iron content. Prices are quoted in U.S. cents per ton unit of iron. A unit is 1/100, or 1%, of the weight of a ton of iron so that 1 metric ton unit corresponds to 1/100th of a metric ton. This means that a steelmaker that buys 1 ton of ore that is about 65% iron is paying for 1 ton of iron contained in that ore and will receive about 1½ tons of ore.

These prices are usually set during lengthy negotiations between Brazilian iron ore producers and German steelmakers and between Australian producers and Japanese steelmakers. Australia and Brazil with roughly equal shares dominate the export market, have a combined share of world iron ore exports of 62%; the next largest exporter has only a 6% share. Europe and Japan, with roughly equal shares, have a combined share of world imports of 57%; the next largest importer has 12%. The price agreed on for ore to Europe is applicable for the calendar year effective January 1st of that year. For ore sold to Japan, prices are set for the Japanese fiscal year, which begins on April 1st and ends on March 31st. The price for iron ore fines is usually settled first because it is the predominant type of ore used in Europe and Japan. Prices for pellets and lump ore are then set based on the fines prices.

The steel recession that was the result of the OPEC oil embargo created downward pressure on iron ore prices that can be seen in the Brazilian fines price for 1978, the lowest level of the 1976- through-1998 period (See price tables). As the world economy recovered, iron ore prices peaked in 1982. Prices then dropped as the 1981-82 recession combined with major increases in iron ore production capacity in Australia, Brazil, and Venezuela created a situation of oversupply. During this period, one U.S. steelmaker permanently closed 16% of its production capacity. U.S. iron ore production fell from 73.4 million tons in 1981 to 36.0 million tons in 1982.

Prices continued to fall until 1989, when economic conditions began to improve. Decreasing steel production caused prices to fall until 1994 when they began rising as the world steel industry enjoyed a number of years of increased production. In 1997, domestic steelmakers increased shipments for the sixth consecutive year, the longest consecutive increase ever.

During the second half of 1998, the U.S. steel industry became a victim of the world's growing financial crisis (Hogan, 1999). With the spread of the Asian economic recession, steel demand and export opportunities were curtailed within the region and Asian steel producers, particularly in Japan and the Republic of Korea, started to divert more of their products for export, much of it aimed at the United States. Despite high demand for steel, U.S. steel shipments declined by about 3%. Lower steel production in the United States and the rest of the world in 1998 caused the Brazilian fines price for 1999 to fall to $26.96, a decrease of 9.2%.

References Cited

Franz, Juergen, Stenberg, Bo, and Strongman, John, 1986, Iron ore—Global prospects for the industry, 1985-95: World Bank Industry and Finance Series, v. 12, p. 32.

Hogan, W.T., 1999, Iron and steel—A historic year for steel: Engineering & Mining Journal, v. 199, no. 3, p. 74-78.

Marcus, P.F., Kirsis, K.M, and Kakela, P.J., 1996, North American iron ore industry—Opportunities and threats: PaineWebber World Steel Dynamics Core Report, January, variously paginated.

Annual Brazilian Iron Ore Pellet Price[1]

(U.S. dollars per metric ton contained iron)

Year	Price	Year	Price	Year	Price	Year	Price
1976	43.80	1982	47.50	1988	40.35	1994	43.64
1977	42.80	1983	39.00	1989	47.33	1995	49.14
1978	36.40	1984	36.00	1990	51.60	1996	52.40
1979	39.96	1985	36.00	1991	52.15	1997	52.10
1980	47.05	1986	36.60	1992	48.47	1998	53.56
1981	43.05	1987	36.70	1993	43.64		

[1] Prices are for Brazilian iron ore pellets sold to Europe, f.o.b. Tubaro terminal, Southern System, Cia. Vale do Rio Doce.

Source: TEX Report Co. Ltd., Iron ore manual, [various years].

Annual Brazilian Iron Ore Fines Price[1]

(U.S. dollars per metric ton contained iron)

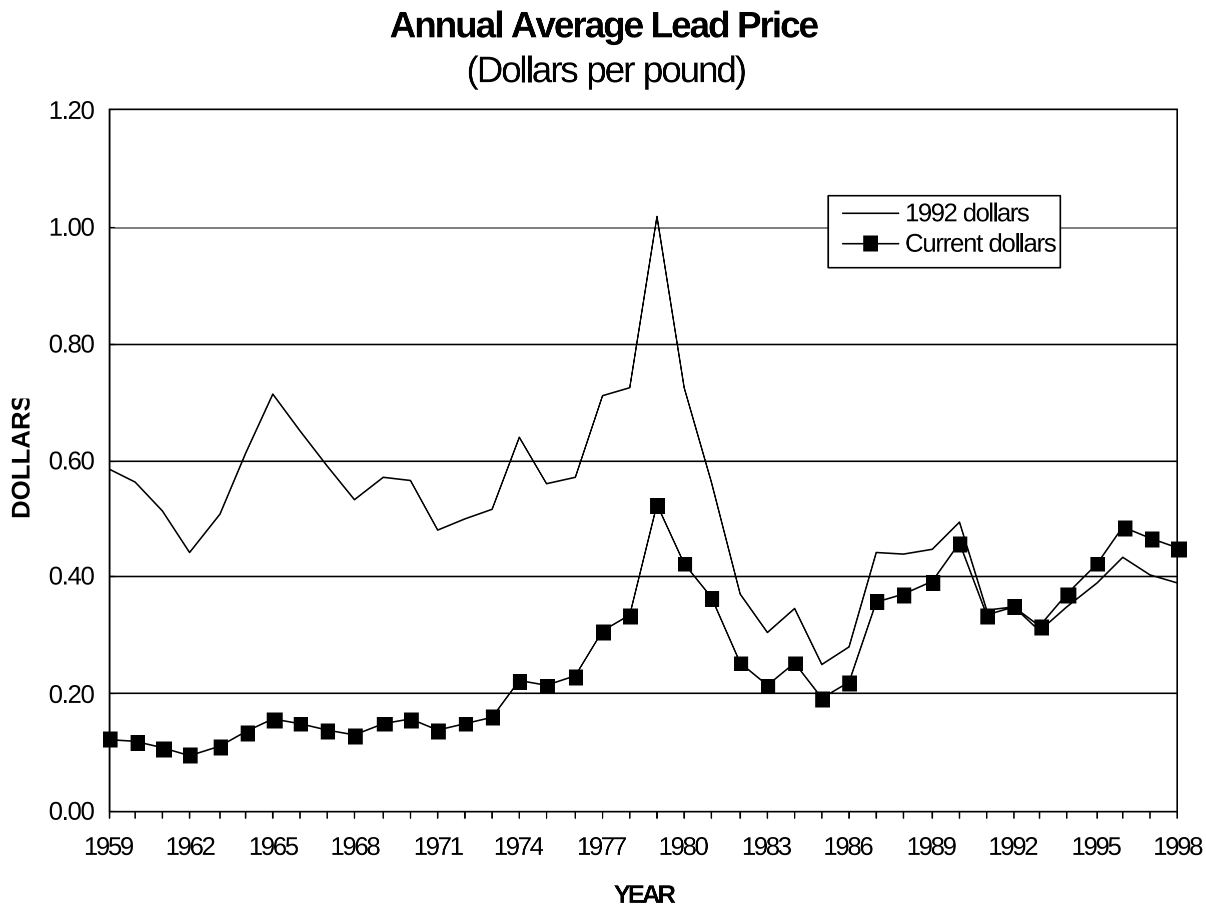
Year	Price	Year	Price	Year	Price	Year	Price
1976	22.70	1982	32.50	1988	23.50	1994	24.47
1977	23.00	1983	29.00	1989	26.56	1995	26.95
1978	21.50	1984	26.15	1990	30.80	1996	28.57
1979	23.30	1985	26.56	1991	33.25	1997	28.88
1980	28.10	1986	26.26	1992	31.62	1998	29.69
1981	28.10	1987	24.50	1993	28.14		

[1] Prices are for Brazilian iron ore fines sold to Europe, f.o.b. Tubaro terminal, Southern System, Cia. Vale do Rio Doce.

Source: TEX Report Co. Ltd., Iron ore manual, [various years].

Lead

by Gerald R. Smith



Significant events affecting lead prices since 1958

1961-1969	Lead and Zinc Mining Stabilization Program in effect
1971-1973	Price controls
1976-1979	Post-Vietnam War boom—highest historical price
1982-1986	More stringent environmental controls imposed on production
1986-1991	Industry retrenchment—attendant cost reductions
1992-1996	Increasing demand, particularly in lead-acid battery sector
1997-1998	Moderate weather in more populated regions—demand for replacement automotive batteries slowed

Lead is a very dense, ductile, malleable, corrosion resistant, blue-gray metal that has been used for at least 5,000 years. Early uses of lead were in building materials, water pipes, and pigments for glazing. The castles and cathedrals of Europe contain considerable quantities of lead in roofs, windows, pipes, and decorative fixtures (Shea, 1996, p. 1). In the United States, lead was first mined in Virginia in 1621. During the colonial period, mining was carried out in New York, North Carolina, and several New England States. By the late 1860's, most of the mine production of lead came from the lower and upper Mississippi Valley regions. A westward expansion of mining began soon thereafter. Many gold and silver mines were developed, some of which contained significant concentrations of lead. In addition, the

Missouri Lead Belt, in southeastern Missouri, was developed, as well as the Tri-State Lead District, which included Kansas, Missouri and Oklahoma. By the late 1950's, depletion of lead reserves in the Lead Belt and discontinuation of mining in the Tri-State region, encouraged the discovery and development of the Viburnum Trend mining region in southeast Missouri, thus establishing the framework of the current domestic primary lead industry. Missouri has been the foremost lead-mining State since 1907 and has retained that status throughout the century, except for 1962 when mine output was curtailed by a prolonged strike (Hofman, 1918, p. 1-6; Howe, 1980, p. 1-5).

In conjunction with the mining of lead, numerous primary lead smelters and refineries have been operated in the United States since primary lead production was first recorded in 1825. By 1887, annual production of primary refined lead had reached 132,000 metric tons and had increased to a high of 725,000 tons by 1926, representing 87% of the total refined lead production. As the production of secondary lead increased, production of refined lead from primary sources gradually decreased. In 1997, annual production of primary refined lead was 343,000 tons, representing 24% of the total refined lead production. The price of primary refined lead increased from $0.04 per pound in the early 1900's to $0.12 per pound in 1959, reaching a high of about $0.18 per pound during the post-World War II economic boom from 1946 to 1948 and the Korean conflict in the early 1950's. Between 1959 and 1973, lead prices remained fairly stable, ranging from $0.12 to $0.16 per pound. This stability was due, in part, to the enactment of Public Law 87-374, the Lead and Zinc Mining Stabilization Program, in 1961. The program, which remained in effect through 1969, authorized payments to qualified miners when the market price of lead dropped below $0.145 per pound. In the early 1970's, movement in the price of lead was restrained by anti-inflation price controls.With the lifting of price controls in December 1973, the price of lead quickly increased, reaching a historic high in 1979 during the post-Vietnam War economic boom. By the late 1990's, the price of lead had increased tenfold compared with the price at the beginning of the century. In terms of 1992 dollars, however, the price of primary refined lead was $0.39 per pound in 1998 compared with $0.59 per pound in 1959.

Historically, lead has not been and is not a price-elastic commodity. Its significant uses in any given era have not depended on price and, for the most part, other metals cannot substitute for lead in these cases. Prior to the early 1900's, uses of lead were primarily for shot, bullets, water lines and pipes, pewter, brass, glazes, paints or other protective coatings, burial vault liners, and leaded glass or crystal. With the advent of the electrical age and communications accelerated by technological developments in World War I, cable lead and solders became preeminent. With the growth in production of public and private motorized vehicles and the associated use of starting-lighting-ignition (SLI) lead-acid storage batteries and terne metal for gas tanks after World War I, demand for lead increased. In addition to their continued use in SLI applications, new uses of storage batteries have included motive sources of power for industrial forklifts, airport ground equipment, mining equipment, and a variety of other electrical-powered, non-road utility vehicles, as well as stationary sources of power in industrial-type applications, such as uninterruptible electrical power supply equipment for hospitals, computer and telecommunications networks, and load-leveling equipment for commercial electrical power systems. Most of these uses continued to expand with the population and the national economy, and total demand accelerated further with electronic developments (primarily television and video display tubes) and demand for leaded gasoline after World War II, peaking between 1977 and 1979. With the near phaseout of lead in gasoline, paints, solders, and water systems, and the imposition of expensive environmental production controls, the industry experienced hard times between 1982 and 1986. However, the industry made a dramatic recovery by the late 1980's, owing to massive retrenchment in the primary and secondary producing sectors with attendant cost reductions, and to expansion in demand for industrial-type battery systems, and record SLI battery shipments. Growth in the battery industry continued into the 1990's. By 1997, lead-acid storage batteries represented a record-high 87% of reported U.S. consumption of lead. Demand for lead in the battery sector is associated, to a significant extent, with the demand for replacement automotive batteries. In 1997 and 1998, there was some softness in the price of lead owing to 2 consecutive years of moderate temperatures in the more-populated regions of the United States that reduced the rate of failure of automotive-type batteries.

References Cited

Hofman, H.O., 1918, Metallurgy of lead: New York, McGraw-Hill, 664 p.

Howe, W.B., 1980, Viburnum Trend, Missouri—The geology and ore deposits of selected mines: Rolla, Missouri Department of Natural Resources Report of Investigation 58, 56 p.

Shea, E.E., 1996, Lead regulation handbook: Rockville, MD, Government Institutes, Inc., 240 p.

Annual Average Lead Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1909	0.043	1932	0.032	1955	0.151	1978	0.337
1910	0.044	1933	0.039	1956	0.160	1979	0.526
1911	0.044	1934	0.039	1957	0.147	1980	0.425
1912	0.045	1935	0.041	1958	0.121	1981	0.365
1913	0.044	1936	0.047	1959	0.122	1982	0.255
1914	0.039	1937	0.060	1960	0.119	1983	0.217
1915	0.047	1938	0.047	1961	0.109	1984	0.256
1916	0.069	1939	0.051	1962	0.096	1985	0.191
1917	0.088	1940	0.052	1963	0.111	1986	0.221
1918	0.074	1941	0.058	1964	0.136	1987	0.359
1919	0.058	1942	0.065	1965	0.160	1988	0.371
1920	0.080	1943	0.065	1966	0.151	1989	0.394
1921	0.045	1944	0.065	1967	0.140	1990	0.460
1922	0.057	1945	0.065	1968	0.132	1991	0.335
1923	0.073	1946	0.081	1969	0.149	1992	0.351
1924	0.081	1947	0.147	1970	0.157	1993	0.317
1925	0.090	1948	0.180	1971	0.139	1994	0.372
1926	0.084	1949	0.154	1972	0.150	1995	0.423
1927	0.068	1950	0.133	1973	0.163	1996	0.488
1928	0.063	1951	0.175	1974	0.225	1997	0.465
1929	0.068	1952	0.165	1975	0.215	1998	0.453
1930	0.055	1953	0.135	1976	0.231		
1931	0.042	1954	0.141	1977	0.307		

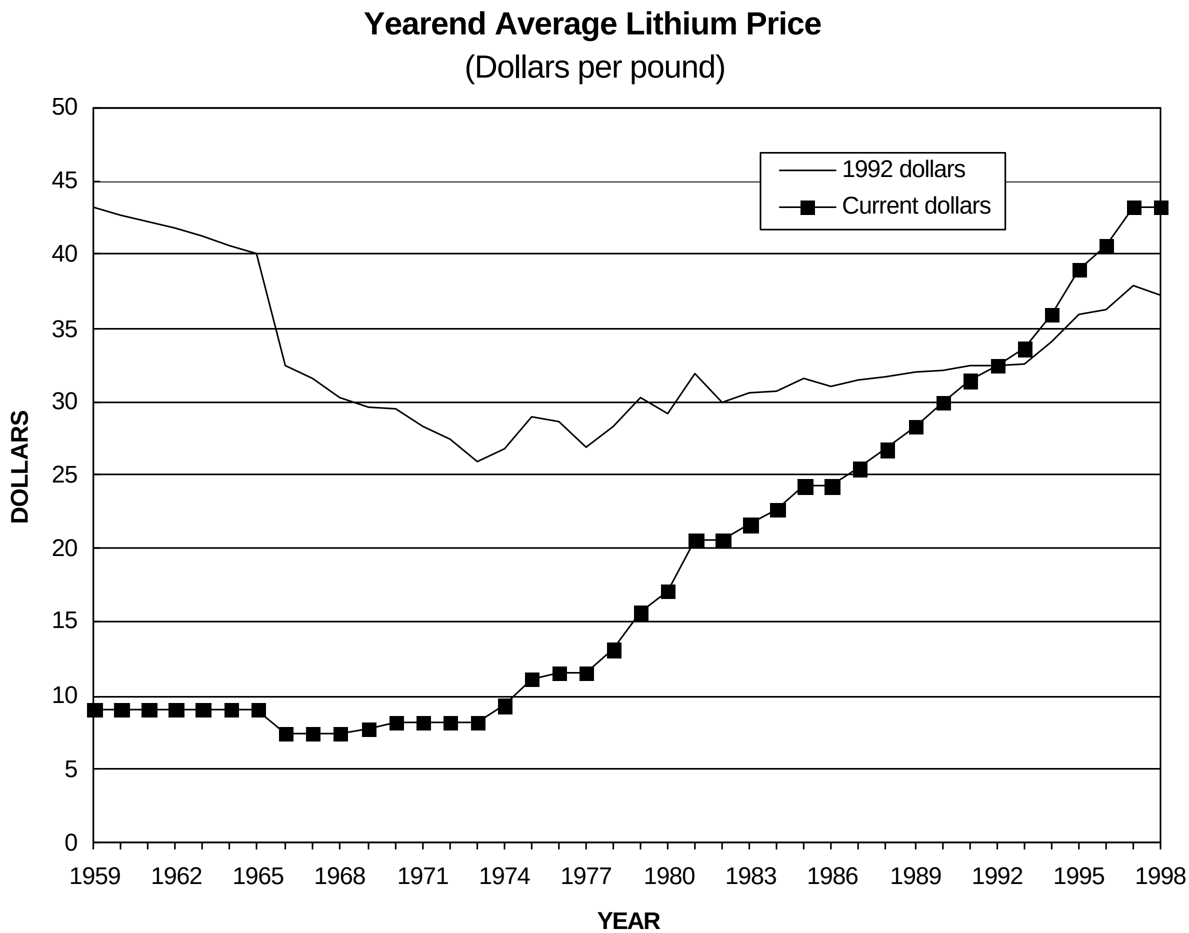
[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:
1909-36, Primary producer price, New York (Common lead, 99.94% pure), *in* Engineering and Mining Journal.
1937-66, Primary producer price, New York (Common lead, 99.94% pure), *in* E&MJ Metal and Mineral Markets.
1967-70, Primary producer price, New York (Common lead, 99.94% pure), *in* Metals Week.
1971-85, Primary producer price, delivered (Minimum 99.97% pure), *in* Metals Week.
1986-93, North American producer price, delivered (Minimum 99.97% pure), *in* Metals Week [through June 14, 1993].
1993-99, North American producer price, delivered (Minimum 99.97% pure), *in* Platt's Metals Week.

(This page intentionally left blank.)

Lithium

by Joyce A. Ober



Production of lithium minerals was first reported in the United States in 1898. Spodumene and amblygonite from California and South Dakota were exported for conversion to lithium chemicals. It was not until about 1916, during World War I, that lithium chemical production began in the United States (Schaller, 1917). Shortly after that, the United States became the largest producer of lithium minerals and chemicals in the world (Schaller, 1917). Dominant production sites shifted from the original States to North Carolina in 1942 (Broadhurst, 1956, p. 11) and Nevada in 1966 (Skillings Mining Review, 1968). In 1976, the Bureau of Mines reported that the United States provided nearly 80% of the world lithium demand (Quan, 1976). In 1984, lithium carbonate production began in Chile (Foote Prints, 1984). In the past 2 years, lithium carbonate production has shifted from the United States to South America with two new operations coming onstream, a second operation in Chile in 1996 (Minsal S.A., 1996), and a facility in Argentina in 1997 (FMC Corp., 1999, p. 28).

The majority of lithium end uses require lithium as one of its compounds rather than in the metallic form. Although a few lithium chemicals require lithium metal for their production, the metal used to produce the chemicals is produced and converted by the same company and so is not sold and does not enter the market or affect the prices of commercial lithium metal products (Lithium Corporation of America, 1985, p. 4). The changes in lithium metal prices appear to be independent of any significant events. Although lithium metal prices were first reported in trade publications in 1952, demand was very low (Arundale and Mensch, 1952). Small quantities were used as scavengers in the production of low-oxygen copper alloys, but other uses were just beginning to be investigated (Arundale and Mensch, 1952).

From 1952 to 1974, lithium prices remained flat in terms of current dollars; in terms of constant dollars, however, prices decreased. The potential use of lithium in batteries for electric vehicles was first discussed in the Minerals Yearbook in 1972 (Wininger, 1972). The downward trend in lithium metal prices reversed in 1974. At about the same time, research efforts increased for identifying aluminum lithium alloys for use in aerospace applications. Increased demand for lithium in batteries and alloys resulted in steadily increasing lithium metal prices since that time.

The growth in the demand for lithium metal, however, cannot be quantified. Because lithium has been a small industry with very few major producers, published information on production and markets is hard to find. One estimate places the use of lithium in batteries at 7% of the lithium market of about 2,600 metric tons of contained lithium in the United States in 1996. Lithium required for alloys is less than 2% of consumption (Harben and Edwards, 1997).

The use of lithium in batteries should continue to expand, but not necessarily in the form of lithium metal. The requirement for lithium metal for those batteries may grow more slowly as battery makers search for the optimum battery chemistry, balancing energy density, cost, and safety.

References Cited

Arundale, J.C., and Mensch, F.B., 1952, Lithium, *in* Minerals Yearbook 1952, v. I: U.S. Bureau of Mines, p. 650-659.

Broadhurst, S.D., 1956, Lithium resources of North Carolina: North Carolina Department of Conservation and Development Information Circular 15, 37 p.

FMC Corp., 1999, FMC annual report 1998: FMC Corp., 56 p.

Foote Prints, 1984, New lithium frontier in Chile: Foote Prints, v. 47, no. 1, p. 2-14.

Harben, P.W., and Edwards, G.H., 1997, The global lithium industry—A portrait of rapid flux: JOM, v. 49, no. 6, p. 21-22, 68.

Lithium Corporation of America, 1985, Lithium: Lithium Corporation of America company report, 18 p.

Minsal S.A., 1996, First lithium carbonate precipitation at Minsal: Santiago, Chile, Minsal S.A. press release, October 30, 1 p.

Quan, C.K., 1976, Lithium, *in* Minerals Yearbook 1976, v. I: U.S. Bureau of Mines, p. 767-781.

Schaller, W.T., 1917, Lithium minerals in 1916, *in* Mineral resources of the United States 1916: U.S. Geological Survey, pt. 2, p. 7-17.

Skillings Mining Review, 1968, Foote Mineral Co.'s lithium operation in Nevada: Skillings Mining Review, v. 57, no. 3, January 20, p. 10.

Wininger, D.C., 1972, Lithium, *in* Minerals Yearbook 1972, v. I: U.S. Bureau of Mines, p. 1362-1365.

Yearend Average Lithium Price
(Dollars per pound[1])

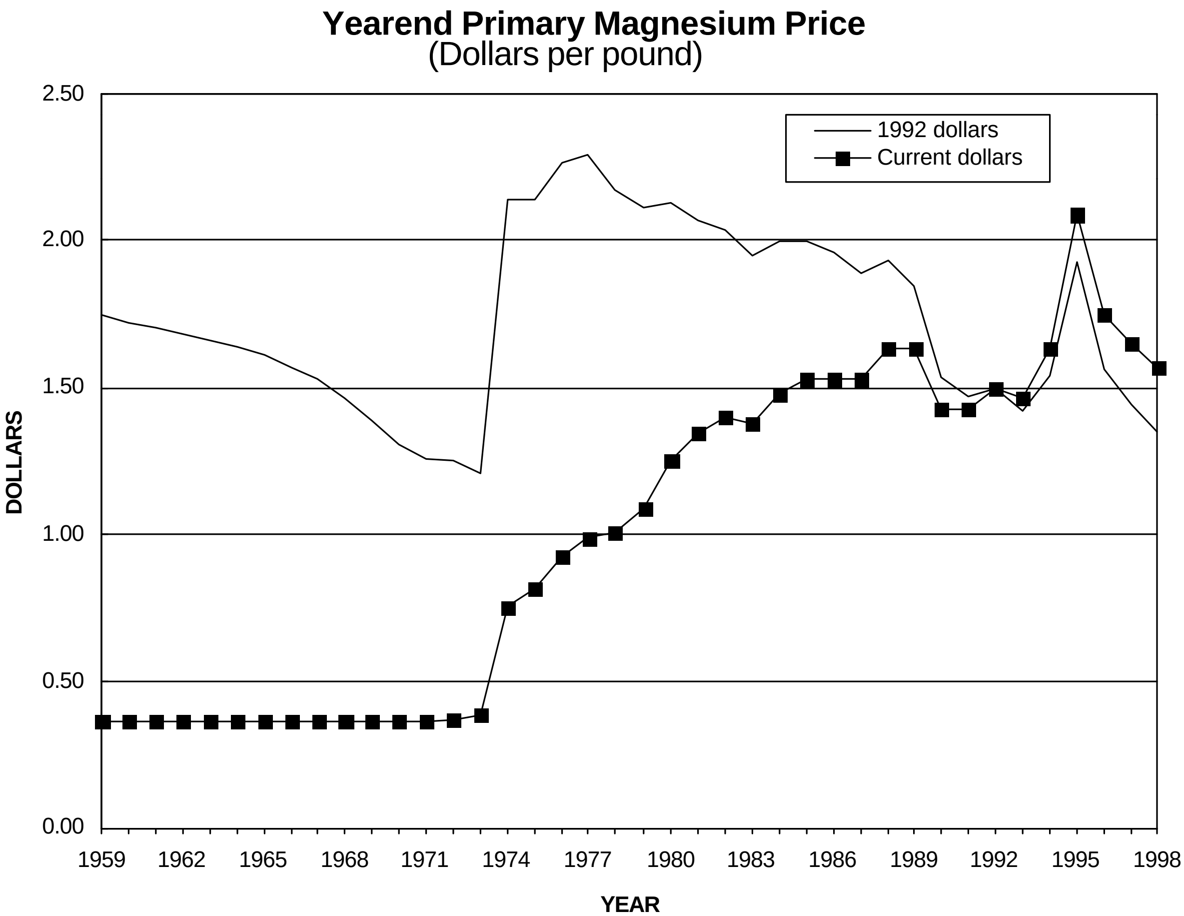
Year	Price	Year	Price	Year	Price	Year	Price
1952	9.85	1964	9.00	1976	11.60	1988	26.70
1953	11.00	1965	9.00	1977	11.60	1989	28.30
1954	11.00	1966	7.50	1978	13.20	1990	30.00
1955	11.00	1967	7.50	1979	15.65	1991	31.50
1956	11.00	1968	7.50	1980	17.15	1992	32.45
1957	11.00	1969	7.75	1981	20.65	1993	33.60
1958	9.00	1970	8.18	1982	20.65	1994	35.98
1959	9.00	1971	8.18	1983	21.70	1995	39.05
1960	9.00	1972	8.18	1984	22.70	1996	40.60
1961	9.00	1973	8.18	1985	24.20	1997	43.33
1962	9.00	1974	9.38	1986	24.20	1998	43.33
1963	9.00	1975	11.10	1987	25.45		

[1] To convert to dollars per kilogram, divide by 0.454.

Note:
1952-57, 98%-pure lithium metal, *in* E&MJ Metal and Mineral Markets.
1958-65, 99.5%-pure lithium metal, *in* E&MJ Metal and Mineral Markets.
1966-71, Standard or technical grade lithium of at least 99.8% purity, *in* Oil, Paint, and Drug Reporter.
1972-77, Standard or technical grade lithium of at least 99.8% purity, *in* Chemical Marketing Reporter.
1978-90, Producers average list price for standard or technical grade lithium of at least 99.8% purity.
1991-94, Average of producer and published prices for standard or technical grade lithium metal of at least 99.8% purity, *in* Chemical Marketing Reporter.
1995-96, Producers' average list price for standard or technical grade lithium of at least 99.8% purity.
1997-98, Standard or technical grade lithium of at least 99.8% purity, *in* Chemical Market Reporter.

Magnesium

by Deborah A. Kramer



Significant events affecting magnesium prices since 1958

1974-79	Increased energy costs and rapid inflation boost prices
1987-88	Tight supply of magnesium because of increased aluminum consumption
1991	Antidumping and countervailing duty investigations of magnesium imports from Canada initiated; dissolution of the Soviet Union
1994	Antidumping duty investigation initiated on magnesium imports from China, Russia, and Ukraine

Because of its military applications, World War II brought increased demand for magnesium. From 1941 through 1944 supplies of magnesium were allocated to manufacturers of military components. Seven Government-owned plants were brought on-stream during World War II to supply the military demand, and prices were controlled from 1943 through 1945 by the Office of Price Administration.

After the end of the War, the price controls were lifted, and consumer demand was not great enough to sustain the war-time production levels. The rearmament program, between 1947 and 1953, brought a rise in consumption, but when military supplies were replenished, demand declined significantly, and the Government-owned plants were closed. Because the large demand was not sustained, prices after World War II remained constant.

In the 1950's and early 1960's magnesium prices remained steady. Development of new rolling techniques and new alloys helped increase magnesium's usage, particularly in machinery and transportation equipment. By maintaining magnesium's price at a constant level, these industries were encouraged to use magnesium components. From 1964 through 1974, magnesium that had been acquired for the National Defense Stockpile in the early 1950's was released because magnesium was removed from the list of strategic and critical materials. This stockpile release provided an additional source of magnesium to supply the growing demand, which kept prices stable.

In 1974, a combination of increased energy costs, rising inflation rates, and the surge in use of aluminum beverage cans, which contain magnesium, led to a dramatic price increase. The price of magnesium nearly doubled within 1 year. Effects of rapid inflation rates continued to be felt through the remainder of the 1970's and into the early 1980's. As inflation rates decreased, the price of magnesium stabilized. In 1987 and 1988, magnesium supplies tightened as aluminum consumption increased. Because magnesium's principal use was as an alloying addition to aluminum, its use was directly related to aluminum consumption. In addition, high-purity magnesium alloys were developed as a measure to increase domestic consumption, particularly in automobiles. This supply shortage led to increased magnesium prices from 1987 to 1988.

In early 1990, North American production increased with the opening of a new 40,000-metric-ton-per-year plant in Canada (Metals Week, 1990). Much of the Canadian production was imported into the United States, alleviating the supply shortage. As a result, producers' quoted prices dropped in 1990, and by the end of 1991, press reports indicated that the actual selling price of primary magnesium was about $1.10 to $1.20 per pound. These low prices prompted one of the U.S. producers to request countervailing and antidumping duty investigations into imports of magnesium from Canada in September 1991; as a result of this action, magnesium imports from Canada essentially ceased.

With the dissolution of the former Soviet Union at the end of 1991, however, new suppliers entered the world market. Because of stockpiles that had been built up over many years, Russia and Ukraine had significant quantities of magnesium available to exchange for hard currency in the world market. In spite of the cessation of magnesium imports from Canada, U.S. imports were strong because of the increased supply of metal, particularly from Russia. As a result, U.S. prices dropped significantly in 1992, and a two-tier price system was established—a U.S. import price and a U.S. transaction price, which reflected the prices charged by the U.S. producers.

By mid-1992, the U.S. International Trade Commission (ITC) had established antidumping and countervailing duties on magnesium imported from Canada, so this material essentially was eliminated from the U.S. market (U.S. Department of Commerce, 1992). Imports of magnesium from Canada were approximately replaced by imports from Russia, so the change in U.S. magnesium supplies was not significant, and as a result, the U.S. price moderated during 1992 and 1993.

Low unit values for magnesium imported from Russia and Ukraine prompted one U.S. producer to request an anti-dumping duty investigation of magnesium imports from these two countries, as well as from China, in mid-1994. This resulted in a cessation of magnesium imports from these countries. As domestic demand, mostly for magnesium components for automotive applications, continued to increase, the elimination of imported magnesium from Canada, China, Russia, and Ukraine led to tight U.S. supplies. As a result, the price began to increase.

Supplies remained tight though most of 1995, and by mid-year, the price escalated to its highest level since magnesium was first produced in 1915.

The ITC established final antidumping determinations in April 1995 for magnesium imports from China, Russia, and Ukraine (U.S. Department of Commerce, 1995a, b, c). Because the antidumping duty on Russian magnesium was established at 0% for all the large producers (as long as they imported the magnesium through specified importing companies), magnesium again could be imported from Russia, which had been the United States' largest magnesium supplier.

By 1996, the price began to drop as Russian magnesium returned to the U.S. market. At the same time, the countervailing duties on magnesium imports from Canada dropped enough so that Canada began exporting significant quantities of magnesium alloy into the United States. With these sources of imported material, the United States experienced an oversupply of magnesium, and prices dropped dramatically by yearend 1996. Also in 1996, the United States imported more magnesium than it exported for the first time in more than 20 years.

The United States continued to rely on imports of magnesium to meet its increasing demand, so U.S. prices continued to weaken slightly through 1998, although they were returning to more normal levels from the 1995 price spike. World supply in 1997 and 1998 also increased with production from a new 27,500-ton-per-year primary magnesium plant that had been commissioned at the end of 1996 in Israel (Platt's Metals Week, 1997).

References Cited

Metals Week, 1990, Becancour plant will be up to par in June: Metals Week, v. 61, no. 10, March 5, p. 3.

Platt's Metals Week, 1997, Dead Sea Magnesium to top capacity in 1998: Platt's Metals Week, v. 68, no. 16, April 21, p. 12.

U.S. Department of Commerce, 1992, Pure and alloy magnesium from Canada—Recission of investigation and partial dismissal of petition: Federal Register, v. 57, no. 134, July 13, p. 30939-30955.

——1995a, Notice of final determination of sales at less than fair value—Pure magnesium and alloy magnesium from the People's Republic of China: Federal Register, v. 60, no. 61, March 30, p. 16437-16440.

———1995b, Notice of final determination of sales at less than fair value—Pure magnesium and alloy magnesium from the Russian Federation: Federal Register, v. 60, no. 61, March 30, p. 16440-16450.

———1995c, Notice of final determination of sales at less than fair value—Pure magnesium from Ukraine: Federal Register, v. 60, no. 61, March 30, p. 16432-16437.

Yearend Primary Magnesium Price
(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1915	5.03	1936	0.26	1957	0.3625	1978	1.01
1916	4.13	1937	0.30	1958	0.3625	1979	1.09
1917	2.02	1938	0.30	1959	0.3625	1980	1.25
1918	1.81	1939	0.30	1960	0.3625	1981	1.34
1919	1.83	1940	0.27	1961	0.3625	1982	1.40
1920	1.60	1941	0.23	1962	0.3625	1983	1.38
1921	1.60	1942	0.23	1963	0.3625	1984	1.48
1922	1.60	1943	0.21	1964	0.3625	1985	1.53
1923	1.25	1944	0.21	1965	0.3625	1986	1.53
1924	1.07	1945	0.21	1966	0.3625	1987	1.53
1925	0.86	1946	0.21	1967	0.3625	1988	1.63
1926	0.80	1947	0.21	1968	0.3625	1989	1.63
1927	0.68	1948	0.21	1969	0.3625	1990	1.43
1928	0.55	1949	0.21	1970	0.3625	1991	1.43
1929	0.57	1950	0.25	1971	0.3625	1992	1.50
1930	0.48	1951	0.25	1972	0.3725	1993	1.46
1931	0.30	1952	0.27	1973	0.3825	1994	1.63
1932	0.29	1953	0.27	1974	0.75	1995	2.09
1933	0.28	1954	0.28	1975	0.82	1996	1.75
1934	0.26	1955	0.325	1976	0.92	1997	1.65
1935	0.26	1956	0.3525	1977	0.99	1998	1.57

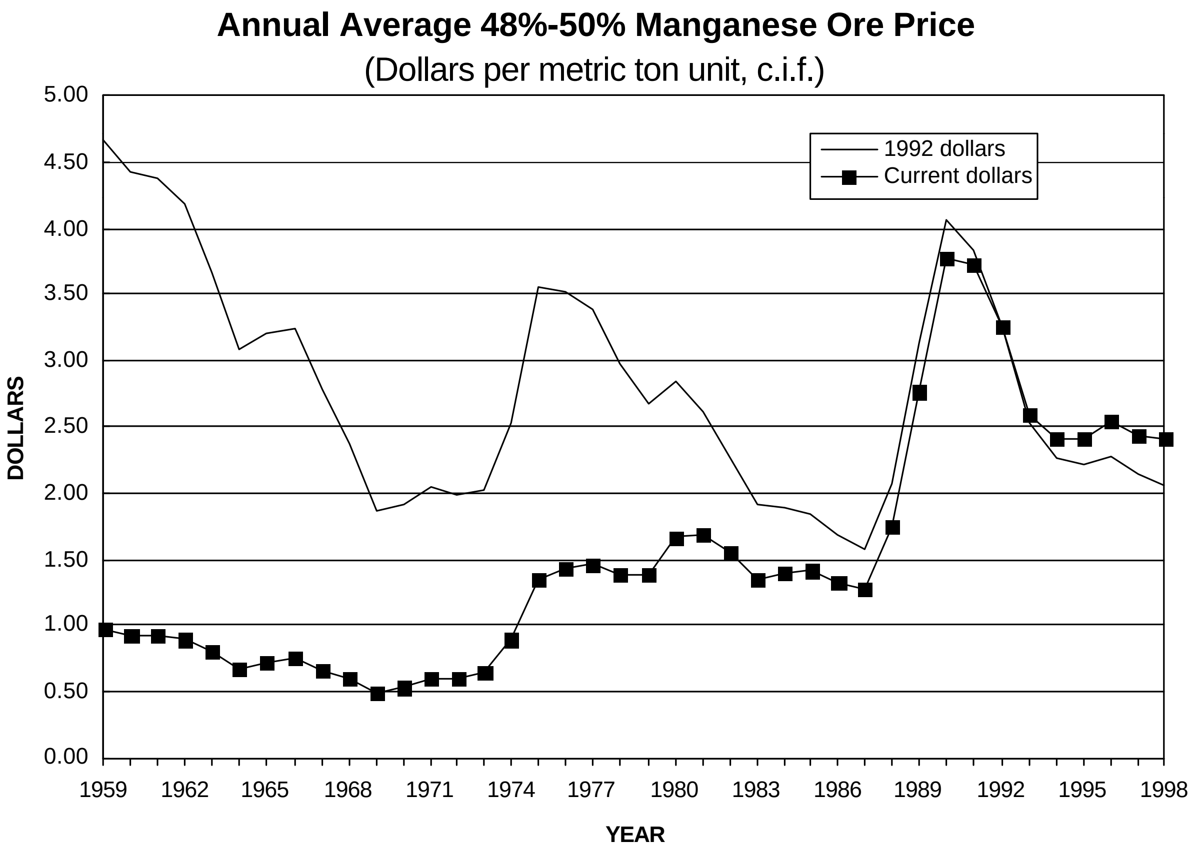
[1] To convert to dollars per metric ton, multiply by 2,204.62.

Note:
1915-34, Producers' average selling prices for 99%-pure magnesium bars.
1935-56, Producer price for 99.8%-pure magnesium ingot, *in* Engineering & Mining Journal.
1957-91, Producer price for 99.8%-pure magnesium ingot, *in* American Metal Market.
1992, U.S. transaction price for 99.8%-pure magnesium ingot, *in* Metals Week.
1993-98, U.S. spot Western price for 99.8%-pure magnesium ingot, *in* Platt's Metals Week.

(This page intentionally left blank.)

Manganese

by Thomas S. Jones



Significant events affecting manganese ore prices since 1958

1960's	Production begins from the Groote Eylandt deposit in Australia and Moanda deposit in Gabon and potential of deposits in South Africa's Kalahari Field begins to be recognized
1965-78	Releases of stockpile excesses
1973-74	High levels of steel production
1974, 1978, 1981	Sharp increases in oil price
Early 1980's	Economic recession, strong U.S. dollar
1980's	Adoption of steelmaking technology that significantly reduces amount of manganese required per ton of steel produced
1983-90	Significant imports of high-grade ore by China and the Soviet Union
1991	Dissolution of the Soviet Union

This discussion of manganese price is based on the price of manganese units in metallurgical-grade ore, for which a lengthy history exists. Manganese is used mostly in the production of iron and steel. Manganese metal, a minor component of overall manganese demand, is a brittle substance that has little use except as an alloying element. The most important metallic materials containing manganese are the manganese ferroalloys, of which high-carbon ferromanganese and silicomanganese have the greatest uses. The value of manganese in upgraded forms reflects the extraction cost so that for materials used in the United States in 1997, the ratio of price per manganese unit as contained in upgraded form versus that in ore was 2.5:1 for high-carbon ferromanganese, 2.6:1 for silicomanganese, and 10:1 for manganese metal (Jones, 1998). Price trends for these materials do not necessarily parallel those for ore because of differences in such factors as world structure and number of suppliers and also because most ore usage is by way of ferroalloy smelters.

No central exchange has existed for setting the price of manganese ore. Rather, prices have been established by negotiation between buyers and sellers, taking into account such factors as content of elements other than manganese, physical character, quantity, and, of considerable significance, ocean freight rates. Trade journals have published prices reflecting their sense of the market. These journals mainly list the price for metallurgical-grade ore; price listings for ore used in battery and so-called chemical applications are fragmentary or nonexistent. The benchmark price for metallurgical-grade ore is for relatively high-grade ore with a manganese content in the range of 48% to 50%. Prices stated herein for metallurgical-grade ore generally meet that standard, although this may not be strictly true throughout the entire time interval tabulated, particularly when the countries that are dominant sources of ore change.

The unit pricing system is used with manganese ore to accommodate variations in manganese content. For some years now, the metric ton unit has been used; formerly, pricing had been based on the long ton unit. A unit is 1/100, or 1%, of the weight unit, so that 1 metric ton unit corresponds to 0.01 metric ton, or 10 kilograms, of manganese. To obtain the price of a metric ton of ore, the metric ton unit price is multiplied by the percent manganese content of the ore. For example, an ore priced at $2 per metric ton unit that contains 50% manganese would have a value of $2 x 50 = $100 per ton. At the price level of $2 per 10 kilograms of manganese, the value of the manganese content of the ore also could be expressed as 20 cents per kilogram of manganese-in-ore.

The larger year-to-year users of manganese ore have tended to make their purchases by means of annual contracts, which have been much more important than spot contracts. The U.S. market was once the largest for manganese ore so that prices tended to be set in the latter part of the calendar year for the next year's shipments. With the decline in smelting of manganese ferroalloys in the United States, however, the Japanese have been the key factor in setting annual prices for a number of years. The timing of price negotiations has tended to revolve around the Japanese fiscal year, which begins on April 1. After the price to Japanese consumers is set at about that time, settlements on a similar basis usually follow elsewhere (Carmichael, 1992).

Between 1959 and 1998, manganese ore price exhibited peaks in 1981 and 1990 and valleys in 1969, 1987, and 1994-95. The average annual rate of advance in price throughout these four decades has been about 4.8%; since the late 1960's, ore price has advanced at a 6.7% annual rate. These rates of advance might be compared with those for the Consumer Price Index (CPI), which grew at an annual rate of 5.3% during this time period. The CPI grew at an annual rate of 8.6% during the 1970's, but since the early 1980's, it has been advancing at an annual rate of only 3.6%.

The downward trend in ore price between 1959 and 1969 was a continuation of a recession from a then-record high price in 1957. This was about the time that the Suez Canal was closed briefly and that shipments began from the Amapá deposit in Brazil, an important new source of manganese. Between 1951 and 1959, the U.S. Government had stock-piled manganese ore from foreign and domestic sources. Beginning in the mid-1960's, however, the Government sold sizable quantities of excess ore so that the stockpile effectively became a medium-size "mine." Stocks of metallurgical-grade ore that had been more than 9 million tons in 1969 were reduced to less than 4 million tons by 1978 (DeHuff, 1971, 1980). Also in the 1960's, development of several significant mostly new manganese deposits contributed to declining ore prices and alteration of the international supply pattern for manganese ore. Two of these were the Groote Eylandt deposit in Australia's Northern Territory and the Moanda deposit in Gabon, both of which were developed into large surface mines (DeYoung, Sutphin, and Cannon, 1984). During the 1960's and 1970's, several major mines based on the enormous manganese deposits of the Kalahari Field in South Africa's Northern Cape Province were opened, typified in the north by the Black Rock Mine and in the south by the Mamatwan Mine (Coffman and Palencia, 1984).

The declining trend of ore price in the 1960's was replaced by an even steeper upward trend in the 1970's. The low of $0.49 per metric ton unit in 1969 was followed by prices of about $1.40 per metric ton unit between 1975 and 1979. Contributing factors were the comparatively high rates of domestic and international steel production, especially in 1973-74, and the shock effects of oil price increases between 1974 and 1981.

After an ore price of nearly $1.70 was attained in 1980-81, the direction of the trend again reversed in 1982 with onset of a worldwide recession. In the early 1980's, the more-efficient use of manganese in steelmaking depressed demand for manganese. For example, by changing the way in which pig iron was converted into steel, domestic steelmakers reduced their unit consumption of manganese in steelmaking by about one-fifth within about 2 years. This reduction was much larger than the steel-related growth in manganese demand that otherwise would have been expected, ordinarily about 1% per year. The U.S. ore price in the early 1980's was also depressed by the relative strength of the dollar in relation to other currencies.

After having decreased to $1.27 per metric ton unit as of 1987, ore price rose sharply to three consecutive all-time record highs in terms of current dollars between 1988 and 1990, concurrent with recovery of domestic and world steel production. Prior to the recovery in steel production, the nature of the international manganese ore market was changed when the then-U.S.S.R. and China began importing substantial quantities of ore in 1983 and 1984, respectively. The imports were from such countries as Australia, Brazil, and Gabon, whose traditional principal export markets were Japan, Western Europe, and the United States. With so few competitors on the supply side, the market constituted an oligopoly. An apparent shortage of high-grade ore that developed because of unusually large ore purchases led to a price of $3.78 per metric ton unit in 1990, the record high to the present.

Prices generally have receded since the 1990 peak. One of the main reasons was dissolution of the former U.S.S.R. in 1991 and the subsequent contraction of industrial production in its successor republics; this caused the developing ore market to disappear within a short period of time. Another factor was the reactivation of mining or development at known deposits, as in Western Australia (Chadwick, 1991); this led to modest additions to supply from what might be termed "mini-mines," which nevertheless had a significant impact on price negotiations.

During the 1990's, a continuing trend, often on an international scale, has been the integration of mine production with ferroalloy production, which has the potential to affect the way ore is priced in the future.

References Cited

Carmichael, Malcolm, 1992, An introduction to manganese, *in* Bailey, John, ed., Iron and manganese ore databook: Worcester Park, England, Metal Bulletin Books Ltd., p. xli-xlix.

Chadwick, John, 1991, Pilbara progress: Mining Magazine, v. 164, no. 5, p. 278-285.

Coffman, Joseph, and Palencia, C.M., 1984, Manganese availability—Market economy countries: U.S. Bureau of Mines Information Circular 8978, 26 p.

DeHuff, G.L., 1971, Manganese, *in* Minerals Yearbook 1969, v. I-II: U.S. Bureau of Mines, p. 673-684.

———1980, Manganese, *in* Minerals Yearbook 1978-79, v. I: U.S. Bureau of Mines, p. 577-591.

DeYoung, J.H., Jr., Sutphin, D.M., and Cannon, W.F., 1984, International Strategic Minerals Inventory summary report—Manganese: U.S. Geological Survey Circular 930-A, 22 p.

Jones, T.S., 1998, Manganese—1997 Annual review: U.S. Geological Survey Mineral Industry Surveys, August, 14 p.

Annual Average 48%-50% Manganese Ore Price[1]

(Dollars per metric ton unit, c.i.f. U.S. ports)[2]

Year	Price	Year	Price	Year	Price	Year	Price
1910	0.26	1933	0.41/0.19	1956	1.49/1.44	1979	1.38
1911	0.26	1934	0.45/0.23	1957	1.61/1.56	1980	1.67
1912	0.25	1935	0.47/0.25	1958	1.25/1.19	1981	1.69
1913	0.25	1936	0.37/0.26	1959	1.02/0.97	1982	1.56
1914	0.26	1937	0.55/0.44	1960	0.98/0.93	1983	1.36
1915	0.31	1938	0.47/0.36	1961	0.98/0.93	1984	1.40
1916	0.49	1939	0.43/0.32	1962	0.95/0.90	1985	1.41
1917	0.96	1940	0.62/0.51	1963	0.85/0.80	1986	1.32
1918	1.25	1941	0.76/0.65	1964	0.71/0.68	1987	1.27
1919	0.65	1942	0.83/0.72	1965	0.72	1988	1.75
1920	0.66	1943	0.83/0.72	1966	0.75	1989	2.76
1921	0.28	1944	0.78/0.67	1967	0.66	1990	3.78
1922	0.31	1945	0.84/0.73	1968	0.59	1991	3.72
1923	0.63/0.41	1946	0.77/0.66	1969	0.49	1992	3.25
1924	0.60/0.38	1947	0.69/0.58	1970	0.53	1993	2.60
1925	0.64/0.42	1948	0.70/0.64	1971	0.59	1994	2.40
1926	0.60/0.38	1949	0.77/0.71	1972	0.59	1995	2.40
1927	0.60/0.38	1950	0.96/0.91	1973	0.64	1996	2.55
1928	0.59/0.37	1951	1.18/1.12	1974	0.89	1997	2.44
1929	0.53/0.31	1952	1.33/1.27	1975	1.36	1998	2.40
1930	0.49/0.27	1953	1.25/1.19	1976	1.43		
1931	0.46/0.24	1954	1.00/0.95	1977	1.46		
1932	0.43/0.21	1955	1.08/1.02	1978	1.38		

[1] Values to the left of the slash include U.S. duty.

[2] C.i.f denotes cost, insurance, and freight.

Note:

1910-37, calculated from U.S. Geological Survey and Bureau of Mines, 1940, Report upon certain deficient strategic minerals: U.S. Geological Survey and Bureau of Mines, p. 8.

1938-41, Barbour, P.E., 1941, Manganese prices, production and imports: Mining and Metallurgical Society of America Bulletin 263, v. 34, no. 5, December, p. 156-161.

1942-62, E&MJ Metal and Mineral Markets.

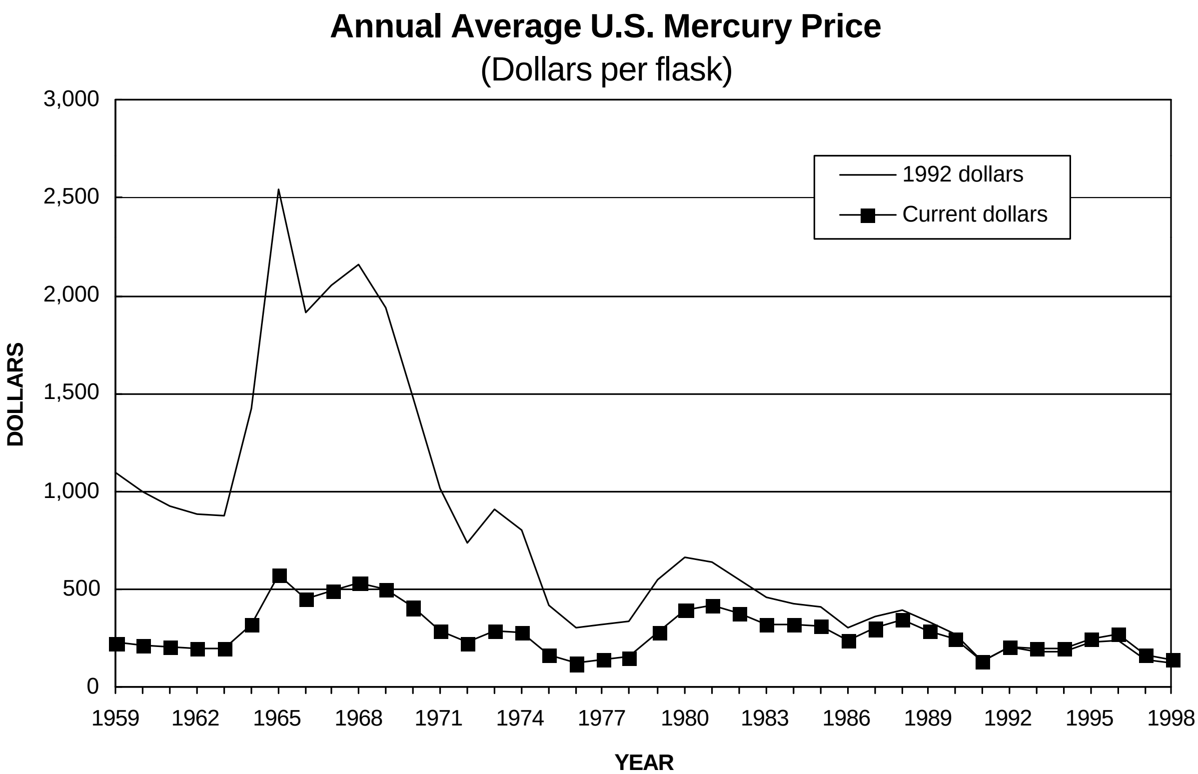
1963-77, American Metal Market.

1978-94, Manganese Commodity Specialist, U.S. Bureau of Mines (G.L. DeHuff and T.S. Jones).

1995-98, Manganese Commodity Specialist, U.S. Geological Survey (T.S. Jones).

Mercury

by Robert G. Reese, Jr.



Significant event affecting mercury prices since 1958

1971 Mercury declared a hazardous air pollutant by the U.S. Environmental Protection Agency

In the 20th century, the mercury price has been very volatile. During the first half of the century, the price increased significantly three times. These increases coincided with periods of increased demand, namely, World Wars I and II and a period in the late 1920's of high prices established and maintained by the Spanish-Italian mercury cartel—Mercurio Europeo (Pennington, 1959, p. 47). Following World War II, through the run to its peak price in 1965, the volatility can be explained in part by mercury's erratic demand and frequent overproduction. Since the early 1970's, the average price has generally trended downward. Growing awareness of health and environmental problems associated with mercury have resulted in numerous regulations restricting or eliminating mercury use in various applications, and governing its ultimate disposal. These regulations have the combined effect of lowering demand while at the same time increasing the supply of secondary mercury. As a result, the price has declined. Although it is believed that mercury producers have attempted to use sales restrictions or floor prices to stabilize or raise the price at various times during these three decades, these efforts have failed other than for very short periods.

Reference Cited

Pennington, J.W., 1959, Mercury—A materials survey: U.S. Bureau of Mines Information Circular 7941, 92 p.

Annual Average U.S. Mercury Price

(Dollars per flask[1])

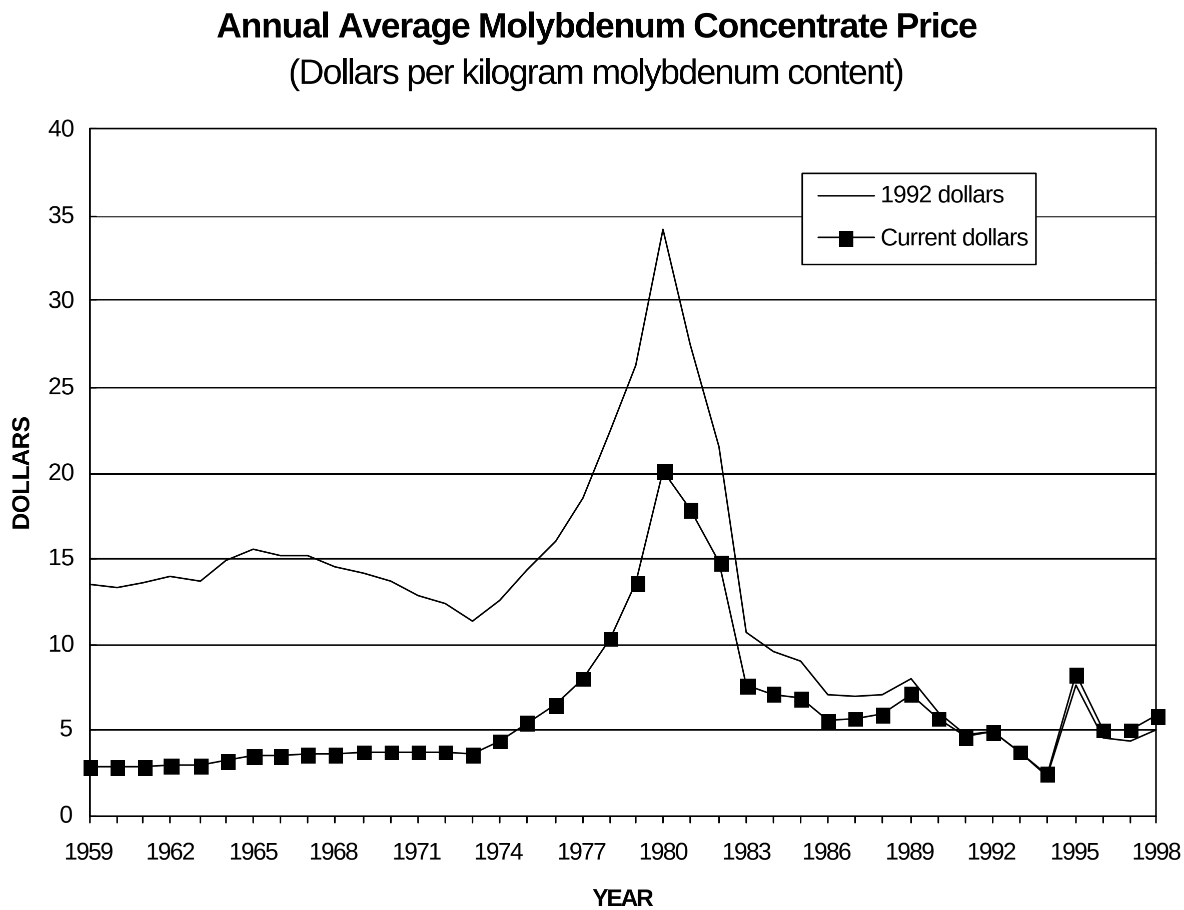
Year	Price	Year	Price	Year	Price	Year	Price
1899	43.63	1924	69.76	1949	79.46	1974	281.69
1900	51.00	1925	83.13	1950	81.26	1975	158.12
1901	47.00	1926	91.90	1951	210.13	1976	121.30
1902	48.03	1927	118.16	1952	199.10	1977	135.71
1903	41.32	1928	123.51	1953	193.03	1978	153.32
1904	41.00	1929	122.15	1954	264.39	1979	281.10
1905	38.50	1930	115.01	1955	290.35	1980	389.45
1906	40.90	1931	87.35	1956	259.92	1981	413.86
1907	41.50	1932	57.93	1957	246.98	1982	370.93
1908	44.84	1933	59.23	1958	229.06	1983	322.44
1909	46.30	1934	73.87	1959	227.48	1984	314.38
1910	47.06	1935	71.99	1960	210.76	1985	310.96
1911	46.54	1936	79.92	1961	197.61	1986	232.79
1912	42.46	1937	90.18	1962	191.21	1987	295.50
1913	39.54	1938	75.47	1963	189.45	1988	335.52
1914	48.31	1939	103.94	1964	314.79	1989	287.72
1915	87.01	1940	176.86	1965	570.75	1990	249.22
1916	125.49	1941	185.02	1966	441.72	1991	122.42
1917	106.30	1942	196.35	1967	489.36	1992	201.39
1918	123.47	1943	195.21	1968	535.56	1993	187.00
1919	92.15	1944	118.36	1969	505.04	1994	194.45
1920	81.12	1945	134.89	1970	407.77	1995	247.39
1921	45.46	1946	98.24	1971	292.41	1996	261.61
1922	58.95	1947	83.74	1972	218.28	1997	159.52
1923	66.50	1948	76.49	1973	286.23	1998	139.84

[1] To convert to dollars per kilogram, multiply by .029008.

Note:
1899-1986, 76-pound flasks, *in* Engineering and Mining Journal.
1987-93, 76-pound flasks, 99.99%-pure mercury, *in* Metals Week (through June 14, 1993).
1993-98, 76-pound flasks, 99.99%-pure mercury, *in* Platt's Metals Week.

Molybdenum

by John W. Blossom



Significant events affecting molybdenum prices since 1958

1971-74	Price controls imposed by the U.S. Government, including metal products
1990-91	Persian Gulf War and recession
1991	Dissolution of the Soviet Union

From the period of the Greek and Roman civilizations to the late 18th century, such terms as “molybdos” or “molybdaena” were applied to minerals that were soft and “leadlike” in character; these minerals probably included those now known as galena, graphite, and molybdenite. This confusion was resolved in 1778 when the Swedish chemist, Karl Scheele, demonstrated that molybdenite, the principal molybdenum mineral, was a discrete mineral sulfide. Four years later, P.J. Hjelm of Sweden reduced the acid-forming oxide of the metal by heating it with charcoal, thereby producing an impure powder of the metal, which he named “molybdenum.” Various properties of the element and its compounds were determined during the 19th century, and in 1893, German chemists produced a 96%-pure metal by reducing calcium molybdate. About this time, impure metal was reported to have been used experimentally as a substitute for tungsten in tool steels (Sutulov, 1965, p. 13-16).

Molybdenum-bearing armorplate was produced in France in 1894; this was the first recorded use of the metal as an alloying element in steel. Soon thereafter, Henri Mossiam, a

French chemist, succeeded in producing a 99.9%- pure metal by reduction of molybdenum in an electric furnace. Mossiam then conducted studies to establish the element's atomic weight and to determine its physical and chemical properties. These studies stimulated interest in the metal and its compounds and investigations of commercial applications. By the late 1890's, molybdenum was used in certain chemicals and dyes, and in 1898, a self-hardening molybdenum tool steel was marketed (Schneider, 1963).

Since the early 1930's, industrial research and marketing programs have considerably expanded the range of metallurgical materials in which molybdenum is a preferred or essential alloy ingredient. The use of molybdenum as a refractory metal and in a variety of chemical applications has also grown significantly (Sutulov, 1965).

The period from 1959 to 1970 resulted in steadily but only slightly increasing prices. The 1970 price of molybdenum was about 35% more than the 1959 price; the constant dollar price remained nearly unchanged. From 1971 to 1974, price controls were imposed by the U.S. Government, and between 1970 and 1980 consumers presumed a shortage would develop, but one did not materialize. The price of molybdenum did increase nearly six times from its 1970 level, while the spot price increased by eight times owing to relatively high demand compared with that of the 1960's and early 1970's. Consumers made inquiries about purchasing, as well as actually purchasing material in excess of their needs. This action motivated the producers to develop additional unneeded mine capacity that became a major problem. The new mines came on-stream about 3 years after the peak in 1980. Prices continued to decrease through 1986 but then slowly increased for 3 years. Between 1992 and 1994, just after the Persian Gulf War, the dissolution of the former Soviet Union, and a recession, prices decreased yearly. The price in 1995 increased more than three times that of 1994, as consumers again presumed a shortage would develop; again, one did not materialize. The average price in 1996 was about 40% lower than that of 1995. As the market stabilized, prices remained about the same or increased slightly from 1996 to 1998.

References Cited

Schneider, V.B., 1963, Molybdenum: Ottawa, Canada, Department of Mines and Technical Surveys, Mineral Report 6, p. 1-4.

Sutulov, Alexander, 1965, [Molybdenum extractive metallurgy]: University of Concepcion, Chile, 239 p.

Annual Average Molybdenum Concentrate Price
(Dollars per kilogram molybdenum content)

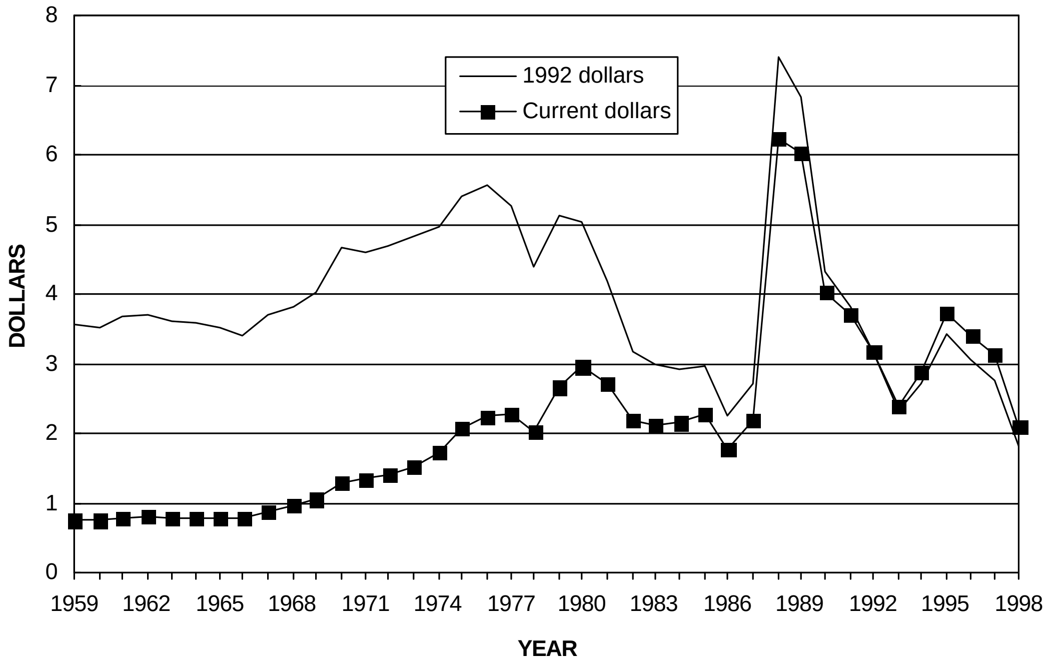
Year	Price	Year	Price	Year	Price	Year	Price
1912	0.45	1934	1.57	1956	2.51	1978	10.40
1913	0.67	1935	1.57	1957	2.64	1979	13.60
1914	2.24	1936	1.48	1958	2.67	1980	20.10
1915	2.24	1937	1.52	1959	2.80	1981	17.80
1916	2.24	1938	1.57	1960	2.80	1982	14.80
1917	3.16	1939	1.52	1961	2.90	1983	7.60
1918	3.27	1940	1.55	1962	3.00	1984	7.10
1919	2.58	1941	1.52	1963	3.00	1985	6.90
1920	1.12	1942	1.59	1964	3.30	1986	5.60
1921	1.57	1943	1.59	1965	3.50	1987	5.70
1922	0.49	1944	1.59	1966	3.50	1988	6.00
1923	1.70	1945	1.59	1967	3.60	1989	7.10
1924	2.02	1946	1.52	1968	3.60	1990	5.70
1925	0.90	1947	1.52	1969	3.70	1991	4.60
1926	1.57	1948	1.55	1970	3.80	1992	4.90
1927	1.70	1949	1.86	1971	3.70	1993	3.80
1928	2.24	1950	1.90	1972	3.70	1994	2.50
1929	1.12	1951	2.13	1973	3.60	1995	8.30
1930	1.23	1952	2.15	1974	4.40	1996	5.00
1931	0.94	1953	2.17	1975	5.50	1997	5.00
1932	1.12	1954	2.24	1976	6.50	1998	5.80
1933	1.68	1955	2.31	1977	8.00		

Sources: Prices for the period from 1912 to 1955 were published by the U.S. Bureau of Mines, but origin is undetermined. E&MJ Metal and Mineral Markets (1956-66). Metals Week (1967-92). Platt's Metals Week (1993-98).

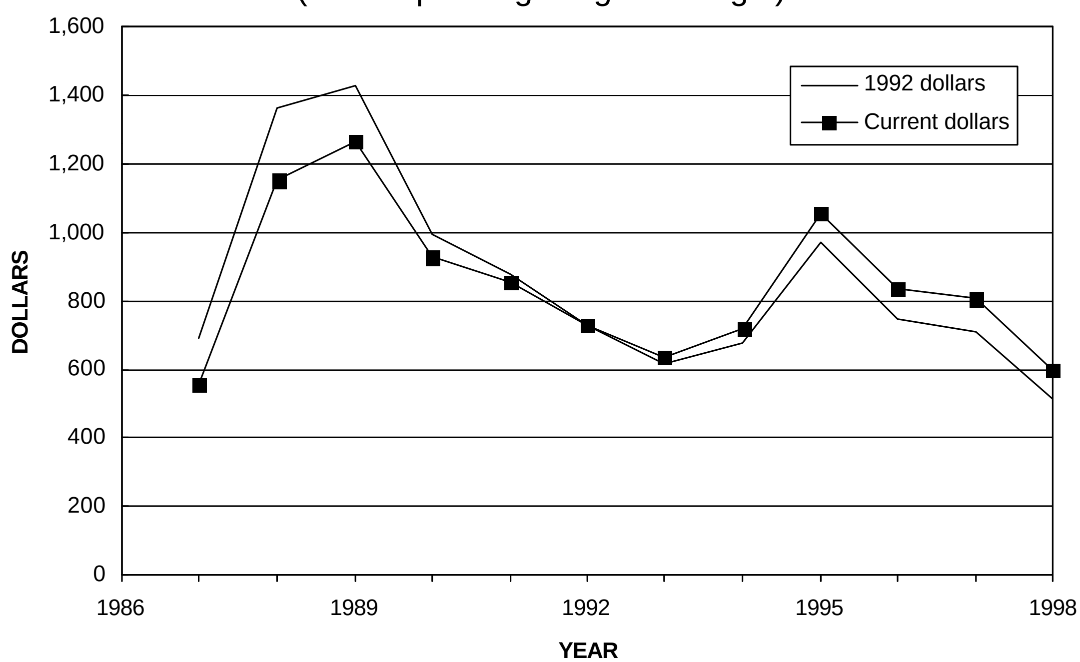
Ni

Nickel
by Peter H. Kuck

Annual Average Nickel Price
(Dollars per pound)



Annual Average Price for 18-8 Stainless Steel Scrap
(Dollars per long ton gross weight)



Significant events affecting nickel prices since 1958

1966	Western Mining Corp. discovered nickel sulfide mineralization at Kambalda, Western Australia, triggering extensive exploration of the greenstone belts between Norseman and Wiluna
1969	Canadian labor strike led to a severe spot shortage of nickel and a sixfold increase in the price of cathode
1972	Falconbridge Dominicana C. por A. commissioned its ferronickel smelter at Bonao, Dominican Republic
1977	P.T. International Nickel Indonesia (P.T. Inco) commissioned its Soroako mining and smelting complex on the Indonesian island of Sulawesi; laterite mining began in Guatemala
1978-79	Labor strike in the Sudbury District of Ontario reduced Canadian mine output by more than 40%
1979	Nickel became the seventh metal traded on the London Metal Exchange (LME)
1981-82	A worldwide recession caused nickel demand and prices to fall sharply
1987-88	The Government of the Dominican Republic levied a substantial export duty on ferronickel; Falconbridge Dominicana countered by limiting ferronickel shipments and declaring force majeure
1987-89	Supply shortages; Stainless steel production in the Western World passed the 10-million-metric-ton-per-year mark
1991	Dissolution of the Soviet Union followed by a sharp rise in exports of Russian nickel
1993	Voisey's Bay nickel-copper deposit discovered in northeastern Labrador by diamond prospectors
1999	The Murrin Murrin laterite mine and two other pressure acid-leaching operations came onstream in Western Australia

During the 17th century, German miners had difficulty processing certain copper sulfide ores because of an associated mineral that they called kupfernickel, or "Old Nick's copper." The troublesome mineral turned out to be nickel arsenide and is known today as "niccolite" or "nickeline." In 1751, Axel Fredrik Cronstedt isolated a previously unknown chemical element from niccolite. This element was subsequently named "nickel." Nickel was mined on only a limited scale until the large lateritic nickel deposits in New Caledonia came into production about 1875 (Boldt and Queneau, 1967, p. 61-65). The first nickel operations processed sulfide ores—primarily in Canada, Central Europe, China, Pennsylvania, and Scandinavia. Nickel had little economic or industrial significance until 1820 when Michael Faraday succeeded in making synthetic meteoric iron by adding nickel to pure iron. Faraday's alloy was the forerunner of nickel steel, a family of ferrous alloys that continues to play an important role in industrial development. One of the first uses of nickel steel was for ordnance. Nickel-steel armor plate was first produced commercially in France in 1885 (Hall, 1954). Competitiveness trials of nickel-steel armor took place in the United States in 1890-91, and within a few years, Bethlehem Iron Co. (forerunner of Bethlehem Steel Corp.) was producing large nickel-steel guns for the U.S. military (Wharton, 1897). The nickel steels developed before World War I contained only 1.5% to 4.5% nickel, with a carbon content of 0.2% to 0.5% (Hess, 1917). Other important early uses were bridge structures, railroad rails, axles, ship propeller shafts, and automobile engine parts (Cammen, 1928). The first commercial chromium-nickel steel—and one of the first grades of stainless steel—was made at St. Chamond, France, in 1891. Like nickel-steel armor, chromium-nickel-steel armor proved to be much superior to the carbon-steel plate then in use, triggering extensive production of the new type of steel (Hall, 1954, p. 1-62).

In the late 1990's, stainless steel production accounts for more than 60% of world nickel consumption and is the primary factor in nickel pricing. Stainless steel is defined as an iron alloy that contains at least 11% chromium. Nickel-bearing stainless steels are termed "austenitic", a reference to their characteristic solid solution microstructure, and typically contain between 6% and 22% nickel—with 18% chromium and 8% nickel being the most common composition. In the Western World, total stainless steel production has grown at about 6.1% per year since 1950 (Inco Limited, 1998, p. 3-8). Since 1985, the austenitic share of Western stainless steel production has accounted for about 75% of total stainless output, the rest being ferritic or martensitic. In recent years, the austenitic percentage for the United States has ranged from 63% to 67% because its steel plants produce significant amounts of ferritic stainless for the North American automobile industry. Since 1970, demand for stainless steel in the United States has grown at a much faster rate than that of carbon steel but still constitutes only 2% of total U.S. raw steel production. For the next 20 years, stainless steel production is expected to continue to play a prominent role in determining nickel price levels.

Like petroleum, nickel is a critical commodity in wartime. Nickel, as well as cobalt, is needed to make superalloys for engines that propel jet aircraft and guided missiles. Pure nickel is used in high-performance batteries, such as those that start jet engines or power satellites. Austenitic stainless steel and nickel-base superalloys are commonly used if chemical corrosion is a serious problem, such as on submarines and surface naval vessels or at food-processing or petroleum-storage facilities. Merchant nickel prices traditionally spike in wartime when demand far exceeds supply and frequently rise in times of political unrest and instability. Producer prices, in contrast, have been frozen in several crises by war-production boards or emergency price-control regulations.

The Korean Conflict is a good illustration of price spiking and distribution controls. During the transition from a civilian to a defense economy, demand for nickel exceeded available supply even though North American nickel mines and plants were operating at full capacity. At the outset of the conflict, the U.S. Government took control of the distribution of nickel, and from 1951 to 1957, all nickel in the United States was under Government allocation. At the same time, the Government also acquired nickel for the national strategic stockpile. The combination of these actions resulted in a severe shortage of nickel for nondefense uses (Davis, 1956). Shortages continued throughout the conflict despite the addition of significant new production capacity in Canada and the United States and the rehabilitation of a number of older mines and plants. Moreover, the U.S. Government continued to purchase nickel for the strategic stockpile after the conflict ended. As a result, supply did not exceed civilian demand until the latter part of 1957, 4 years after the armistice. The producer price of nickel—tracking consumption—began a gradual rise in 1950 and did not peak until 1957. A period of oversupply followed, during which quoted producer and merchant prices for nickel approximately paralleled inflation. This situation produced a constant-dollar price for the metal that was fairly stable for more than 10 years.

In 1969, the Canadian nickel, copper, and iron ore industries were shut down by a prolonged series of labor strikes. Canada was the dominant nickel-producing country in the world at the time. Canada's two largest producers, Inco Limited and Falconbridge Limited, accounted for 48% of world production the previous year. Because of the strikes, Canadian nickel production was almost 20% less than that of 1968 (Morrell, 1971). The strikes took place at a point in time when global stocks were low and world demand was restricted by available supply.

The 1969 strikes affected nickel prices in two ways. Before the strikes, the major producers, led by the Canadians, controlled the nickel price. The short-term effect was a brief price increase. The long-term effect was to diminish the importance of the producer price. Canadian and non-Canadian producers accelerated efforts to expand existing operations and to bring greenfield projects onstream before prices weakened. Between 1969 and 1974, new mines and processing plants were commissioned in Australia, Canada, the Dominican Republic, and New Caledonia. The increased capacity resulted in a reduction of the Canadians' share of the world market and, thus, their influence on prices—a turning point in the history of nickel marketing.

In the mid-1970's, Western Mining Corp. Ltd. (now WMC Ltd. of Southbank, Victoria) sharply expanded its mining operations in the Kalgoorlie region of Western Australia. Australia is now the third largest nickel producer in the world because of additional discoveries in Western Australia, the subsequent construction of a major natural gas pipeline from the North West Shelf to Kalgoorlie, and the advent of new extraction technologies (Government of Australia, 1999).

Nickel prices, reflecting consumption, rose slightly from 1970 until 1975, when the cumulative effect of opening several new production facilities began to be felt. In 1975, U.S. demand for nickel weakened, partially because of the termination of U.S.-led military operations in Vietnam. In 1977, P.T. Inco commissioned its Soroako mining and smelting complex on the Indonesian island of Sulawesi, bringing additional metal into the marketplace. An oversupply situation and declining consumption caused prices to remain flat until the Inco strike of 1978-79. The strike at Inco's operations in the Sudbury District lasted from September 16, 1978, to June 3, 1979 (Inco Limited, 1980, p. 4-9). Between February 1979 and the end of the year, Inco raised its Port Colborne price for cathode six times. The effect of the Inco strike on prices was compounded by the fact that major producers had been operating at 55% to 60% of capacity to reduce inventories and to improve the price situation.

The Inco strike helped accelerate major changes in nickel pricing. In spring 1979, nickel became the seventh metal traded on the LME—marking a major turning point in pricing of the metal. Today, nickel prices are set by the LME rather than by the producers. Since 1979, nickel has become a commodity whose price is driven by world supply and demand, irrespective of production costs. Many consumers, as well as producers, were opposed to LME trading at the time. Most, however, would now agree that the LME is a practical and effective forum for establishing an international reference price for nickel, improving price transparency, and rapidly disseminating price data. It is difficult to say how much nickel, probably a small proportion, actually sells at the LME price. The LME price has more importance than appears at first glance because it is used as a reference price in long-term contracts. For example, a large nickel producer might ask for a premium to the LME price, and a smaller one might sell at a discount. Because of the LME, producer prices became irrelevant in the early 1980's.

The Second Oil Crisis (1979-82), triggered by the revolution in Iran, had a major dampening effect on world consumption of steel and most metals. The resulting recession that began in summer 1981 caused a marked decline in nickel consumption. Nickel demand in the Western World declined about 8% in 1981; this was the first time since the late 1940's that demand had declined for two consecutive years. The recession ended in November 1982, but prices continued to weaken until 1985 because of slackening demand. In 1987, the market suddenly changed direction, catching producers off guard. The annual average price surged from its lowest level ever in 1986 to its highest in 1988 (in terms of 1992 constant dollars for the period 1910-97).

The monthly average LME cash price rose gradually from \$1.60 per pound at the beginning of 1987 to \$2.69 in November. In December 1987, it suddenly shot up to \$3.48. The rapid increase continued in 1988, with the monthly price reaching \$8.17 in April. These price levels would have been unimaginable to the nickel market 4 years earlier. Three factors were primarily responsible for the increase. The first was a substantial and unforseen increase in demand for stainless steel, the largest end use for nickel. More than 50% of stainless steel production in the United States and Europe is sold through service centers (companies that buy directly from a stainless mill and sell to customers). Service centers do not publish detailed sales statistics in terms of end use, making it difficult for stainless producers to monitor consumption of their product. The second factor was that nickel producers reduced world production capacity because of low metal prices during the early and mid-1980's. At least five nickel producers closed operations during this period. A third factor was the decreased availability of stainless steel scrap.

Although Western demand for nickel grew continuously between 1985 and 1991, the LME price peaked in 1988 and declined each year afterward until 1994. The reasons for this paradoxical trend were threefold—the former Soviet Union (FSU) began gradually increasing nickel shipments to the West, scrap availability increased worldwide, and world production of primary nickel increased.

The breakup of the Soviet Union in December 1991 produced massive changes in the Russian economy, one of which was the partial privatization of the largest nickel producer in the country, RAO Norilsk Nickel. At the same time, the downsizing of the FSU military-industrial complex caused nickel consumption within Russia to plummet. In 1997, Russia consumed only 20,000 metric tons of primary nickel, compared with 180,000 tons in 1989 (International Nickel Study Group, 1998). Russian consumption weakened even more in 1998, slipping to less than 18,000 tons. These changes led to a surge of primary nickel from Russia, putting downward pressure on world prices for primary nickel and nickel-bearing scrap. Russian exports of stainless steel scrap and high-nickel scrap to the European Union (EU) also sharply increased, further depressing world nickel prices. Russia continues to maintain its position as the largest nickel producer in the world despite its difficult economic situation. More than 90% of Russia's output currently (1998) comes from mines operated in the Arctic by Norilsk Nickel. Because of internal demands within Russia for hard currency and the depressed state of the Russian stainless steel industry, Norilsk Nickel is expected to continue exporting the bulk of its production to the West at least until 2005.

The Russian situation, the current recession in Japan, and economic problems in other parts of East Asia have caused the monthly LME cash price to decline from \$3.20 per pound in June 1997 to \$1.76 in December 1998. Since 1997, Western nickel producers have had to struggle to cut costs in the face of weakening prices for the metal. Prices improved slightly in the first half of 1999, climbing back to the \$2.25 to \$2.50 level. The commissioning of three nickel mining and metallurgical complexes in Western Australia at the beginning of 1999 is, however, expected to put renewed downward pressure on prices. All three operations use variations of a high-pressure acid leach process to extract nickel and cobalt from limonitic laterite ores. The nickel is then separated from the cobalt by solvent extraction. Several analysts believed that the three Australian complexes will have low operational costs and will be extremely competitive because of their cobalt byproduct credits.

Inco remains committed to the development of the huge Voisey's Bay nickel-copper-cobalt deposit in northeastern Labrador (Inco Limited, 1999, p. 20-21). In December 1997, Inco submitted a comprehensive environmental impact statement on the proposed mine and mill to Canadian regulatory authorities. Since then, the Voisey's Bay project has undergone extensive environmental and socio-economic scrutiny. In March 1999, a special panel overseeing the environmental review recommended that the project proceed, subject to a number of stipulations. Complex and lengthy negotiations are currently (1999) underway with the Provincial Government and other key stakeholders. The development of the deposit, which Inco acquired in 1995-96, is expected to have a major impact on the world nickel market sometime after 2003.

Pricing Mechanisms for Nickel Metal

On April 23, 1979, nickel contracts were introduced for the first time on the LME. Leading nickel producers at first stiffly opposed the LME pricing mechanism. Nickel business on the LME, however, steadily grew in spite of the producers' opposition, convincing the producers to reverse their position. Producer participation has increased considerably since 1985 because of the LME's hedging and options capabilities. Today, LME prices are the principal pricing mechanism used worldwide by producers and consumers of nickel. LME prices and archival statistics are available 24 hours a day at the LME website, thus minimizing arbitrage. LME prices are also quoted by day in a variety of weekly trade publications, including Metal Bulletin, Platt's Metals Week, and Ryan's Notes. In 1999, the LME pricing system had the support of nine of the larger nickel producers in the world. Five of the nine are Associate Trade Members of the Exchange—Inco; Falconbridge (through its principal shareholder, Noranda Inc.); Outokumpu Oyj of Espoo, Finland; Rio Tinto Plc. of London; and WMC. All five sell metal that meets LME specifications. Metal produced by Norilsk Nickel and the ERAMET Group—two other major producers—has also been approved for delivery on LME warrants, together with metal from Sumitomo Metal Mining Co. Ltd. and several smaller producers. QNI Limited of Brisbane, Australia—the ninth company—recently became a major player in the nickel market. QNI has ties to the LME through its parent, Billiton Plc., but produces material unlisted on the LME: sintered-nickel rondelles, nickel oxide powder, nickel oxide granules, and ferronickel.

The principal purpose of the LME since its opening in 1877 has been to serve as a futures market, providing protection to producers, traders, and consumers alike against unpredictable price fluctuations (Rudolf Wolff & Co. Ltd., 1995). The LME has a membership of more than 100 firms. Of these, 15 take part in Ring dealing, which consists of open outcry trading sessions that take place twice a day. Unlike other futures markets, the LME also serves as a center for physical trading and has an international network of approved warehouses. In the case of nickel, the bulk of the warehousing is done in the Netherlands at Rotterdam. The LME is regulated by the British Treasury under the Financial Services Act of 1985.

Hedging, a form of insurance available to producers and consumers alike, is a key component of the futures market and reduces a producer's exposure to price changes while the raw nickel is moving through different processing stages at the producer's facilities. To guard against sudden price movements, the producer will hedge a planned physical transaction by entering into an offsetting forward contract on the LME. The forward contract is often designed to mature at about the same time as the physical sales date. Most hedged contracts are bought or sold back before they mature. Only about 5% of LME contracts result in an actual delivery.

Speculators play an important role in futures trading because they bring liquidity to the market and assume the risk that the hedger is trying to avoid. Because metals speculation is a high-risk venture, only professional investors or institutions with sufficient capital to withstand the risk are normally allowed to participate. Option contracts give hedgers and investors more flexibility than a straight futures hedge. The option allows the hedger to lock in a contract at a fixed price but, at the same time, gives the hedger the flexibility to abandon the option if a favorable price movement occurs.

Five different price series for nickel are available from the LME:

- Cash
- Settlement
- 3-month futures
- 15-month futures
- 27-month futures.

Prices are quoted at midday and at the close of the afternoon session. Metal Bulletin and Platt's Metals Week also publish daily LME mean or index prices. The data shown in the accompanying table for the years since 1979 represent the annual average cash price.

North American consumers have several other price series that they can use in contract negotiations. For example, Platt's Metals Week and Ryan's Notes compile and publish their own copyrighted prices. Three of the Metals Week prices most commonly quoted are New York Dealer Cathode, New York Dealer Melting Grade, and New York Dealer Plating Grade. The New York Dealer Cathode price closely tracks the LME cash price but is normally slightly higher because it reportedly incorporates insurance and freight costs incurred when cathode is transferred from LME warehouses in Europe to the East Coast. Prices for plating grades typically carry a premium of 15 to 25 cents (U.S.) per pound, and melting grade premiums are on the order of 5 to 15 cents per pound (Platt's Metals Week, 1972-98).

Pricing Mechanisms for Stainless Steel Scrap

Nickel is less abundant than either chromium or iron in the Earth's crust because of nickel's higher atomic number and differences in the nuclear stability of the respective isotopes of the three elements. As a result, on an elemental basis, ferronickel is about 5 to 8 times more expensive than ferrochromium and 30 to 50 times more expensive than pig iron, depending upon the market situation at the time. As a rule of thumb, austenitic (Ni+Cr) stainless steel scrap is roughly three times more valuable than ferritic (Cr only) stainless steel scrap. Because the highest value material in austenitic stainless steel is nickel, stainless steel scrap prices closely track those of nickel cathode except when ferrochromium is in short supply.

Almost all stainless steel produced in the United States is made in electric-arc furnaces. The majority of the stainless steel production facilities are in Pennsylvania. Nickel-base superalloys and other nickel-chromium alloys also are commonly made in electric-arc furnaces. The characteristics of the electric furnace permit the operator to use a large percentage of scrap, economizing on consumption of virgin chromium and nickel.

The stainless steel scrap prices shown in the accompanying table were derived from daily data published by American Metal Market. The data represent consumer buying prices in the Pittsburgh, PA, area for austenitic stainless steel scrap and are quoted in dollars per long ton gross weight. The scrap is in the form of bundles, solids, and clippings typically containing 18% chromium and 8% nickel. Turnings of 18-8 alloy are more difficult to handle than bundles and fetch only about 85% of the bundle price. American Metal Market also publishes estimated prices that a dealer, broker, or processor would pay for 18-8 scrap delivered to yards in 10 different areas of the United States plus the Montreal area of Canada.

Although many types of nickel scrap are recycled in the United States, most is in the form of stainless steel. Stainless steel scrap currently (1999) accounts for about 85% of reclaimed nickel in the country. This includes scrap consumed in foundries in addition to that used in raw steelmaking. Scrap accounts for as much as 80% of total feed materials at some European stainless steel production facilities but typically 60% to 70% in the United States—the remainder being ferroalloys or virgin metals. The bulk of the scrap is conventional austenitic or ferritic stainless steel. The scrap is often blended and may include lesser amounts of low alloy steel, superalloys and other high-nickel-chromium alloys, and/or specially-processed fines of high-carbon ferrochromium. A high scrap ratio (i.e., a high percentage of scrap in the total charge) reduces melting time and electricity consumption but makes final chemical adjustments to the melt more difficult. A few foreign mills have recently dropped their scrap ratio down to 30% or 40% because of problems in purchasing quality scrap at a reasonable price.

Copper-nickel and superalloy scrap make up a large portion of the remaining 15% of nickel reclaimed in the United States. Aircraft engine manufacturers return turnings, chippings, and similar forms of prompt superalloy scrap to superalloy producers for remelting. Segregation of these materials by the engine manufacturers is absolutely critical. Because of quality control concerns, part of the obsolete superalloy scrap generated at aircraft engine repair facilities is downgraded and used to make stainless steel.

References Cited

Boldt, J.R., Jr., and Queneau, Paul, 1967, The winning of nickel: Princeton, NJ, D. Van Nostrand Co., Inc., 487 p.

Cammen, Leon, 1928, Alloy steels, Chap. 6 of Principles of metallurgy of ferrous metals: American Society *of* Mechanical Engineers, p. 142-162.

Davis, H.W., 1956, Nickel, *in* Minerals Yearbook 1953, v. I: U.S. Bureau of Mines, p. 837-853.

[Government of Australia], 1999, Australian national statement: International Nickel Study Group, 9th General Session, [The Hague, the Netherlands], April 21, 1999, presentation, 2 p.

Hall, A.M., 1954, Nickel in iron and steel: New York, John Wiley & Sons, Inc., 595 p.

Hess, F.L., 1917, Nickel, *in* Mineral resources of the United States 1915: U.S. Geological Survey, pt. 1, p. 743-766.

Inco Limited, 1980, Annual report—1979: Toronto, Ontario, Inco Limited, 41 p.

———1998, World stainless steel statistics: Toronto, Ontario, Inco Limited, October, 128 p.

———1999, Annual report—1998: Toronto, Ontario, Inco Limited, October, 81 p.

International Nickel Study Group, 1998, World nickel statistics: The Hague, the Netherlands, International Nickel Study Group, v. 8, no. 11, November, p. 64-66.

Morrell, L.G., 1971, The mineral industry of Canada, *in* Minerals Yearbook 1969, v. IV: U.S. Bureau of Mines, p. 163-181.

Platt's Metals Week, 1972-98, Metals Week price handbook: New York, The McGraw-Hill Companies, Inc.

Rudolf Wolff & Co. Ltd., 1995, Nickel, chap. 15 *of* Wolff's guide to the London Metal Exchange (5th ed.): Surrey, United Kingdom, Metal Bulletin Books Ltd., p. 127-133.

Wharton, Joseph, 1897, Nickel and cobalt, *in* Eighteenth Annual Report of the United States Geological Survey, 1896-97: U.S. Geological Survey, pt. 5, p. 329-342.

Annual Average Price for 18-8 Stainless Steel Scrap

(Dollars per long ton gross weight[1])

Year	Price	Year	Price	Year	Price	Year	Price
1987	560	1990	927	1993	634	1996	834
1988	1,150	1991	855	1994	719	1997	808
1989	1,266	1992	728	1995	1,055	1998	600

[1] To convert to dollars per metric ton, multiply by 0.984207.

Note:

1987-98, Derived from the average of the Friday consumer buying price range for 18% Cr-8% Ni scrap in bundles, solids, and clips, Pittsburgh, PA, *in* American Metal Market.

Annual Average Nickel Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1840	1.70	1880	0.95	1920	0.42	1960	0.74
1841	1.70	1881	0.91	1921	0.42	1961	0.78
1842	2.09	1882	0.99	1922	0.38	1962	0.80
1843	2.40	1883	1.11	1923	0.36	1963	0.79
1844	2.75	1884	0.70	1924	0.30	1964	0.79
1845	3.05	1885	0.65	1925	0.33	1965	0.79
1846	3.05	1886	0.48	1926	0.36	1966	0.79
1847	2.89	1887	0.62	1927	0.35	1967	0.88
1848	2.19	1888	0.58	1928	0.37	1968	0.95
1849	1.93	1889	0.65	1929	0.35	1969	1.05
1850	1.93	1890	0.65	1930	0.35	1970	1.29
1851	1.93	1891	0.55	1931	0.35	1971	1.33
1852	1.93	1892	0.75	1932	0.35	1972	1.40
1853	1.70	1893	0.52	1933	0.35	1973	1.53
1854	1.70	1894	0.57	1934	0.35	1974	1.74
1855	1.57	1895	0.30	1935	0.35	1975	2.07
1856	1.57	1896	0.33	1936	0.35	1976	2.25
1857	1.45	1897	0.33	1937	0.35	1977	2.27
1858	1.20	1898	0.33	1938	0.35	1978	2.04
1859	1.20	1899	0.32	1939	0.35	1979	2.66
1860	1.20	1900	0.50	1940	0.35	1980	2.96
1861	1.20	1901	0.56	1941	0.35	1981	2.71
1862	1.08	1902	0.45	1942	0.32	1982	2.18
1863	1.65	1903	0.40	1943	0.32	1983	2.12
1864	2.29	1904	0.40	1944	0.32	1984	2.16
1865	1.68	1905	0.40	1945	0.32	1985	2.26
1866	1.55	1906	0.40	1946	0.35	1986	1.76
1867	1.52	1907	0.45	1947	0.35	1987	2.19
1868	1.14	1908	0.45	1948	0.36	1988	6.25
1869	1.39	1909	0.40	1949	0.40	1989	6.04
1870	1.28	1910	0.40	1950	0.45	1990	4.02
1871	1.32	1911	0.40	1951	0.54	1991	3.70
1872	2.25	1912	0.40	1952	0.57	1992	3.18
1873	3.84	1913	0.42	1953	0.60	1993	2.40
1874	3.10	1914	0.41	1954	0.61	1994	2.88
1875	2.96	1915	0.41	1955	0.66	1995	3.73
1876	2.52	1916	0.42	1956	0.65	1996	3.40
1877	1.60	1917	0.42	1957	0.74	1997	3.14
1878	0.95	1918	0.41	1958	0.74	1998	2.10
1879	0.89	1919	0.40	1959	0.74		

[1] To convert to dollars per metric ton, multiply by 2,204.62.

Note:

1840-1912, Price of refined metal, *as* supplied by Inco Ltd.

1913-21, Price of refined metal, *in* Historical Statistics of the United States, Colonial Times to 1970, U.S. Department of Commerce, Bureau of the Census.

1922-45, Price quoted by International Nickel Co. of Canada, Ltd., for electrolytic nickel cathode at New York, in 2-short-ton minimum lots, *in* the nickel chapter of the U.S. Bureau of Mines Minerals Yearbook.

1946-47, Contract price to U.S. buyers of electrolytic nickel cathode in carlots, f.o.b. Port Colborne, Ontario, including duty of 2.50 cents per pound, *in* the nickel chapter of the U.S. Bureau of Mines Minerals Yearbook.

1948-61, Contract price to U.S. buyers of electrolytic nickel cathode in carlots, f.o.b. Port Colborne, Ontario, including duty of 1.25 cents per pound, *in* the nickel chapter of the U.S. Bureau of Mines Minerals Yearbook. [Duty was halved on January 1, 1948.]

1962-79, Contract price to U.S. buyers of electrolytic nickel in carlots, f.o.b. Port Colborne, Ontario, *in* American Metal Market. Weighted average for the year. U.S. import duty of 1.25 cents per pound was suspended on September 27, 1965.

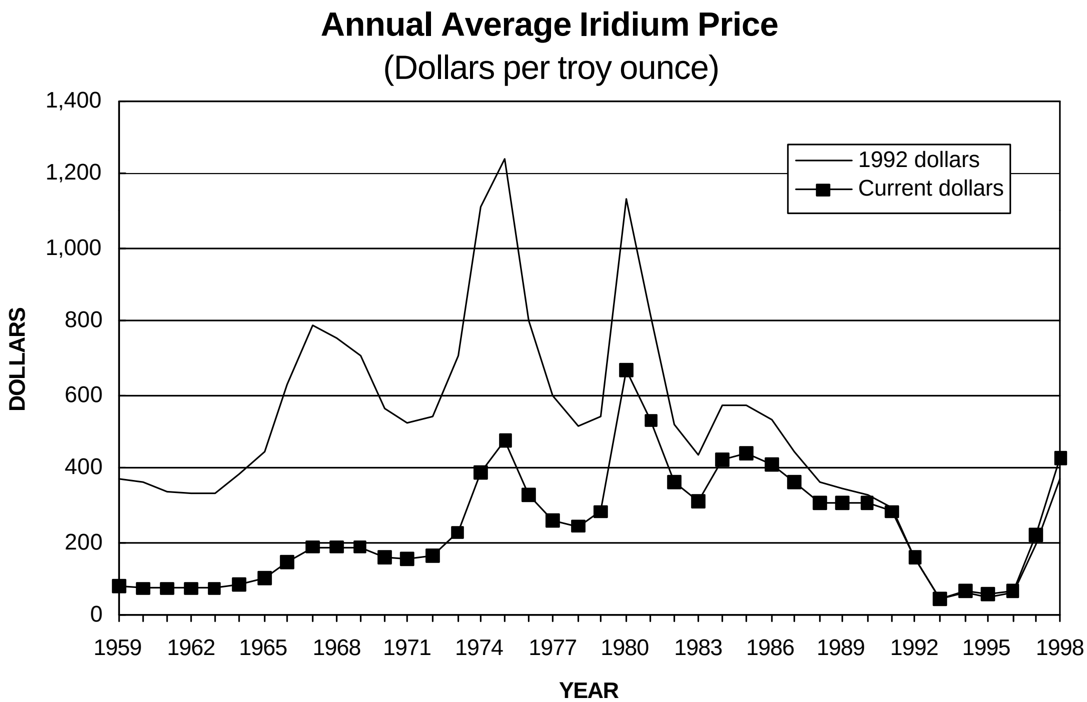
1980-93, London Metal Exchange cash price for primary nickel of minimum 99.80% purity, delivered in the form of either cut cathodes or pellets or briquets, lots of 6 metric tons, *in* Metals Week [through June 14, 1993].

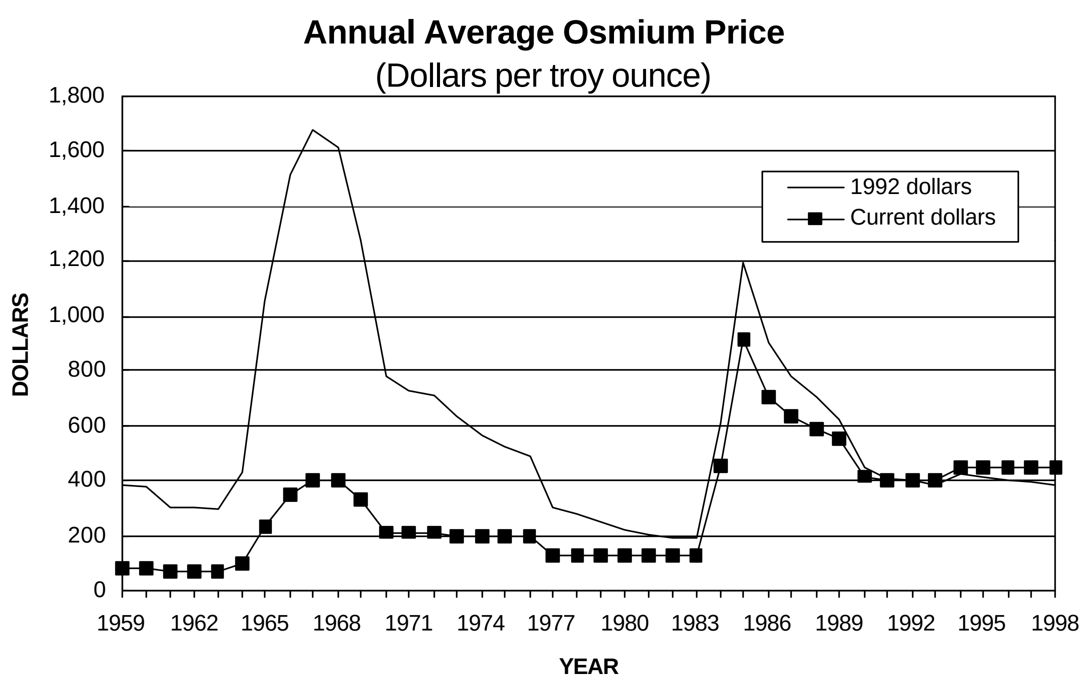
1993-98, London Metal Exchange cash price for primary nickel of minimum 99.80% purity, delivered in the form of either cut cathodes or pellets or briquets, lots of 6 metric tons, *in* Platt's Metals Week.

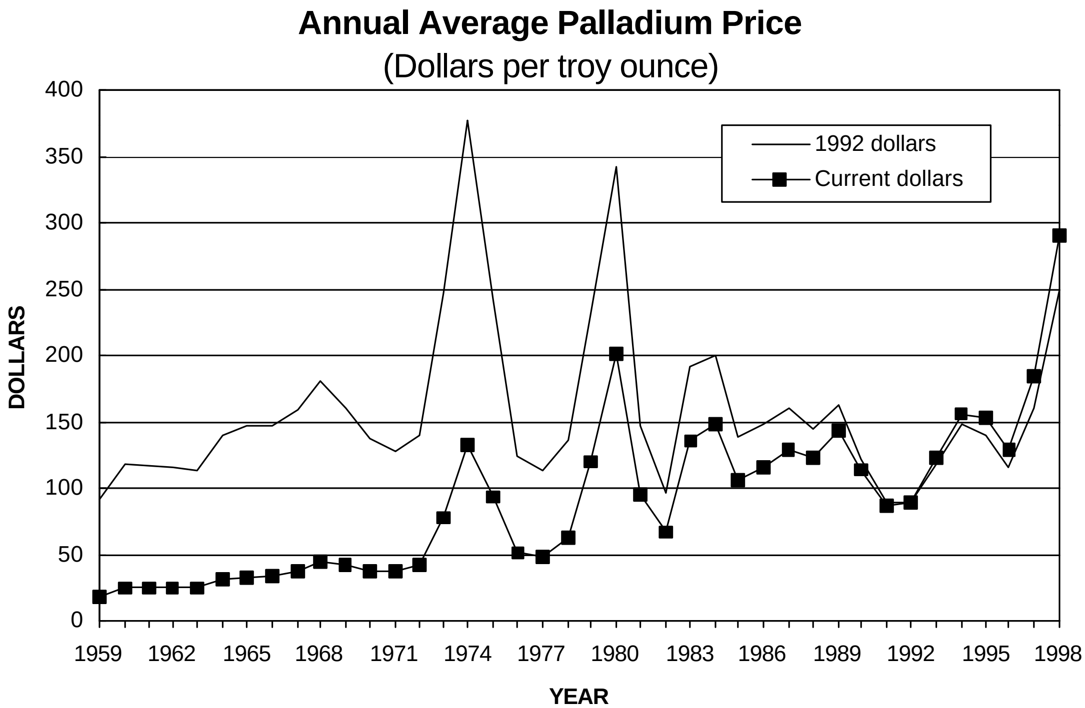
(This page intentionally left blank.)

Platinum-Group Metals

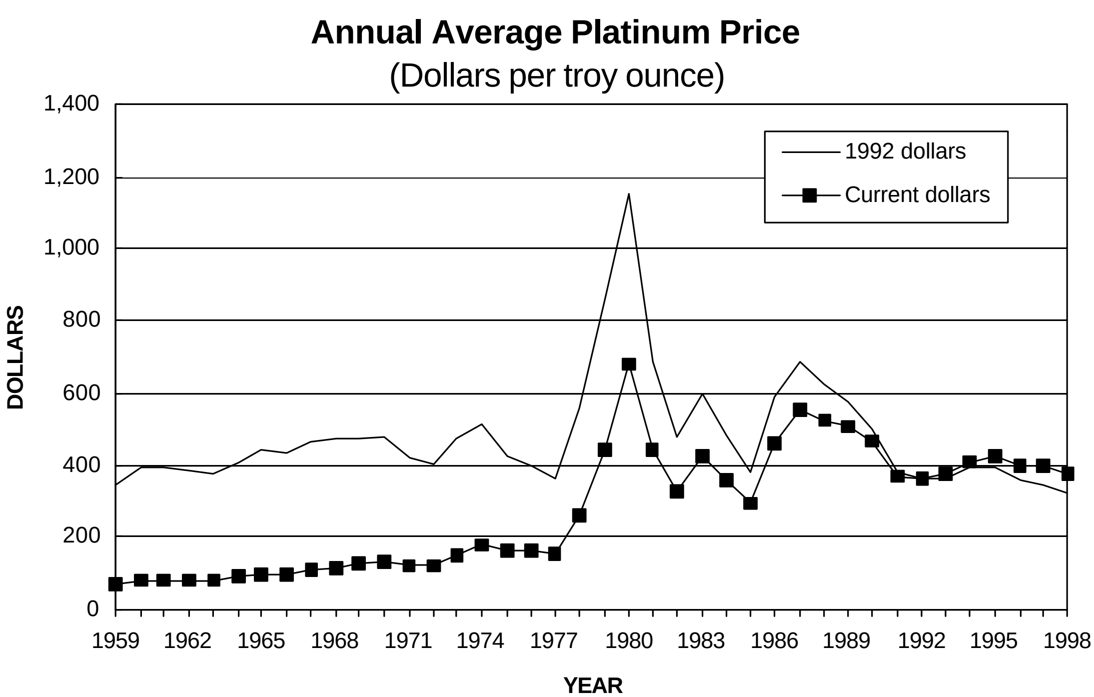
by Henry E. Hilliard



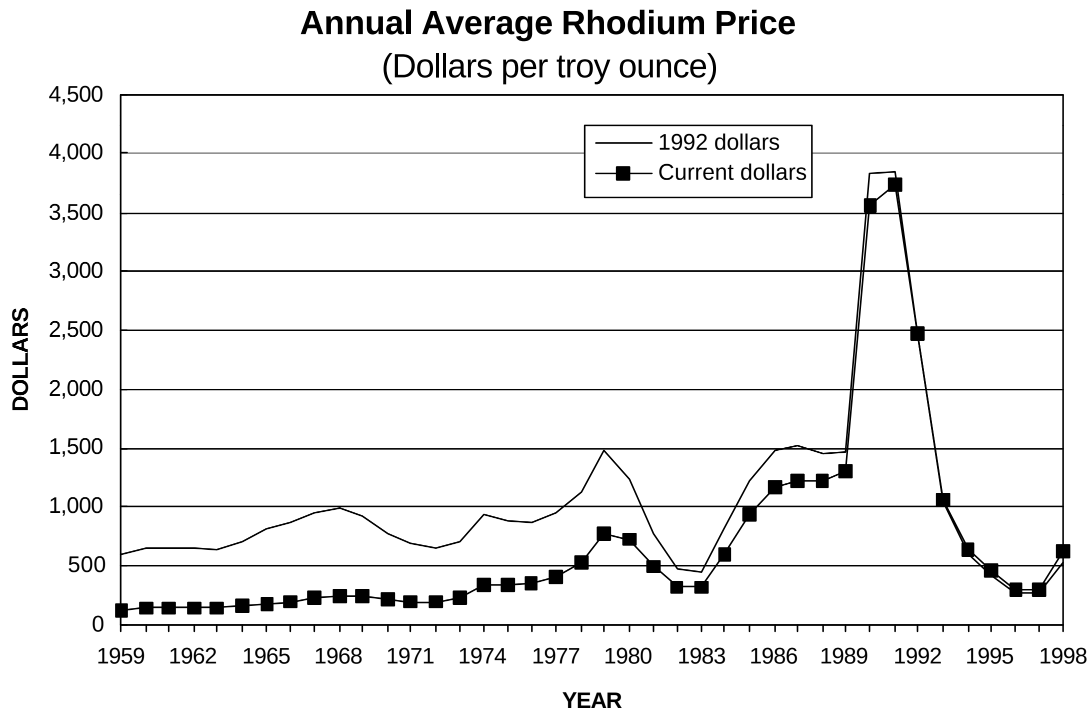


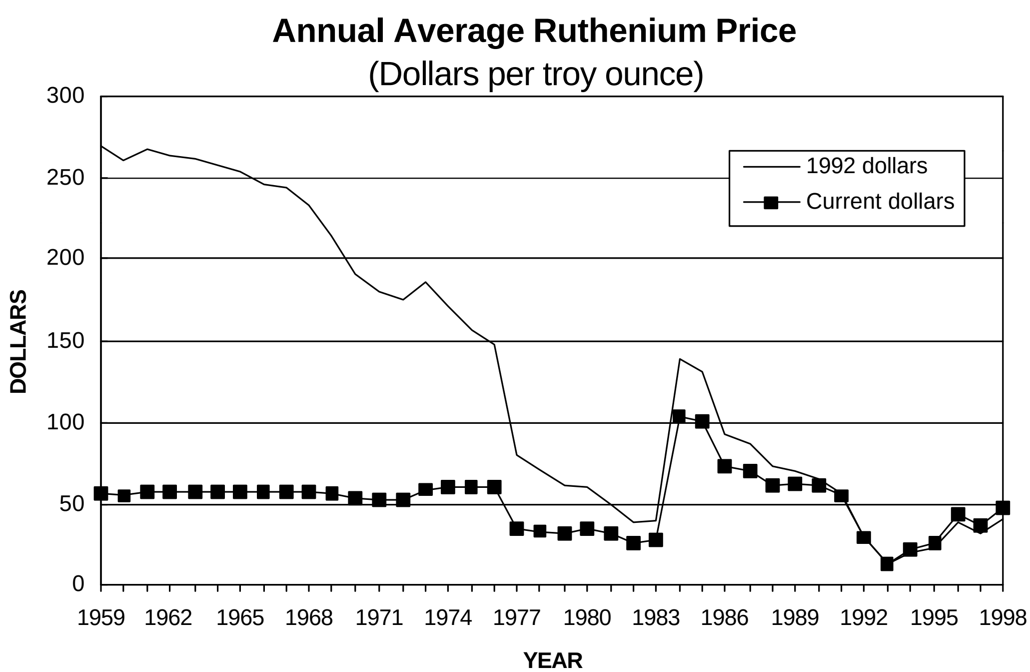


Annual Average Palladium Price
(Dollars per troy ounce)
1992 dollars
Current dollars
DOLLARS
YEAR
0
50
100
150
200
250
300
350
400
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998



Annual Average Platinum Price
(Dollars per troy ounce)
1992 dollars
Current dollars
DOLLARS
YEAR
0
200
400
600
800
1,000
1,200
1,400
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998


Annual Average Rhodium Price
(Dollars per troy ounce)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
DOLLARS
1992 dollars
Current dollars
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR


Annual Average Ruthenium Price
(Dollars per troy ounce)
300
250
200
150
100
50
0
DOLLARS
1992 dollars
Current dollars
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR

Significant events affecting platinum-group metals (PGM) prices since 1958

1964-68	Tight supply for platinum owing to start-up demands for new petroleum refineries
1971	PGM price declines owing to expansion of production in South Africa and economic recessions in the United States and other countries
1973	Anticipated demand for platinum and palladium in automobile catalytic converters in the United States puts pressure on prices, catalytic converters first used in 1974
1980	Strong investor speculation pushes up prices for all precious metals
1983	Rustenburg Platinum Holdings Ltd. in South Africa suspends its producer price quotations for PGM, increased trading of futures contracts on the New York Mercantile Exchange (NYMEX)
1984	Price increase for rhodium because of higher demand for rhodium in automobile three-way catalytic converters
1986	Platinum price increase after a work stoppage at Impala Platinum Holdings Ltd. in South Africa

Naturally occurring platinum and platinum-rich alloys have been known for a long time. The Spaniards named the metal "platina," or little silver, when they first encountered it in Colombia. They regarded platinum as an unwanted impurity in the silver they were mining. Today, 98% of the world's primary platinum-group metals (PGM) production comes from four countries—South Africa (66%), Russia (23%), the United States (5%), and Canada (4%). The ratio of palladium to platinum in individual PGM ores varies from country to country. South Africa produces about twice as much platinum as palladium, whereas Russia produces about three times as much palladium as platinum (Conradie, 1997, p. 34-40). In Canada, PGM are byproducts of nickel ore processing. The expanding U.S. production of PGM is centered in the Stillwater Complex in Montana. The Stillwater and East Boulder Mines are primary PGM producers with small amounts of byproduct nickel, cobalt, and gold.

The catalytic properties of the six PGM—iridium, osmium, palladium, platinum, rhodium, and ruthenium—are outstanding. Platinum's wear and tarnish resistance characteristics are well suited for making fine jewelry. Other distinctive properties include resistance to chemical attack, excellent high-temperature characteristics, and stable electrical properties. All these properties have been exploited for industrial applications. Platinum, platinum alloys, and iridium are used as crucible materials for the growth of single crystals, especially oxides. The chemical industry uses a significant amount of either platinum or a platinum-rhodium alloy catalyst in the form of gauze to catalyze the partial oxidation of ammonia to yield nitric oxide, which is the raw material for fertilizers, explosives, and nitric acid. In recent years, a number of PGM have become important as catalysts in synthetic organic chemistry. Ruthenium dioxide is used as coatings on dimensionally stable titanium anodes used in the production of chlorine and caustic soda. Platinum supported catalysts are used in the refining of crude oil, reforming, and other processes used in the production of high-octane gasoline and aromatic compounds for the petrochemical industry. Since 1979, the automotive industry has emerged as the principal consumer of PGM. Palladium, platinum, and rhodium have been used as oxidation catalysts in catalytic converters to treat automobile exhaust emissions. A wide range of PGM alloy compositions is used in low-voltage and low-energy contacts, thick- and thin-film circuits, thermocouples and furnace components, and electrodes (Hilliard and Dunning, 1983, p. 129-142).

The most important prices for PGM have been the South African producer prices and the free-market prices fixed daily on the commodity exchanges. In terms of total value of PGM traded, the most important exchange is NYMEX. Producer prices give a certain amount of stability to the platinum and palladium markets. From about 1980 onward, however, the free-market price of platinum fell to well below the producer price, putting pressure on the producer price and inducing consumers to buy increasing quantities on the free market to meet their requirements. Also, the increased growth of investments in platinum added more pressure on producers to adopt a more realistic price level. Consequently, South African producers largely abandoned producer prices and adopted a pricing policy that more closely reflected market conditions. NYMEX and the Tokyo Commodity Exchange for Industry trade PGM on the open market. Russia, the world's largest palladium producer, sells palladium and other PGM through the Government agency Almazjuvelirexport (Roskill Information Services Ltd, 1991, p. 195-197).

Beginning in 1957 and continuing through 1958, a drop in demand for platinum by domestic petroleum refiners and persistent selling pressure by the U.S.S.R. at discount prices caused the platinum price to tumble to the lowest level in a decade. Soviet sales brought a corresponding decline in the price of palladium to the lowest level since 1933. In 1959, prices for platinum and palladium advanced, reversing the trend of 1957 through 1958. The more orderly selling policy by the U.S.S.R. was a significant factor in the PGM market recovery. Also, U.S. Government purchases contributed to the higher price of palladium.

In spring 1963, the U.S.S.R. disrupted the orderly marketing of PGM by selling large amounts of metal at below-market prices but curtailed its offerings later in the year. U.S. consumption of PGM reached the highest amount in history, more than 1 million ounces. The largest use for platinum was in the chemical industry, and the largest use for palladium was in the electrical industry (Ware, 1963, p. 901).

From 1964 to 1968, supplies of platinum were tight, putting upward pressure on prices. In 1965, U.S. suppliers allocated platinum to established customers at $100 per ounce. U.S. purchases of platinum were up sharply owing to the construction of new petroleum refineries. Prices for PGM during 1967 reflected the short supplies that persisted throughout the year. Although the producer price for platinum showed a small increase, dealer prices were up sharply. At the start of 1967, the producer price for platinum was $100 per ounce. On January 24, the price was increased to $109 to $112 per ounce and was unchanged until December when sales were made at $125. Dealer prices, which started the year at $157 to $160 per ounce, began to increase in May and were $225 to $230 by yearend. The producer price of palladium, which was $35 to $37 per ounce in October 1966, increased to $37 to $39 in January 1967 and remained unchanged for the remainder of the year. The price of rhodium was $197 to $299 per ounce in January 1969, increased in March and again in December, and closed out the year at $245 to $250. During the following year, dealer prices were two to three times as much as producer prices.

In 1971, prices of PGM declined owing to recession in the United States and other countries and the expansion of platinum capacity in South Africa. In each of the previous 8 years, South Africa increased its output. On the strength of an upturn in consumption and growing anticipation that PGM might be needed in a few years for automotive exhaust emissions control, prices and production posted significant increases in 1972. By the second quarter of 1972, U.S. dealer prices for platinum and palladium had exceeded producer prices. By midyear, the dealer price for iridium had increased from $145 to $148 per ounce to $525. Production and price trends continued the upward trend in 1973. Producer prices, which were under Government control much of the year, increased by 10% to 50% in February, fluctuated between narrow limits in June, and then advanced again in late September. After price controls were removed from most nonferrous metals in December, rhodium and iridium increased by another 14% to 15%. Ruthenium remained unchanged after a February increase to $60 per ounce, and osmium stayed at $200 per ounce through the year. The dealer price of iridium jumped from $250 to $450 per ounce in July, as the metal became scarce, and ended the year at $525 per ounce (Butterman, 1973, p. 1040).

PGM prices were mostly flat from 1975 through 1977. In 1977, the producer price for platinum was steady at $162 per ounce. The producer price for palladium began 1977 at $55 per ounce, increased to $60 in late January, and remained at that level for the remainder of the year. The price of rhodium was about $400 per ounce at the beginning of the year and increased to $450 in March owing to increased industrial demand and speculation regarding the use of rhodium in automotive catalytic converters. Iridium started the year at $300 per ounce, decreased to $250 in June and, returned to $300 for the remainder of the year. The price of osmium was $200 per ounce for the first 6 months of 1977 but declined to around $150 in the last 6 months of the year owing to continued weak demand. The price of ruthenium remained at around $60 per ounce throughout the year.

From 1978 to 1980, prices of platinum rose substantially owing to strong investor interest, chronic world inflation, and tight supply. In 1980, platinum, gold, and silver prices soared as a result of speculative activity. The platinum dealers price peaked at $990 per ounce in March 1980. Palladium prices moved up moderately in 1978 and more sharply in 1979 partly owing to increased investor interest. Rhodium prices increased only moderately in 1978, but in 1979 the price increased sharply. This was in response to larger purchases of the metal by the automotive industry for use as automotive emissions control catalyst.

In 1981 and 1982, lower world demand for PGM resulted in lower prices. In 1983, dealer prices for platinum and palladium increased substantially. A major South African producer, Rustenburg Platinum Holdings Ltd., suspended its producer prices for PGM and began selling most of its output at market prices. Platinum and palladium were recognized more as world commodities rather than commodities controlled exclusively by South African producers. Trading activity in futures contracts on NYMEX increased substantially.

In 1984, the dealer price for rhodium nearly doubled because of higher demand for rhodium in automobile three-way catalytic converters. The automotive industry became the dominant user of rhodium in the early 1980's.

In 1986, the dealer price for platinum increased by 60% owing to a work stoppage at Impala Platinum Holdings Ltd. in South Africa and anticipation that U.S. imports of platinum from South Africa would be cut off because of the antiapartheid legislation passed by the U.S. Congress. PGM were later exempted from the Anti-Apartheid Act of 1986.

In December 1988, the platinum market reacted strongly to an announcement by Ford Motor Company that it had developed a platinum-free automobile catalyst. Spot platinum prices fell to $100 per ounce on the day of the announcement, and futures prices in New York fell the limit of $25 for two consecutive days. The average dealer price for platinum in December was $557 per ounce. By January 1989, the average price had fallen to $528 per ounce.

From 1990 to 1998, the annual average New York dealer price of platinum fluctuated within the relatively narrow range of $375 and $475 per ounce. The price history of palladium was similar. The price of rhodium, however, was dramatically different.

In the late 1970's, market economy countries began implementing measures to reduce pollutants in automobile exhausts. The emphasis on controlling air pollution resulted in increased demand for PGM. Palladium-rhodium and platinum-rhodium oxidation catalysts were developed for use in catalytic converters. The increased demand caused the annual average price of rhodium to increase from $312 per ounce in 1983 to $929 in 1985. From 1986 to 1988, the monthly average New York dealers price of rhodium ranged from $1,150 to $1,300 per ounce. In early 1989, the announcement of problems at South Africa's Rustenburg Platinum precious metals refinery caused the price to jump to more than $2,000 per ounce. By July 3, 1990, rhodium was being quoted at $7,000 per ounce. This level could not be sustained, but the price fell no lower than $4,100 per ounce in November, reached $4,500 in early December, and rose sharply to $5,300 in the last week of 1990. Starting in 1992, the price trend of rhodium turned downward. This was brought on by recession in market economy countries, reduced sales of automobiles and, consequently, reduced demand for automobile catalysts. Demand sank even lower as U.S. automakers made wider use of palladium-only technology instead of platinum-rhodium or palladium-rhodium catalysts. In January 1997, the rhodium price sank to $200 per ounce, its lowest level in nearly 24 years. Prices began to rise again in June, reaching a peak of $370 per ounce, as delayed shipments from Russia caused a shortage of supply. The price retreated to $300 per ounce in August but rallied to $360 at yearend, following speculative buying in the United States. Prices continued to rise in 1998, reaching $640 in April, its highest level since 1994 (Platt's Metals Week, 1998).

From 1990 to 1996, prices for ruthenium and iridium remained mostly unchanged within narrow limits. Supply and demand were in balance and there was little or no upward pressure on prices. At the start of 1997, strong consumer purchasing coupled with increasingly limited availability caused the price of iridium to advance from $110 per ounce to $200 in late January. The price reached $290 in October but eased slightly to $270 at yearend. Strong consumer purchasing and continued tight supply lifted the price to $575 in April 1998. The price subsequently began to ease, as industrial demand slackened and the supply situation improved.

References Cited

Butterman, W.C., 1973, Platinum-group metals, *in* Minerals Yearbook, v. I: U.S. Bureau of Mines, p. 1037-1049.

Conradie, A.S., 1997, Platinum-group metals, *in* South Africa's mineral industry (14th ed.): South Africa Department of Minerals and Industry, November, 216 p.

Hilliard, H.E., and Dunning, B.W., 1983, Recovery of platinum-group metals and gold from electronic scrap, *in* Lundy, D.E., and Zysk, E.D., eds., The platinum group metals—An in depth view of the industry: 1983 IPMI International Seminar, Colonial Williamsburg, VA, April 10-13, 1983, p. 129-142

Platt's Metals Week, 1998, Daily prices: Platt's Metals Week, v. 69, no. 16, April 20, p. 17.

Roskill Information Services Ltd, 1991, The economics of platinum group metals (5th ed.): Roskill Information Services Ltd, 203 p.

Ware, G.C., 1963, Platinum-group metals, *in* Minerals Yearbook, v. I: U.S. Bureau of Mines, p. 899-911.

Annual Average Iridium Price
(Dollars per troy ounce[1])

Year	Price	Year	Price	Year	Price	Year	Price
1911	62	1933	58	1955	103	1977	258
1912	65	1934	59	1956	105	1978	240
1913	65	1935	57	1957	105	1979	280
1914	65	1936	104	1958	77	1980	666
1915	83	1937	88	1959	77	1981	529
1916	94	1938	69	1960	76	1982	359
1917	150	1939	113	1961	72	1983	309
1918	175	1940	169	1962	72	1984	424
1919	255	1941	183	1963	73	1985	438
1920	331	1942	168	1964	85	1986	414
1921	195	1943	165	1965	100	1987	363
1922	200	1944	165	1966	145	1988	306
1923	NA	1945	165	1967	188	1989	303
1924	293	1946	139	1968	188	1990	307
1925	363	1947	92	1969	185	1991	283
1926	169	1948	108	1970	156	1992	158
1927	120	1949	104	1971	152	1993	47
1928	294	1950	146	1972	162	1994	66
1929	238	1951	200	1973	223	1995	55
1930	179	1952	192	1974	391	1996	68
1931	114	1953	178	1975	477	1997	218
1932	68	1954	213	1976	325	1998	430

NA Not available
[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:
1911-29, New York price of refined metal, *in* Hill., J.M., 1922, The marketing of platinum: Engineering & Mining Journal-Press, p. 718.
1930-66, Producer price at New York of 99%-pure iridium, *in* Engineering & Mining Journal, Mineral and Metal Markets.
1967-93, Metals Week New York Dealer, f.o.b. New York, spot, estimated market price for minimum 99%-pure iridium, *in* Metals Week [through June 14, 1993].
1993-98, Metals Week New York Dealer, f.o.b. New York, spot, estimated market price for minimum 99%-pure iridium, *in* Platt's Metals Week.

Annual Average Osmium Price
(Dollars per troy ounce[1])

Year	Price	Year	Price	Year	Price	Year	Price
1930	67	1948	100	1966	350	1984	455
1931	67	1949	100	1967	400	1985	915
1932	62	1950	141	1968	400	1986	704
1933	63	1951	208	1969	335	1987	633
1934	68	1952	208	1970	215	1988	592
1935	50	1953	166	1971	210	1989	549
1936	55	1954	144	1972	212	1990	416
1937	57	1955	96	1973	200	1991	400
1938	57	1956	90	1974	200	1992	400
1939	57	1957	90	1975	200	1993	400
1940	57	1958	80	1976	200	1994	450
1941	47	1959	80	1977	130	1995	450
1942	47	1960	80	1978	130	1996	450
1943	50	1961	65	1979	130	1997	450
1944	50	1962	65	1980	130	1998	450
1945	50	1963	65	1981	130		
1946	67	1964	95	1982	130		
1947	100	1965	236	1983	132		

[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:
1930-66, Producer price at New York of 99.5%-pure osmium, *in* Engineering & Mining Journal, Mineral and Metal Markets.
1967-93, Metals Week New York Dealer, f.o.b. New York, spot, estimated market price for minimum 99.5%-pure osmium, *in* Metals Week [through June 14, 1993].
1993-98, Metals Week New York Dealer, f.o.b. New York, spot, estimated market price for minimum 99.5%-pure osmium, *in* Platt's Metals Week.

Annual Average Platinum Price

(Dollars per troy ounce[1])

Year	Price	Year	Price	Year	Price	Year	Price
1880	4	1910	33	1940	36	1970	133
1881	4	1911	43	1941	36	1971	121
1882	3	1912	45	1942	36	1972	121
1883	3	1913	45	1943	35	1973	150
1884	3	1914	45	1944	35	1974	181
1885	1	1915	47	1945	35	1975	164
1886	2	1916	83	1946	53	1976	162
1887	4	1917	103	1947	62	1977	157
1888	4	1918	106	1948	92	1978	261
1889	4	1919	115	1949	75	1979	445
1890	4	1920	111	1950	76	1980	677
1891	5	1921	75	1951	93	1981	446
1892	7	1922	98	1952	93	1982	327
1893	7	1923	117	1953	93	1983	424
1894	6	1924	119	1954	88	1984	357
1895	6	1925	119	1955	94	1985	291
1896	6	1926	113	1956	105	1986	461
1897	6	1927	85	1957	90	1987	553
1898	15	1928	79	1958	66	1988	523
1899	6	1929	68	1959	72	1989	507
1900	6	1930	44	1960	83	1990	467
1901	20	1931	32	1961	83	1991	371
1902	20	1932	32	1962	83	1992	361
1903	19	1933	31	1963	82	1993	375
1904	21	1934	34	1964	90	1994	411
1905	17	1935	33	1965	100	1995	425
1906	28	1936	42	1966	100	1996	398
1907	NA	1937	47	1967	111	1997	397
1908	21	1938	34	1968	117	1998	373
1909	25	1939	36	1969	124		

NA Not available

[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:

1880-1910, Annual average price of crude platinum, *in* Mineral Resources of the United States: U.S. Geological Survey annual.
1911-29, New York price of refined metal, *in* Hill, J.M., 1922, The marketing of platinum: Engineering & Mining Journal-Press, p. 718.
1930-66, Producer price at New York of 99.9%-pure platinum, *in* Engineering & Mining Journal, Mineral and Metal Markets.
1967-93, New York price per troy ounce of 99.9%-pure platinum in 50-ounce lots, *in* Metals Week [through June 14, 1993].
1993-98, New York price per troy ounce of 99.9%-pure platinum in 50-ounce lots, *in* Platt's Metals Week.

Annual Average Palladium Price

(Dollars per troy ounce[1])

Year	Price	Year	Price	Year	Price	Year	Price
1911	55	1933	18	1955	22	1977	49
1912	55	1934	23	1956	24	1978	63
1913	50	1935	23	1957	24	1979	120
1914	44	1936	23	1958	17	1980	201
1915	56	1937	23	1959	19	1981	95
1916	67	1938	23	1960	25	1982	67
1917	110	1939	23	1961	25	1983	136
1918	135	1940	24	1962	25	1984	148
1919	130	1941	24	1963	25	1985	107
1920	108	1942	24	1964	31	1986	116
1921	59	1943	24	1965	33	1987	130
1922	60	1944	24	1966	34	1988	123
1923	NA	1945	24	1967	38	1989	144
1924	94	1946	24	1968	45	1990	114
1925	79	1947	24	1969	42	1991	87
1926	70	1948	24	1970	38	1992	89
1927	58	1949	24	1971	37	1993	123
1928	46	1950	24	1972	42	1994	156
1929	40	1951	24	1973	78	1995	153
1930	24	1952	24	1974	133	1996	130
1931	18	1953	24	1975	93	1997	184
1932	18	1954	21	1976	51	1998	290

NA Not available

[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:

1911-29, New York price of refined metal, *in* Hill, J.M., 1922, The marketing of platinum: Engineering & Mining Journal-Press, p. 718.
1930-66, Producer price at New York of 99.9%-pure palladium, *in* Engineering & Mining Journal, Mineral and Metal Markets.
1967-93, New York price per troy ounce of 99.9%-pure palladium in 100-ounce lots, *in* Metals Week [through June 14, 1993].
1993-98, New York price per troy ounce of 99.9%-pure palladium in 100-ounce lots, *in* Platt's Metals Week.

Annual Average Rhodium Price

(Dollars per troy ounce[1])

Year	Price	Year	Price	Year	Price	Year	Price
1930	50	1948	125	1966	198	1984	607
1931	50	1949	125	1967	225	1985	929
1932	43	1950	125	1968	247	1986	1,157
1933	49	1951	125	1969	240	1987	1,222
1934	56	1952	125	1970	215	1988	1,218
1935	53	1953	125	1971	200	1989	1,300
1936	65	1954	123	1972	197	1990	3,565
1937	111	1955	121	1973	222	1991	3,739
1938	125	1956	121	1974	329	1992	2,465
1939	125	1957	121	1975	338	1993	1,066
1940	125	1958	121	1976	348	1994	636
1941	125	1959	123	1977	409	1995	463
1942	125	1960	136	1978	524	1996	300
1943	125	1961	139	1979	770	1997	298
1944	125	1962	139	1980	729	1998	620
1945	125	1963	139	1981	498		
1946	125	1964	155	1982	323		
1947	125	1965	183	1983	312		

[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:

1930-66, Producer price at New York of 99.9%-pure rhodium, *in* Engineering & Mining Journal, Mineral and Metal Markets.
1967-76, Producer price at New York of 99.9%-pure rhodium, *in* Metals Week.
1977-93, Dealer price at New York of 99.9%-pure rhodium, *in* Metals Week [through June 14, 1993].
1993-98, Dealer price at New York of 99.9%-pure rhodium, *in* Platt's Metals Week.

Annual Average Ruthenium Price

(Dollars per troy ounce[1])

Year	Price	Year	Price	Year	Price	Year	Price
1930	42	1948	92	1966	57	1984	103
1931	41	1949	75	1967	58	1985	101
1932	41	1950	76	1968	58	1986	73
1933	42	1951	93	1969	56	1987	70
1934	45	1952	86	1970	53	1988	61
1935	40	1953	86	1971	52	1989	62
1936	38	1954	67	1972	52	1990	61
1937	40	1955	52	1973	59	1991	55
1938	37	1956	50	1974	60	1992	29
1939	37	1957	50	1975	60	1993	13
1940	37	1958	50	1976	60	1994	22
1941	37	1959	56	1977	35	1995	26
1942	37	1960	55	1978	33	1996	43
1943	35	1961	57	1979	32	1997	37
1944	35	1962	57	1980	35	1998	47
1945	35	1963	57	1981	32		
1946	68	1964	57	1982	26		
1947	62	1965	57	1983	28		

[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:

1930-66, Producer price at New York of refined metal, *in* Engineering & Mining Journal, Mineral and Metal Markets.

1967-76, Producer price at New York of 99.9%-pure ruthenium, *in* Metals Week.

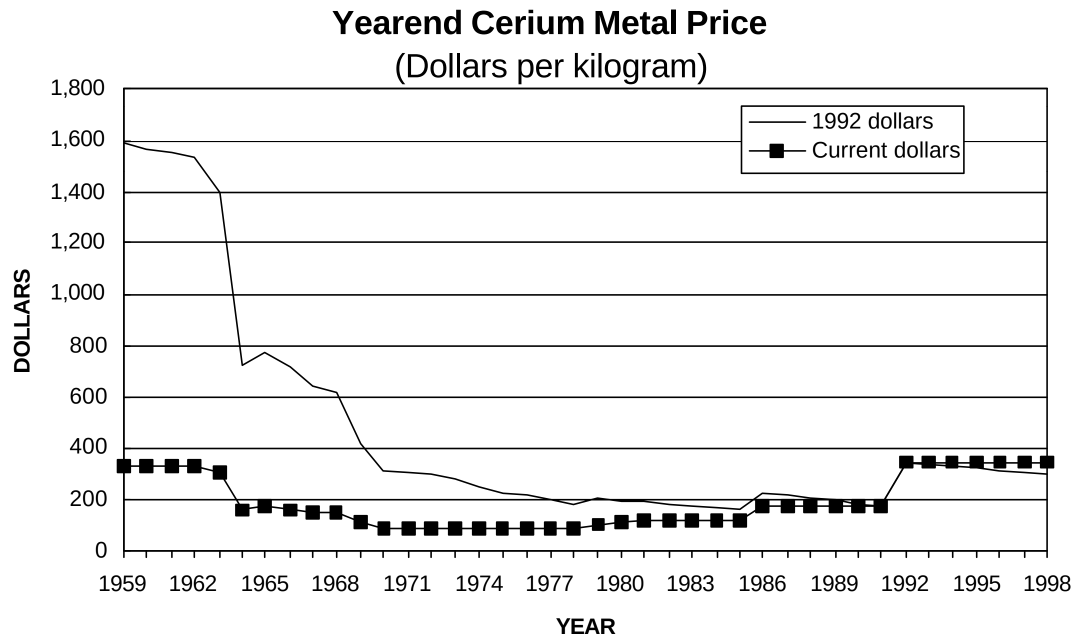
1977-93, Dealer price at New York of 99.9%-pure ruthenium, *in* Metals Week [through June 14, 1993].

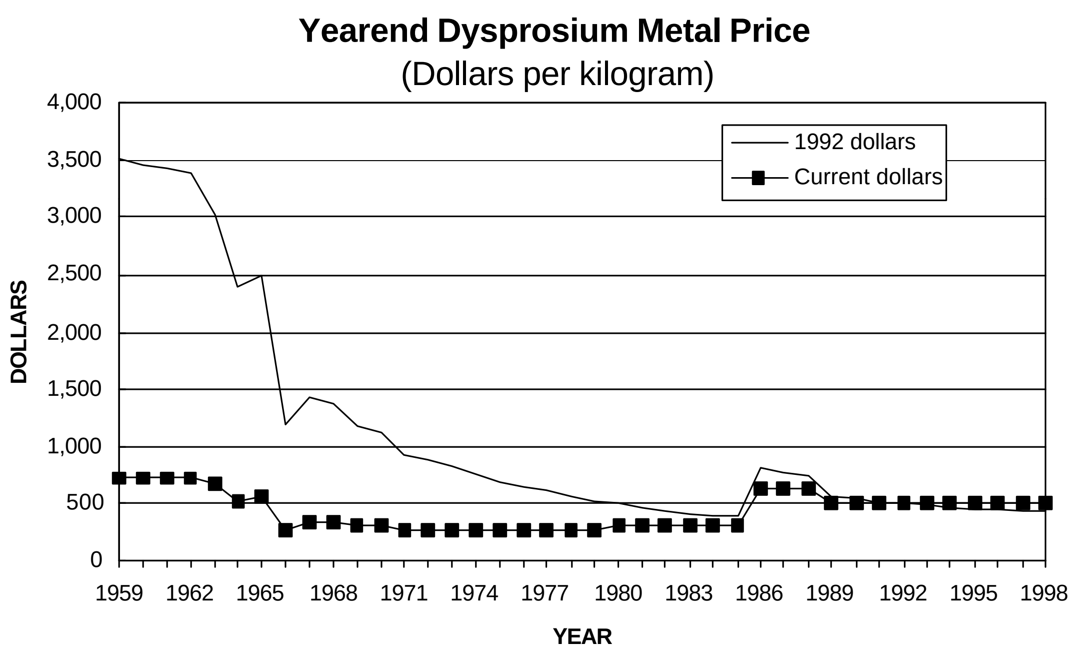
1993-98, Dealer price at New York of 99.9%-pure ruthenium, *in* Platt's Metals Week.

Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Pm, Sm, Sc, Tb, Tm, Yb, Y

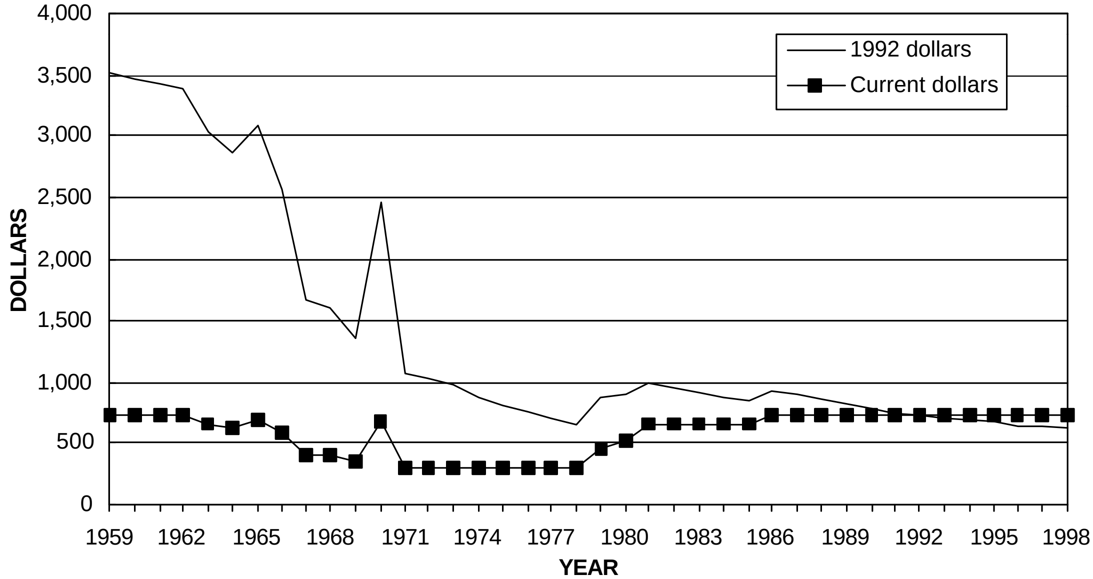
Rare-Earth Metals

by James B. Hedrick

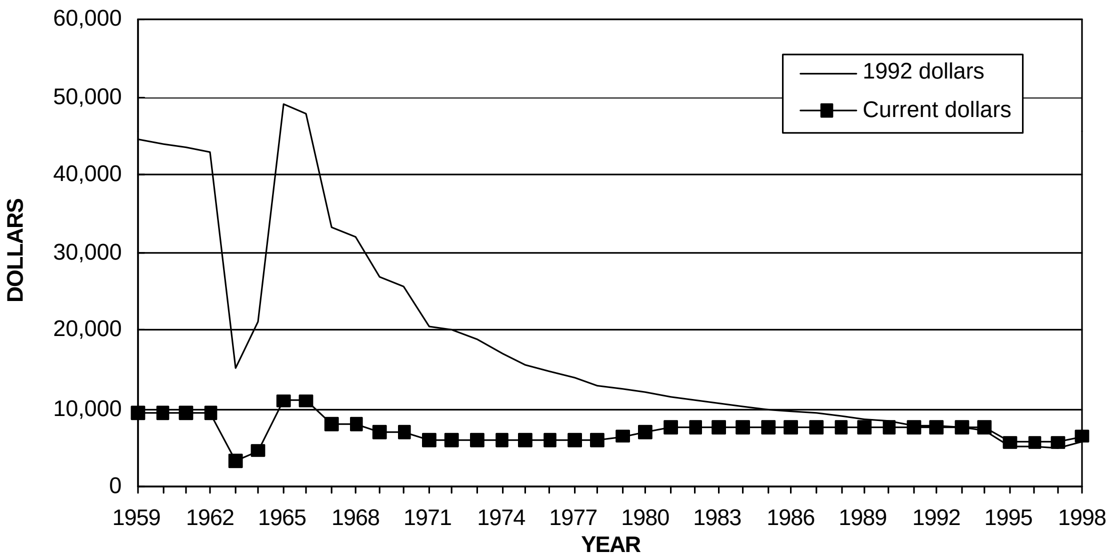




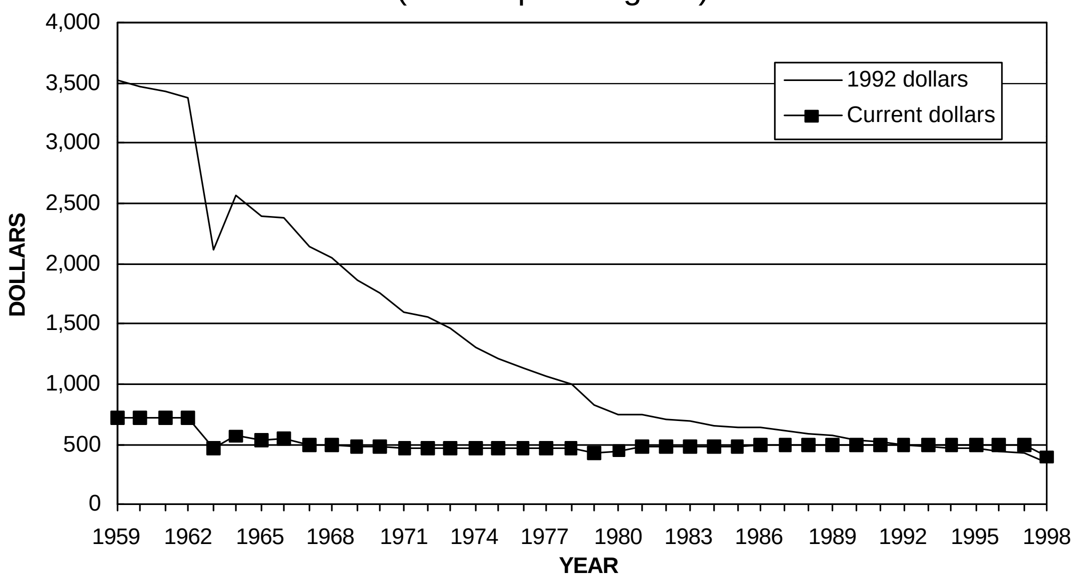
Yearend Erbium Metal Price
(Dollars per kilogram)



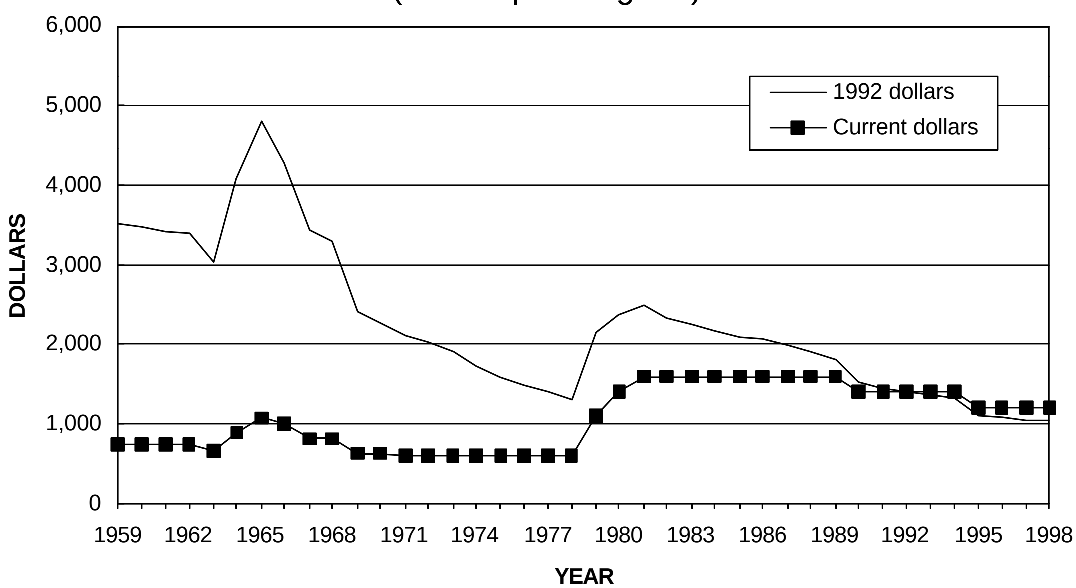
Yearend Europium Metal Price
(Dollars per kilogram)

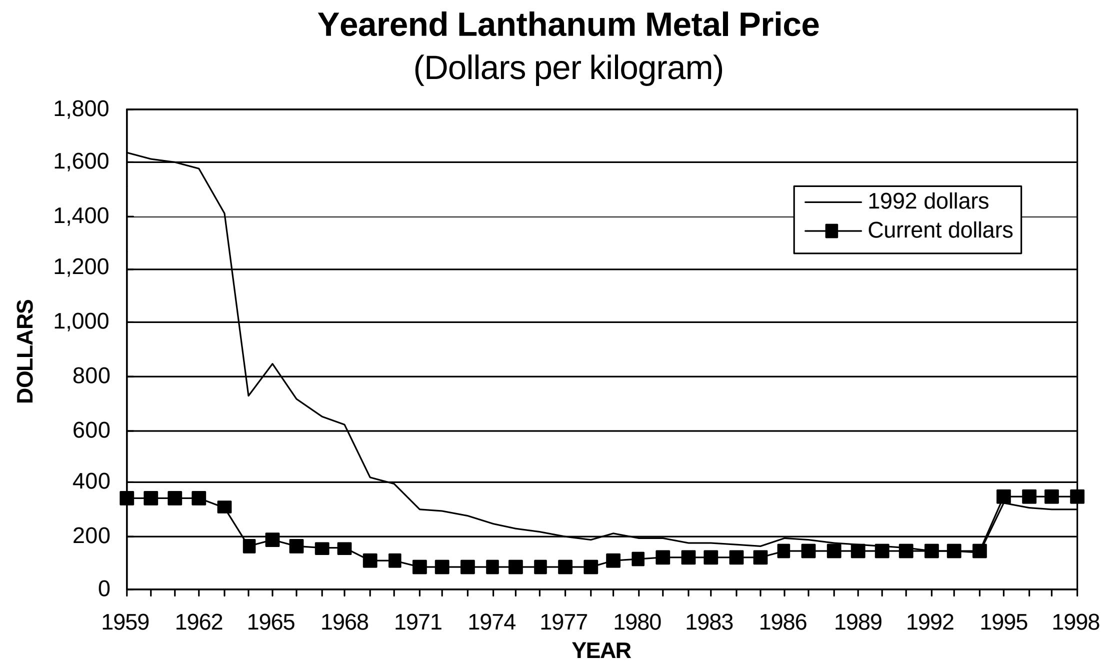


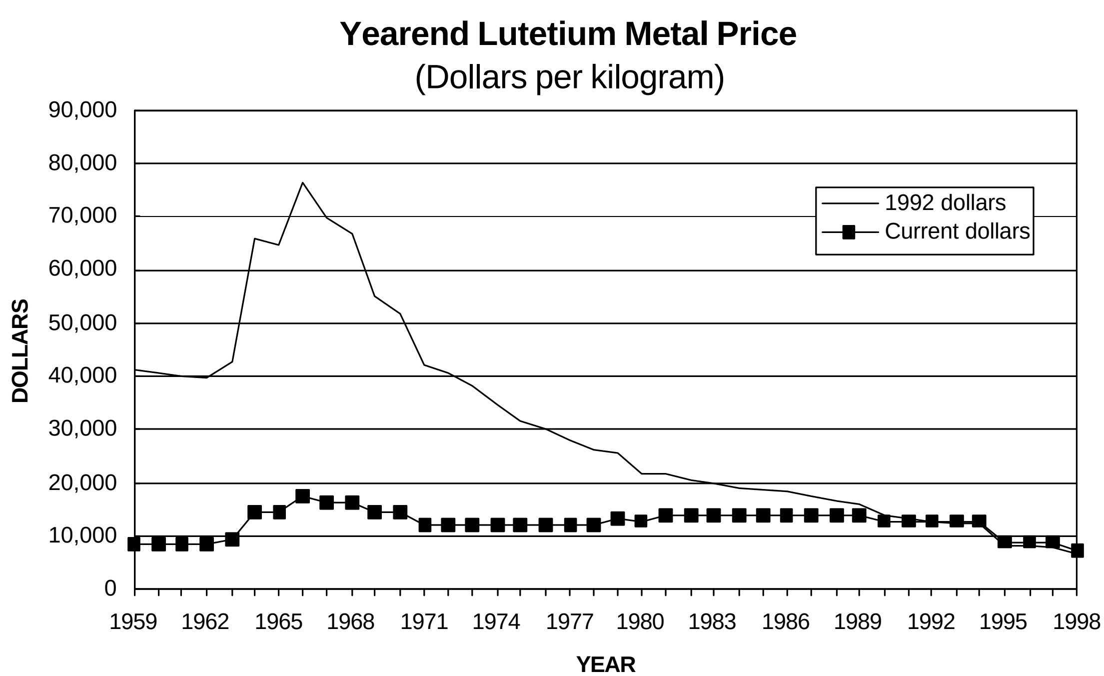
Yearend Gadolinium Metal Price
(Dollars per kilogram)



Yearend Holmium Metal Price
(Dollars per kilogram)

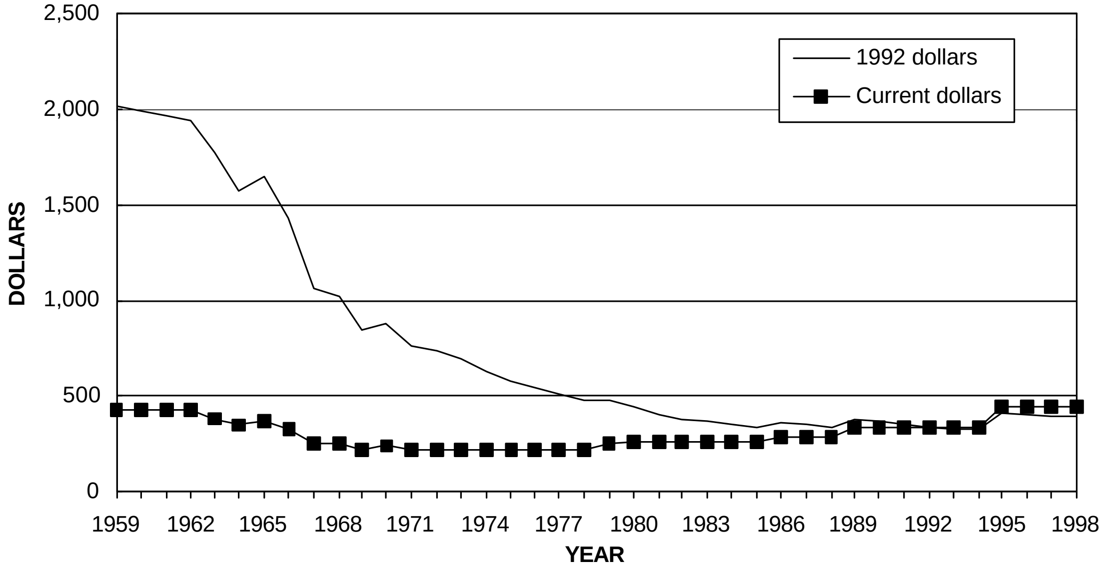



Yearend Lanthanum Metal Price
(Dollars per kilogram)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
DOLLARS
1992 dollars
Current dollars
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR


Yearend Lutetium Metal Price
(Dollars per kilogram)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
DOLLARS
1992 dollars
Current dollars
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR

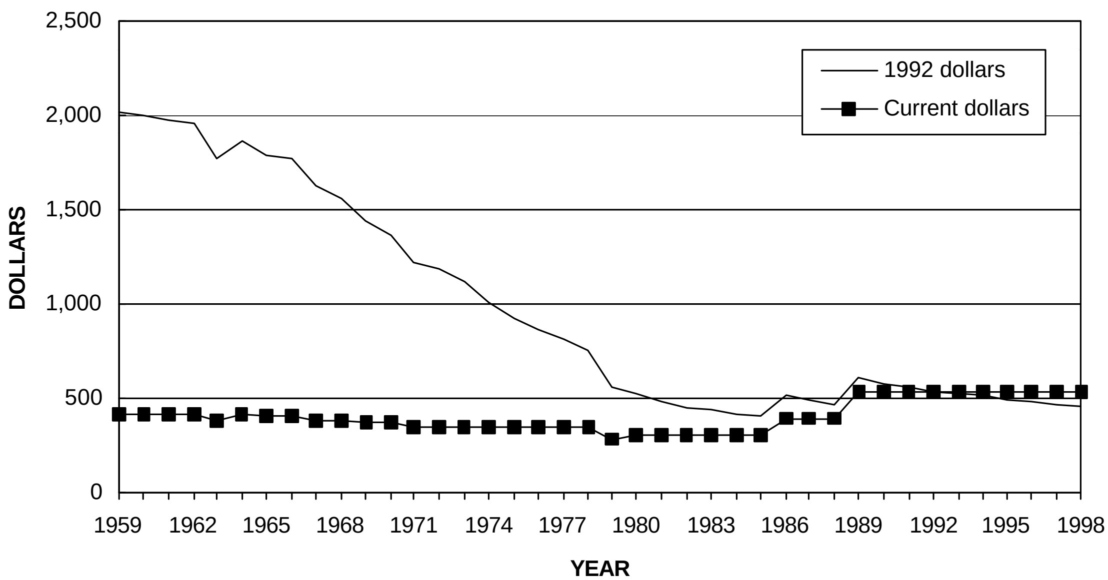
Yearend Neodymium Metal Price

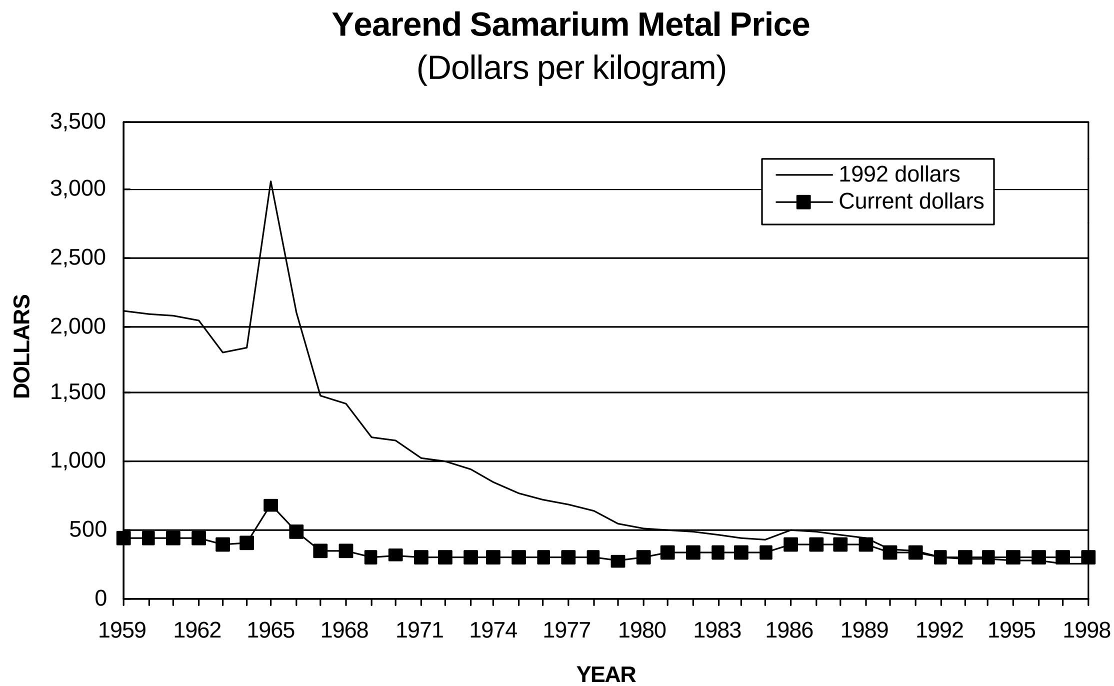
(Dollars per kilogram)

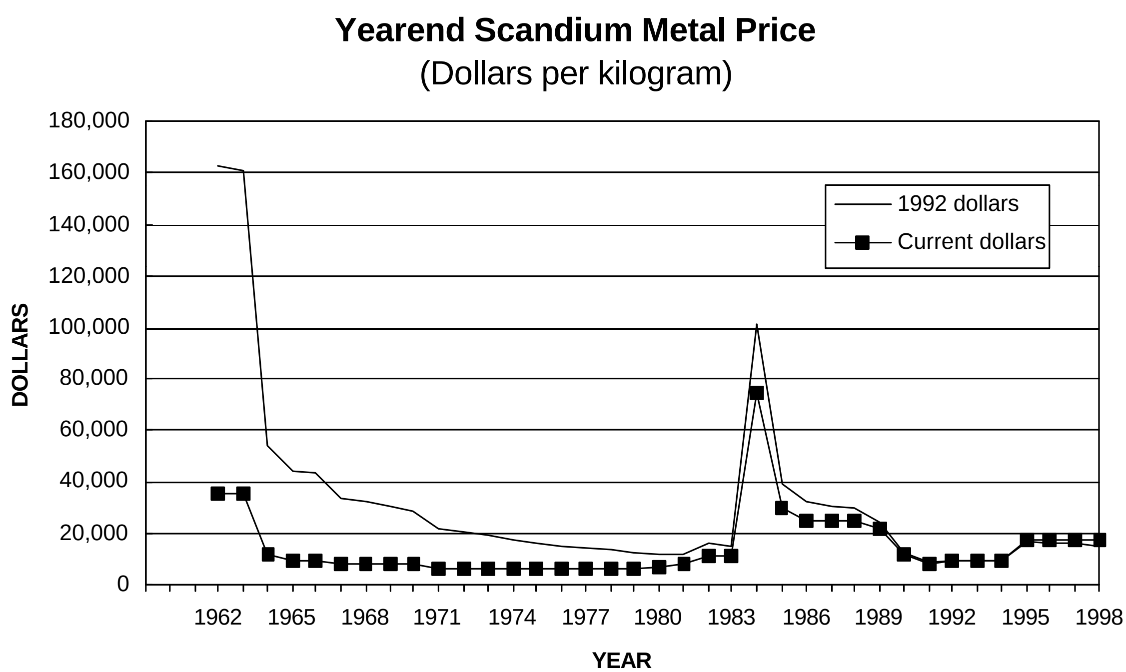


Yearend Praseodymium Metal Price

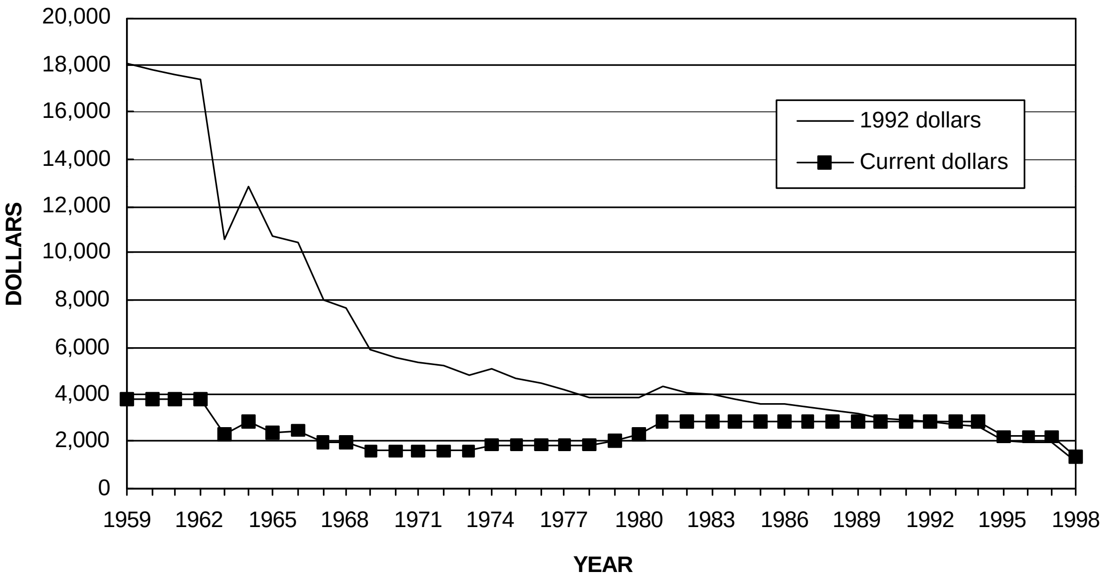
(Dollars per kilogram)



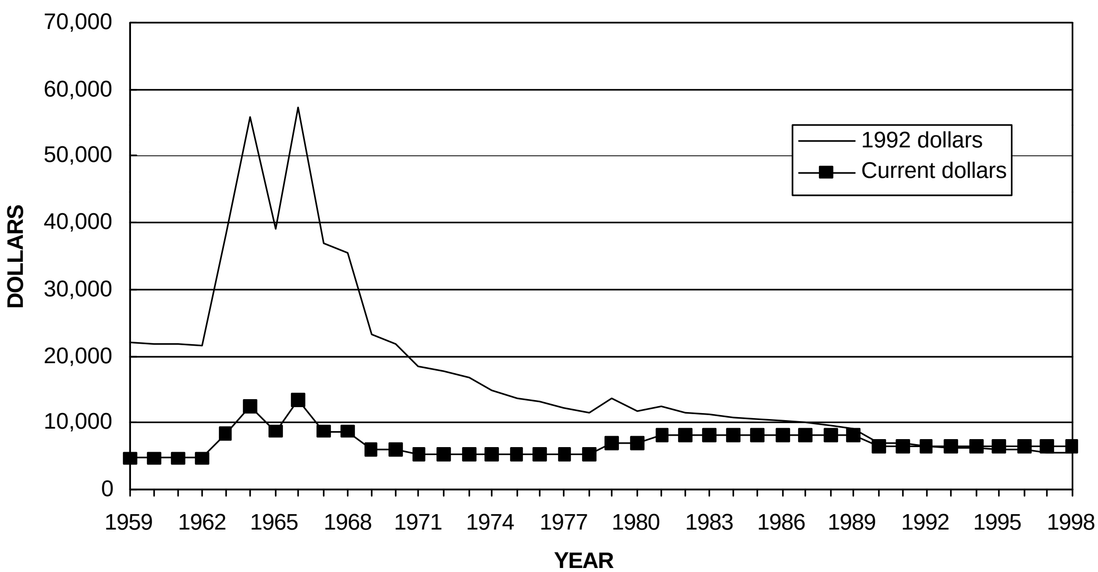

Yearend Samarium Metal Price
(Dollars per kilogram)
1992 dollars
Current dollars
DOLLARS
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR

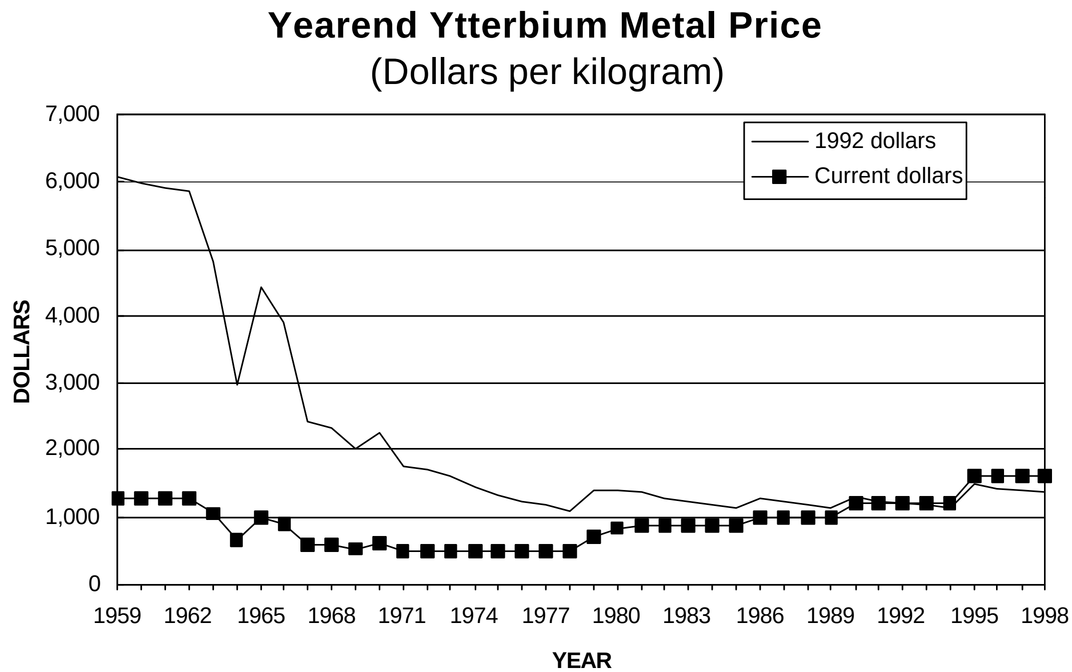

Yearend Scandium Metal Price
(Dollars per kilogram)
1992 dollars
Current dollars
DOLLARS
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR

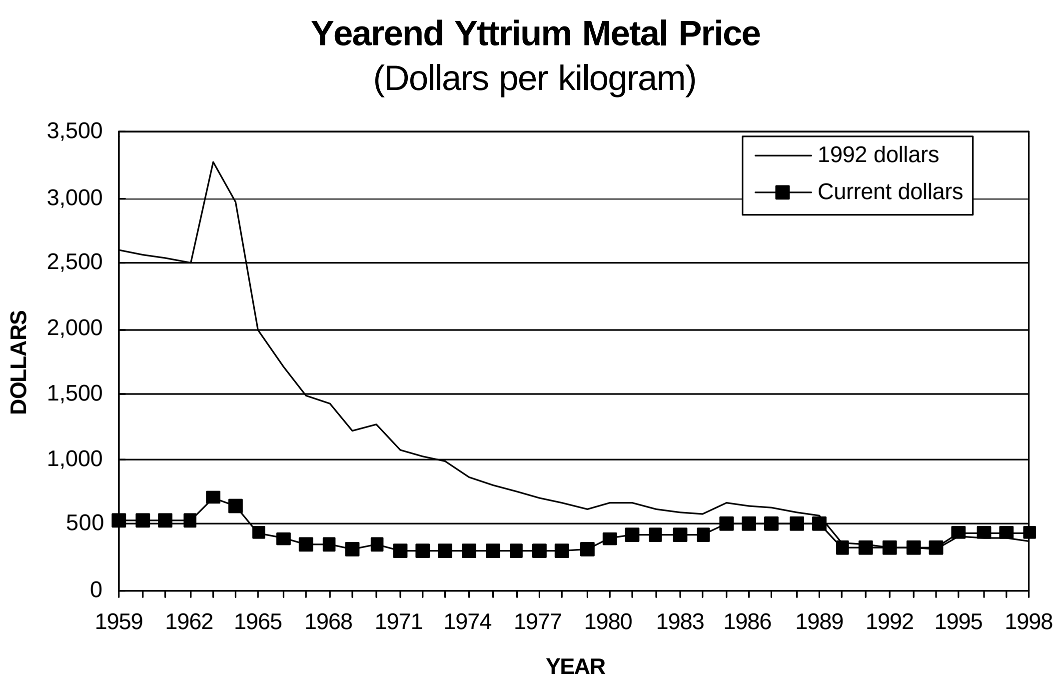
Yearend Terbium Metal Price
(Dollars per kilogram)



Yearend Thulium Metal Price
(Dollars per kilogram)




Yearend Ytterbium Metal Price
(Dollars per kilogram)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
DOLLARS
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR
1992 dollars
Current dollars


Yearend Yttrium Metal Price
(Dollars per kilogram)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
DOLLARS
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
YEAR
1992 dollars
Current dollars

Significant events affecting rare-earth metal prices

1958-71	Rare-earth supply increases
1971-78	Stable supply and demand
1979-81	Economic recession
1984	Scandium import supply cut
1985	U.S. environmental regulations limit lead in gasoline, reducing demand for rare-earth-containing petroleum fluid cracking catalysts
1980-90's	Increased production from China increased demand for permanent magnets, automotive catalytic converters, and rechargeable batteries

The rare earths are defined as the 17 elements comprised of scandium, yttrium, and the 15 lanthanides (Leigh, 1990). Promethium, one of the lanthanide group of elements, is radioactive. Except for very minor occurrences of this element in nature, most commercially available material is created in the laboratory. Of the 13 isotopes known to occur, promethium's half-lives are short, existing for only a few seconds to a few years. Because it is used in very small quantities and isotope price data is typically based on its radioactivity, promethium prices are not included in this report.

Prices of commercial quantities of a complete range of rare-earth metals were first quoted in the United States in the late 1950's and early 1960's. Prices decreased considerably as availability and extraction technology improved. Separation technology and metallurgical methods advanced in the years after Swedish chemist and mineralogist Carl Gustav Mosander first prepared metallic cerium in 1827 (Mosander, 1827).

Mosander prepared the first rare-earth metal by reducing cerous chloride with potassium in a hydrogen atmosphere to produce an impure powdered metal (Mosander, 1827). August Beringer in 1842, Jean-Charles G. de Marginac in 1853, and Friedrich Wöhler in 1867 used different sodium processes to reduce cerous chloride. In 1875, metallurgists were successful in producing fairly pure cerium, lanthanum, and didymium metals by electrolysis of molten rare-earth halides (Hillebrand and Norton, 1875). Subsequent work by different metallurgists contributed to electrowinning of other rare-earth metals. M. Billy and F. Trombe improved on the electrolytic method in the 1930's by producing higher-purity rare-earth metals of cerium, lanthanum, and neodymium (Billy and Trombe, 1931; Trombe, 1932, 1933). In the early 1950's, P.M.J. Gray was believed to be the first to exclude air and moisture in the electrowinning cell, using an argon atmosphere to produce cerium metal from cerium dioxide dissolved in an electrolyte (Gray, 1951-52).

Promethium metal was not prepared until 1963 when F. Weigel applied reduction of the fluoride (Weigel, 1963).

The first large-scale application of rare-earth metals began when Auer von Welsbach patented a pyrophoric alloy that comprised 70% mischmetal (a natural mixture of metallic rare-earth elements as derived from ore) and 30% iron in 1903 (Greinacher, 1981). Five years later, the mischmetal-iron alloy was commercially marketed in an ignition system for incandescent gas lamps. The use of the lamp mantle and mischmetal-iron alloy peaked by 1912, after which electric lighting came into general use. The alloy's use continues today as the "flint" in disposable lighters, camping lanterns, and campfire starter sticks and the sparkers used to ignite laboratory and welding gases.

Rare-earth metals in pure form were first prepared in 1931 (Gschneidner, 1988). In the 1940's, some applications were found for alloying rare-earth metals with ductile iron, but significant uses were not developed until the late 1960's. The use of individual rare-earth metals remained small until the 1950's when separation and metallurgical technologies improved. Demand then increased as lower cost individual rare-earth metals became available.

Rare-earth metal prices vary considerably depending on purity and quantity. Price fluctuations in the late 1950's to 1998 were affected primarily by supply and demand, environmental legislation, and economic factors, especially inflation and energy costs.

The decline in rare-earth metal prices during the period from 1958-71 resulted from the opening of the large rare-earths deposit at Mountain Pass, California, in 1952. The period was characterized by widespread commercialization of the individual rare earths, including compounds and metals. A significant development in the late 1960's was the acceptance of rare-earth silicide, and later, mischmetal, as an additive in high-strength low-alloy (HSLA) steels.

From 1971-78, the rare-earth supply continued to grow and demand kept pace. Demand for mischmetal increased late in the period as a result of its use in steel for the Alaskan oil pipeline. Beginning in 1978, prices for the rare-earth metals were tied primarily to the U.S. economy. Double-digit inflation and higher energy costs increased operating costs throughout the mining industry. Rare-earth metal prices followed the trend and began increasing in 1979 to offset higher operating costs.

After the 1981-82 recession, as the economy improved and inflation subsided, rare-earth metal prices stabilized, for the most part. The exception during this period was scandium. The main source of scandium at this time, the Soviet Union, ceased exports in 1984, reportedly because of internal demand for laser research. The price for scandium rose to an astronomical $75,000 per kilogram. Scandium's price decreased markedly the following year as production in the United States came on-line (Hedrick, 1987a).

In 1985, demand for the rare earths used in petroleum fluid-cracking catalysts, their principal market, dropped sharply. The rapid decline was the result of environmental legislation reducing the amount of lead allowed in gasoline. This legislation caused the refinery industry to switch to fluid-cracking catalysts that used significantly lower amounts of rare earths. With demand down, U.S. mine production decreased by nearly 50% in 1985, resulting in a substantial increase in rare-earth metal prices the following year (Hedrick, 1987b).

Prices for rare-earth metals in the 1980's and 1990's were mixed. Growth in the rare-earth industry between 1986 and 1998 was primarily in the markets for individual high-purity products. Rare-earth metal demand in this period was greatest for neodymium metal used in high-strength neodymium-iron-boron (NIB) permanent magnet alloys. Prices for neodymium and the NIB alloying agent, dysprosium, increased in the mid-1980's as demand increased. As a result of the increased NIB magnet demand, demand and price decreased for samarium metal used in the higher cost samarium-cobalt magnets. The price of cerium metal increased in 1992 as demand increased for cerium compounds used in automotive catalytic converters. Lanthanum's price increased in the mid-1990's as demand increased for lanthanum-nickel metal hydride rechargeable batteries used primarily in cordless tools, camcorders, cellular phones, and laptop computers. The price of yttrium metal declined in 1990, as low-cost yttrium from southern China became widely available on world markets. Europium's price declined in 1995, as low-cost Chinese material pushed prices lower amid strong international competition. Prices for most other rare-earth metals stayed fairly stable or declined because of small demand and limited applications.

References Cited

Billy, Maurice, and Trombe, Félix, 1931, Préparation de cérium pur [Preparation of pure cerium]: Paris, Gauthier-Villars, Comptes Rendus des Séances de l'Académie des Sciences, no. 10, v. 193, September 7, p. 421-423.

Gray, P.M.J., 1951-52, The production of pure cerium metal by electrolytic and thermal-reduction processes: Transactions of the Institution of Mining and Metallurgy, v. 61, p. 141-170.

Greinacher, Ekkehard, 1981, History of rare earth applications, Rare earth market today, chap. 1 of Industrial application of the rare earth elements: American Chemical Society Symposium Series 164, p. 3-17.

Gschneidner, K.A., Jr., 1988, Past, present, and future of rare earth metallurgy in 1787-1987—Two hundred years of rare earths: New York, Rare-earth Information Center and North-Holland, p. 23-32.

Hedrick, J.B., 1987a, Other metals, *in* Minerals Yearbook 1985, v. I: U.S. Bureau of Mines, p. 1096-1097.

———1987b, Rare-earth minerals and metals, *in* Minerals Yearbook 1985, v. I: U.S. Bureau of Mines, p. 741-803.

Hillebrand, W.F., and Norton, T.H., 1875, Elektrolytisch Abscheidung des Cers, Lanthans und Didyms [Electrolytic deposition of cerium, lanthanum, and didymium]: Leipzig, Germany, Annalen der Physik und Chemie, (Poggendorff), no. 8, v. 155 , p. 633-639.

Leigh, G.J., ed., 1990, Nomenclature of inorganic chemistry-recommendations 1990: Oxford, Blackwell Scientific Publications, p. 43.

Mosander, C.G., 1827, Einiges über das Cerium [Something about cerium]: Liepzig, Germany, Annalen der Physik, (Poggendorff), v. 11, p. 406-416.

Trombe, Félix, 1932, Préparation de lanthane métallique exempt de fer et de silicium [Preparation of silicon-free lanthanum metal]: Paris, Comptes Rendus des Séances de l'Académie des Sciences, v. 194, p. 1653-1655.

———1933, Préparation du néodyme métallique exempt de fer et de silicium [Preparation of silicon-free neodymium metal]: Paris, Comptes Rendus des Séances de l'Académie des Sciences, v. 196, p. 704-706.

Weigel, Fritz, 1963, Darstellung von metallischem Promethium [Preparation of metallic promethium]: Weinheim, Germany, Angewandte Chemie, v. 75, May 21, p. 451.

Yearend Cerium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	330.00	1969	110.23	1979	108.00	1989	175.00
1960	330.00	1970	88.18	1980	115.00	1990	175.00
1961	330.00	1971	88.18	1981	125.00	1991	175.00
1962	330.00	1972	88.18	1982	125.00	1992	350.00
1963	304.24	1973	88.18	1983	125.00	1993	350.00
1964	160.94	1974	88.18	1984	125.00	1994	350.00
1965	174.17	1975	88.18	1985	125.00	1995	350.00
1966	165.35	1976	88.18	1986	175.00	1996	350.00
1967	154.32	1977	88.18	1987	175.00	1997	350.00
1968	154.32	1978	88.18	1988	175.00	1998	350.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 1- tp 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Dysprosium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	730.00	1969	308.65	1979	270.00	1989	500.00
1960	730.00	1970	308.65	1980	300.00	1990	500.00
1961	730.00	1971	264.55	1981	300.00	1991	500.00
1962	730.00	1972	264.55	1982	300.00	1992	500.00
1963	661.39	1973	264.55	1983	300.00	1993	500.00
1964	526.90	1974	264.55	1984	300.00	1994	500.00
1965	559.97	1975	264.00	1985	300.00	1995	500.00
1966	275.58	1976	264.55	1986	630.00	1996	500.00
1967	341.72	1977	264.55	1987	630.00	1997	500.00
1968	341.72	1978	264.55	1988	630.00	1998	500.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided *by* American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Erbium Metal Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	730.00	1969	352.74	1979	450.00	1989	725.00
1960	730.00	1970	683.43	1980	530.00	1990	725.00
1961	730.00	1971	308.65	1981	650.00	1991	725.00
1962	730.00	1972	308.65	1982	650.00	1992	725.00
1963	661.39	1973	308.65	1983	650.00	1993	725.00
1964	632.73	1974	308.65	1984	650.00	1994	725.00
1965	694.46	1975	308.65	1985	650.00	1995	725.00
1966	595.25	1976	308.65	1986	725.00	1996	725.00
1967	396.83	1977	308.65	1987	725.00	1997	725.00
1968	396.83	1978	308.65	1988	725.00	1998	725.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1-5 kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Europium Metal Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	9,250.00	1969	7,054.79	1979	6,500.00	1989	7,600.00
1960	9,250.00	1970	7,054.79	1980	7,000.00	1990	7,600.00
1961	9,250.00	1971	5,952.48	1981	7,500.00	1991	7,600.00
1962	9,250.00	1972	5,952.48	1982	7,500.00	1992	7,600.00
1963	3,306.93	1973	5,952.48	1983	7,500.00	1993	7,600.00
1964	4,645.14	1974	5,952.48	1984	7,500.00	1994	7,600.00
1965	11,023.11	1975	5,952.48	1985	7,500.00	1995	5,600.00
1966	11,023.11	1976	5,952.48	1986	7,600.00	1996	5,600.00
1967	7,936.64	1977	5,952.48	1987	7,600.00	1997	5,600.00
1968	7,936.64	1978	5,952.48	1988	7,600.00	1998	6,500.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1- to 2-pound metal ingot prices, 99.9% nominal purity, provided by Research Chemicals.
1965-66, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Gadolinium Metal Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	730.00	1969	485.02	1979	430.00	1989	500.00
1960	730.00	1970	485.02	1980	440.00	1990	500.00
1961	730.00	1971	462.97	1981	485.00	1991	500.00
1962	730.00	1972	462.97	1982	485.00	1992	500.00
1963	462.97	1973	462.97	1983	485.00	1993	500.00
1964	568.79	1974	462.97	1984	485.00	1994	500.00
1965	537.93	1975	462.97	1985	485.00	1995	500.00
1966	551.16	1976	462.97	1986	500.00	1996	500.00
1967	507.06	1977	462.97	1987	500.00	1997	500.00
1968	507.06	1978	462.97	1988	500.00	1998	400.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Holmium Metal Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	730.00	1969	628.32	1979	1,100.00	1989	1,600.00
1960	730.00	1970	628.32	1980	1,400.00	1990	1,400.00
1961	730.00	1971	606.27	1981	1,600.00	1991	1,400.00
1962	730.00	1972	606.27	1982	1,600.00	1992	1,400.00
1963	661.39	1973	606.27	1983	1,600.00	1993	1,400.00
1964	897.28	1974	606.27	1984	1,600.00	1994	1,400.00
1965	1,080.27	1975	606.27	1985	1,600.00	1995	1,200.00
1966	992.08	1976	606.27	1986	1,600.00	1996	1,200.00
1967	815.71	1977	606.27	1987	1,600.00	1997	1,200.00
1968	815.71	1978	606.27	1988	1,600.00	1998	1,200.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Lanthanum Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	340.00	1969	110.23	1979	108.00	1989	150.00
1960	340.00	1970	110.23	1980	115.00	1990	150.00
1961	340.00	1971	88.18	1981	125.00	1991	150.00
1962	340.00	1972	88.18	1982	125.00	1992	150.00
1963	308.65	1973	88.18	1983	125.00	1993	150.00
1964	160.94	1974	88.18	1984	125.00	1994	150.00
1965	189.60	1975	88.18	1985	125.00	1995	350.00
1966	165.35	1976	88.18	1986	150.00	1996	350.00
1967	154.32	1977	88.18	1987	150.00	1997	350.00
1968	154.32	1978	88.18	1988	150.00	1998	350.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Lutetium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	8,580.00	1969	14,330.05	1979	13,200.00	1989	14,200.00
1960	8,580.00	1970	14,330.05	1980	12,900.00	1990	13,000.00
1961	8,580.00	1971	12,125.42	1981	14,200.00	1991	13,000.00
1962	8,580.00	1972	12,125.42	1982	14,200.00	1992	13,000.00
1963	9,369.65	1973	12,125.42	1983	14,200.00	1993	13,000.00
1964	14,550.51	1974	12,125.42	1984	14,200.00	1994	13,000.00
1965	14,550.51	1975	12,125.42	1985	14,200.00	1995	9,000.00
1966	17,636.98	1976	12,125.42	1986	14,200.00	1996	9,000.00
1967	16,534.67	1977	12,125.42	1987	14,200.00	1997	9,000.00
1968	16,534.67	1978	12,125.42	1988	14,200.00	1998	7,500.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964-66, 1- to 2-pound metal ingot prices, provided by Research Chemicals.
1967-73, 1- to 25-pound metal ingot prices, provided by American Potash & Chemical Corp.
1974-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Neodymium Metal Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	420.00	1969	220.46	1979	250.00	1989	340.00
1960	420.00	1970	242.51	1980	260.00	1990	340.00
1961	420.00	1971	220.46	1981	260.00	1991	340.00
1962	420.00	1972	220.46	1982	260.00	1992	340.00
1963	385.81	1973	220.46	1983	260.00	1993	340.00
1964	348.33	1974	220.46	1984	260.00	1994	340.00
1965	370.38	1975	220.46	1985	260.00	1995	450.00
1966	330.69	1976	220.46	1986	280.00	1996	450.00
1967	253.53	1977	220.46	1987	280.00	1997	450.00
1968	253.53	1978	220.46	1988	280.00	1998	450.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Praseodymium Metal Price

(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	420.00	1969	374.79	1979	290.00	1989	540.00
1960	420.00	1970	374.79	1980	310.00	1990	540.00
1961	420.00	1971	352.74	1981	310.00	1991	540.00
1962	420.00	1972	352.74	1982	310.00	1992	540.00
1963	385.81	1973	352.74	1983	310.00	1993	540.00
1964	412.26	1974	352.74	1984	310.00	1994	540.00
1965	401.24	1975	352.74	1985	310.00	1995	540.00
1966	407.86	1976	352.74	1986	400.00	1996	540.00
1967	385.81	1977	352.74	1987	400.00	1997	540.00
1968	385.81	1978	352.74	1988	400.00	1998	540.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Samarium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	440.00	1969	308.65	1979	280.00	1989	395.00
1960	440.00	1970	319.67	1980	300.00	1990	340.00
1961	440.00	1971	297.62	1981	330.00	1991	340.00
1962	440.00	1972	297.62	1982	330.00	1992	300.00
1963	396.83	1973	297.62	1983	330.00	1993	300.00
1964	407.86	1974	297.62	1984	330.00	1994	300.00
1965	687.84	1975	297.62	1985	330.00	1995	300.00
1966	485.02	1976	297.62	1986	395.00	1996	300.00
1967	352.74	1977	297.62	1987	395.00	1997	300.00
1968	352.74	1978	297.62	1988	395.00	1998	300.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 2- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 2- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Scandium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	NA	1969	7,936.64	1979	6,600.00	1989	21,500.00
1960	NA	1970	7,936.64	1980	7,200.00	1990	12,000.00
1961	NA	1971	6,172.94	1981	8,000.00	1991	8,400.00
1962	35,000.00	1972	6,172.94	1982	11,000.00	1992	10,000.00
1963	35,000.00	1973	6,172.94	1983	11,000.00	1993	10,000.00
1964	11,889.53	1974	6,172.94	1984	75,000.00	1994	10,000.00
1965	10,000.00	1975	6,172.94	1985	30,000.00	1995	18,000.00
1966	10,000.00	1976	6,172.94	1986	25,000.00	1996	18,000.00
1967	7,936.64	1977	6,172.94	1987	25,000.00	1997	18,000.00
1968	7,936.64	1978	6,172.94	1988	25,000.00	1998	18,000.00

NA Not available.

Note:
1962, 1-pound metal ingot prices, 99.5+% purity, provided by Atomergic Chemetals, Div. of Gallard Schlesinger.
1963, 100- to 400-gram metal ingot prices, 99.5+% purity, provided by Atomergic Chemetals, Div. of Gallard Schlesinger.
1964, 1971-78, 1- to 2-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 227- to 454-gram metal ingot price, provided by Research Chemicals.
1967-70, 1989-92, 2- to 10-pound metal ingot price, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Terbium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	3,750.00	1969	1,543.24	1979	2,000.00	1989	2,800.00
1960	3,750.00	1970	1,543.24	1980	2,300.00	1990	2,800.00
1961	3,750.00	1971	1,543.24	1981	2,800.00	1991	2,800.00
1962	3,750.00	1972	1,543.24	1982	2,800.00	1992	2,800.00
1963	2,314.85	1973	1,543.24	1983	2,800.00	1993	2,800.00
1964	2,843.96	1974	1,807.79	1984	2,800.00	1994	2,800.00
1965	2,411.86	1975	1,807.79	1985	2,800.00	1995	2,200.00
1966	2,425.08	1976	1,807.79	1986	2,800.00	1996	2,200.00
1967	1,895.98	1977	1,807.79	1987	2,800.00	1997	2,200.00
1968	1,895.98	1978	1,807.79	1988	2,800.00	1998	1,300.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1- to 2-pound metal ingot prices, 99.9% nominal purity, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Thulium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	4,620.00	1969	6,062.71	1979	7,000.00	1989	8,000.00
1960	4,620.00	1970	6,062.71	1980	6,900.00	1990	6,500.00
1961	4,620.00	1971	5,291.09	1981	8,000.00	1991	6,500.00
1962	4,620.00	1972	5,291.09	1982	8,000.00	1992	6,500.00
1963	8,377.57	1973	5,291.09	1983	8,000.00	1993	6,500.00
1964	12,387.77	1974	5,291.09	1984	8,000.00	1994	6,500.00
1965	8,818.49	1975	5,291.09	1985	8,000.00	1995	6,500.00
1966	13,227.74	1976	5,291.09	1986	8,000.00	1996	6,500.00
1967	8,818.49	1977	5,291.09	1987	8,000.00	1997	6,500.00
1968	8,818.49	1978	5,291.09	1988	8,000.00	1998	6,500.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1- to 2-pound metal ingot prices, 99.9% nominal purity, provided by Research Chemicals.
1965-66, 1- to 25-pound metal ingot price, from 99.9%-grade oxides, provided by American Potash & Chemical Corp.
1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Yearend Ytterbium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	1,260.00	1969	529.11	1979	720.00	1989	1,000.00
1960	1,260.00	1970	628.32	1980	825.00	1990	1,200.00
1961	1,260.00	1971	507.06	1981	875.00	1991	1,200.00
1962	1,260.00	1972	507.06	1982	875.00	1992	1,200.00
1963	1,047.20	1973	507.06	1983	875.00	1993	1,200.00
1964	654.77	1974	507.06	1984	875.00	1994	1,200.00
1965	994.28	1975	507.06	1985	875.00	1995	1,600.00
1966	903.90	1976	507.06	1986	1,000.00	1996	1,600.00
1967	573.20	1977	507.06	1987	1,000.00	1997	1,600.00
1968	573.20	1978	507.06	1988	1,000.00	1998	1,600.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965, "over 1 pound" metal ingot prices, provided by Research Chemicals.
1966, 1- to 5- pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

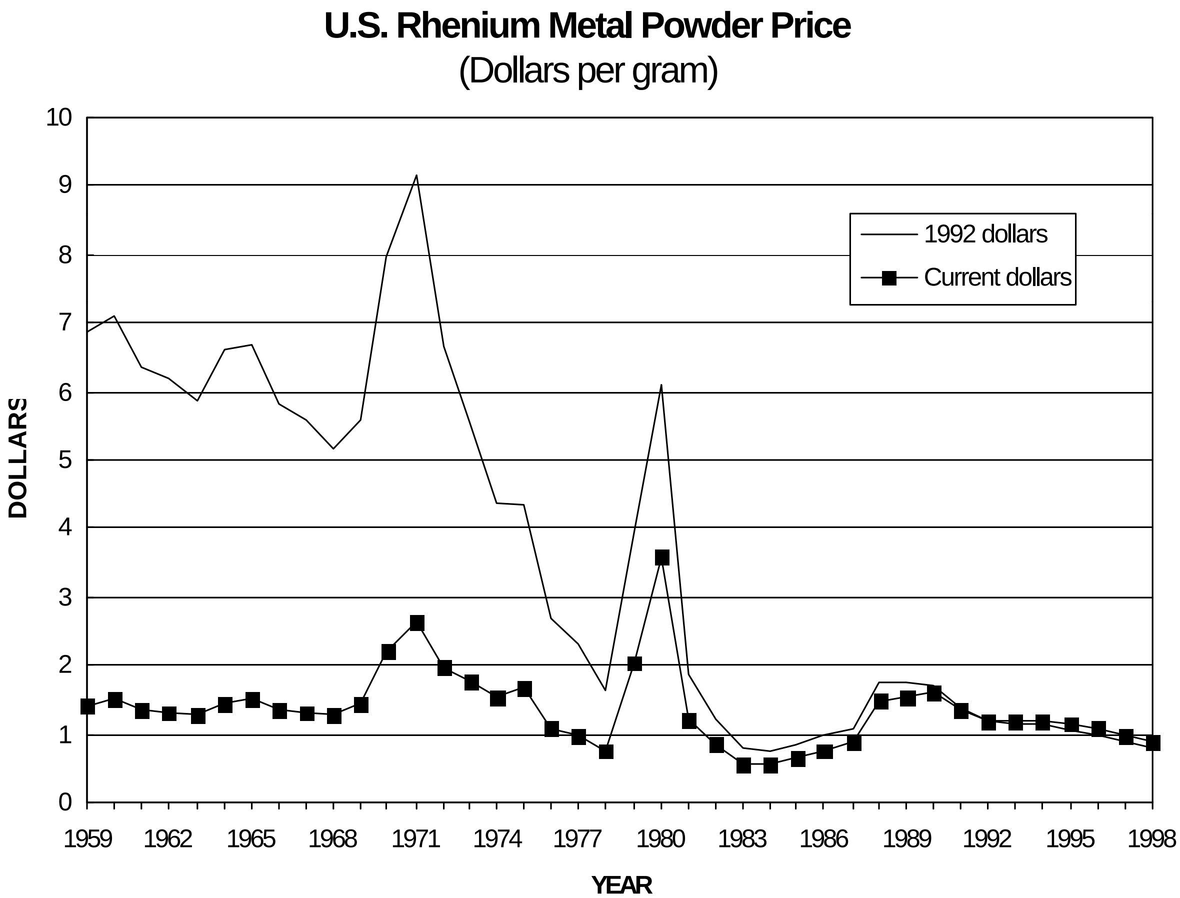
Yearend Yttrium Metal Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	540.00	1969	319.67	1979	320.00	1989	510.00
1960	540.00	1970	352.74	1980	390.00	1990	340.00
1961	540.00	1971	308.65	1981	430.00	1991	340.00
1962	540.00	1972	308.65	1982	430.00	1992	340.00
1963	716.50	1973	308.65	1983	430.00	1993	340.00
1964	654.77	1974	308.65	1984	430.00	1994	340.00
1965	449.74	1975	308.65	1985	510.00	1995	450.00
1966	396.83	1976	308.65	1986	510.00	1996	450.00
1967	352.74	1977	308.65	1987	510.00	1997	450.00
1968	352.74	1978	308.65	1988	510.00	1998	450.00

Note:
1959-62, 100- to 450-gram metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1963, 1- to 4-pound metal ingot prices, 99.9% nominal purity, provided by American Potash & Chemical Corp.
1964, 1967-78, 2- to 10-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1965-66, 1- to 5-pound metal ingot price, from 99.9%-grade oxides, provided by Research Chemicals.
1979-88, 1-kilogram metal ingot, from 99.9%-grade oxides, provided by Research Chemicals.
1989-94, 1-kilogram metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1995-97, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhône-Poulenc Basic Chemicals Co.
1998, 1- to 5-kilogram cast metal ingots, from 99.9%-grade oxides, provided by Rhodia, Inc.

Rhenium

by John W. Blossom



Significant events affecting rhenium prices since 1958

1970	Start of rhenium use in catalysts to make unleaded gasoline
1980	Doubling of percentage of rhenium in catalysts used to make unleaded gasoline
1991	Dissolution of the Soviet Union

Ida (Tache) and Walter Noddack, German chemists, are generally credited with the discovery of rhenium in 1925 (Habashi, 1997). The total cost for producing the first gram of rhenium in 1928 was estimated to be $15,000. At the University of Tennessee in 1942, A.D. Melaven and J.A. Bacon developed a process for extracting the element from the dust that accumulated in the roasting molybdenum ore. This plant in Tennessee was the only rhenium producer in the United States for many years and had a total output of several hundred pounds of the metal and its salts (Sutulov, 1976, p. 206).

In 1942, the price of the metal in the United States was $14 per gram; in Germany, however, the price was reportedly $4 per gram. The price of rhenium decreased from $14 per gram in 1942 to $1.99 per gram in 1951 as techniques for extraction were refined. From 1951 through 1954, interest in rhenium uses was stimulated by research associated with the Korean conflict. Consequently, the price rose to as high as $2.18 per gram. From 1954 through 1969, prices stabilized as new uses for rhenium were developed—the additions of rhenium increase the corrosion resistance of stainless steel; the nuclear properties of rhenium offer potential as a reactor-shielding material for thermal neutrons; rhenium shield, when compared with a lead shield, results in a significant weight savings; and the inherent brittleness of tungsten and molybdenum metals is inhibited and the ductility is improved by alloying with rhenium. In 1968, the usage in alloy applications decreased as Atomic Energy Commission programs were completed. This decrease was reversed by the development of rhenium and rhenium-platinum catalysts used in the cracking of petroleum hydrocarbons (National Research Council, 1968). The use in catalysts reached a high of 75% of the demand for rhenium, resulting in a price peak in 1971 of $2.64 per gram. The price declined to $0.77 per gram in 1978 because the supply/demand was balanced. In 1980, the price increased to $3.58 per gram as a result of increased demand related to the doubling of the percentage of rhenium in the reforming catalysts used to produce unleaded gasoline (Millensifer, 1997). The price quickly deceased to $1.34 per gram in 1981. The price continued to decrease to $0.55 per gram in 1984, then it increased to $0.89 per gram in 1987. In 1988, the price increased to about $1.50 per gram as a result of demand for new alloys to be used in turbine engines for aircraft. This caused the price to increase to $1.60 per gram in 1990. In 1991, it decreased to $1.34 per gram and had decreased to $0.90 per gram by the end of 1998, partly owing to the decreased demand for aircraft engines following the dissolution of the Soviet Union.

References Cited

Habashi, Fathi, 1997, Rhenium seventy years old, *in* Byrskin, B.D., ed., 1997, Rhenium and rhenium alloys—International Symposium on Rhenium and Rhenium Alloys, February 9-13, 1997, Orlando, FL, Proceedings: Warrendale, PA, The Minerals, Metals & Materials Society, p. 15-36.

Millensifer, T.A., 1997, Rhenium background and markets, *in* Byrskin, B.D., ed., 1997, Rhenium and rhenium alloys—International Symposium on Rhenium and Rhenium Alloys, February 9-13, 1997, Orlando, FL, Proceedings: Warrendale, PA, The Minerals, Metals & Materials Society, p. 37-47.

National Research Council, 1968, Trends in usage of rhenium—A report by the Materials Advisory Board: National Academy of Sciences/National Academy of Engineering, MAB-251, Washington, D.C., December, p. 9.

Sutulov, Alexander, 1976, Molybdenum and rhenium 1778-1977: University of Concepcion, Chile, 257 p.

U.S. Rhenium Metal Powder Price
(Dollars per gram)

Year	Price	Year	Price	Year	Price	Year	Price
1942	14.00	1957	1.46	1972	1.98	1987	0.89
1943	10.00	1958	1.45	1973	1.76	1988	1.47
1944	6.50	1959	1.43	1974	1.54	1989	1.55
1945	4.50	1960	1.50	1975	1.67	1990	1.60
1946	3.25	1961	1.35	1976	1.10	1991	1.34
1947	NA	1962	1.33	1977	0.99	1992	1.20
1948	NA	1963	1.28	1978	0.77	1993	1.20
1949	NA	1964	1.46	1979	2.04	1994	1.20
1950	NA	1965	1.50	1980	3.58	1995	1.15
1951	1.99	1966	1.35	1981	1.22	1996	1.10
1952	2.18	1967	1.33	1982	0.84	1997	1.00
1953	2.11	1968	1.28	1983	0.55	1998	0.90
1954	1.43	1969	1.46	1984	0.55		
1955	1.50	1970	2.20	1985	0.66		
1956	1.49	1971	2.64	1986	0.77		

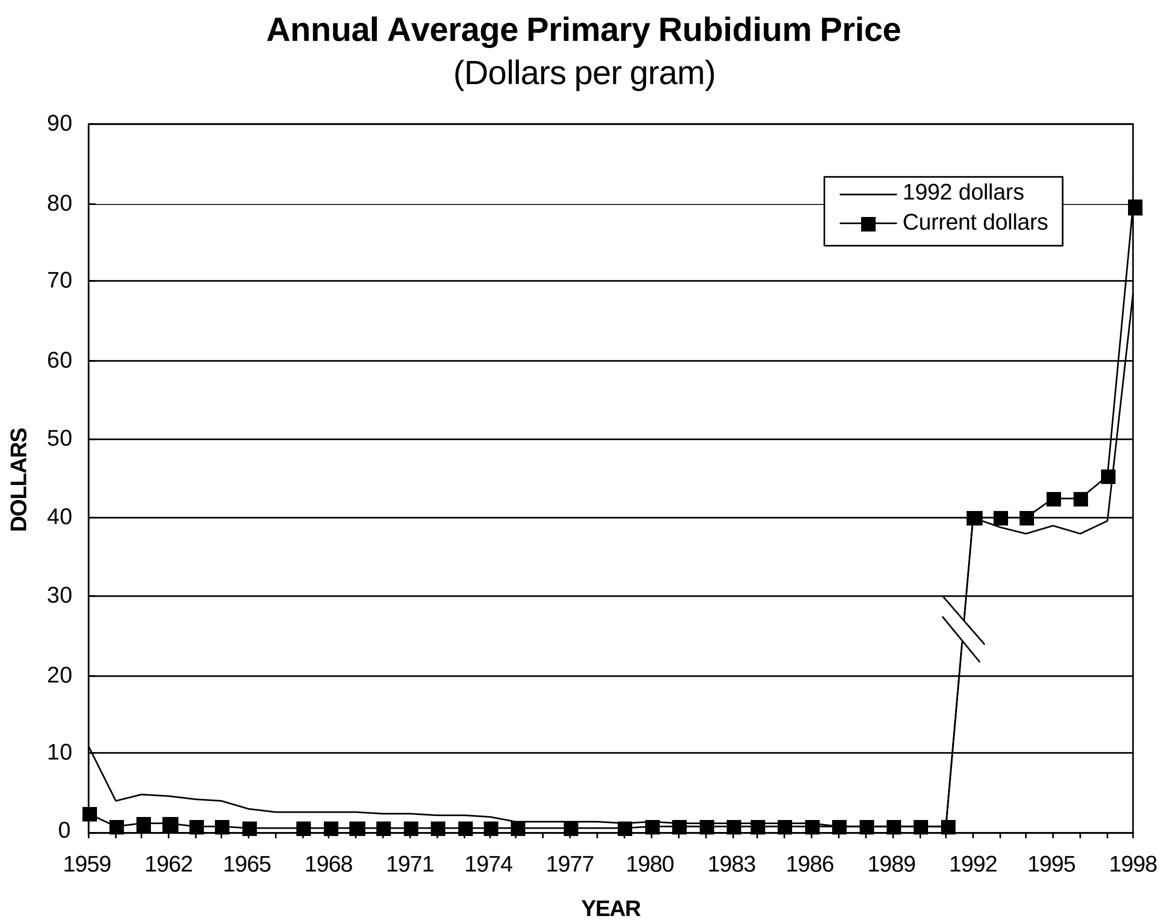
NA Not available.

Note:
1942-82, published by the U.S. Bureau of Mines, but origin is unknown.
1983-94, Rhenium Commodity Specialist, U.S. Bureau of Mines (I.E. Torres and J.W. Blossom).
1995-98, Rhenium Commodity Specialist, U.S. Geological Survey (J.W. Blossom).

Rb

Rubidium

by Robert G. Reese, Jr.



Rubidium was discovered in 1861 but had extremely limited industrial use until the 1920's (Perel'man, 1965, p. 1). Small quantities of rubidium-containing minerals were mined in the United States prior to the mid-1960's, but rubidium is no longer mined domestically. Historically, the most important use for rubidium has been in research and development, primarily in chemical and electronic applications.

Owing to the small size of the industry, quoted rubidium prices are those of individual companies. The price varies directly with the purity of the material and inversely with the quantity purchased. Rubidium metal has been marketed in purities ranging from 99.5% to 99.8%. The annual prices presented in the graph and table may not be comparable from year to year owing to differences in purities, quantity of material purchased, and/or the source of the price. For example, prior to 1963, most of the prices published in the U.S. Bureau of Mines Minerals Yearbooks were for purchases of less than 1 pound of rubidium metal. Some pre-1963 prices, along with the prices published for 1963 through 1988, were for the purchase of at least 1 pound of rubidium metal. The price when buying a 1 pound of metal is significantly lower than the other prices, owing to discounts for the large quantity purchased. For this report, prices were subsequently converted to a per-gram equivalent. The prices for 1992 through 1998 represent the price charged for a 1-gram ampoule of 99.8%-pure rubidium metal.

Reference Cited

Perel'man, F.M., 1965, Rubidium and caesium: New York, The Macmillan Co., 144 p.

Annual Average Primary Rubidium Price

(Dollars per gram)

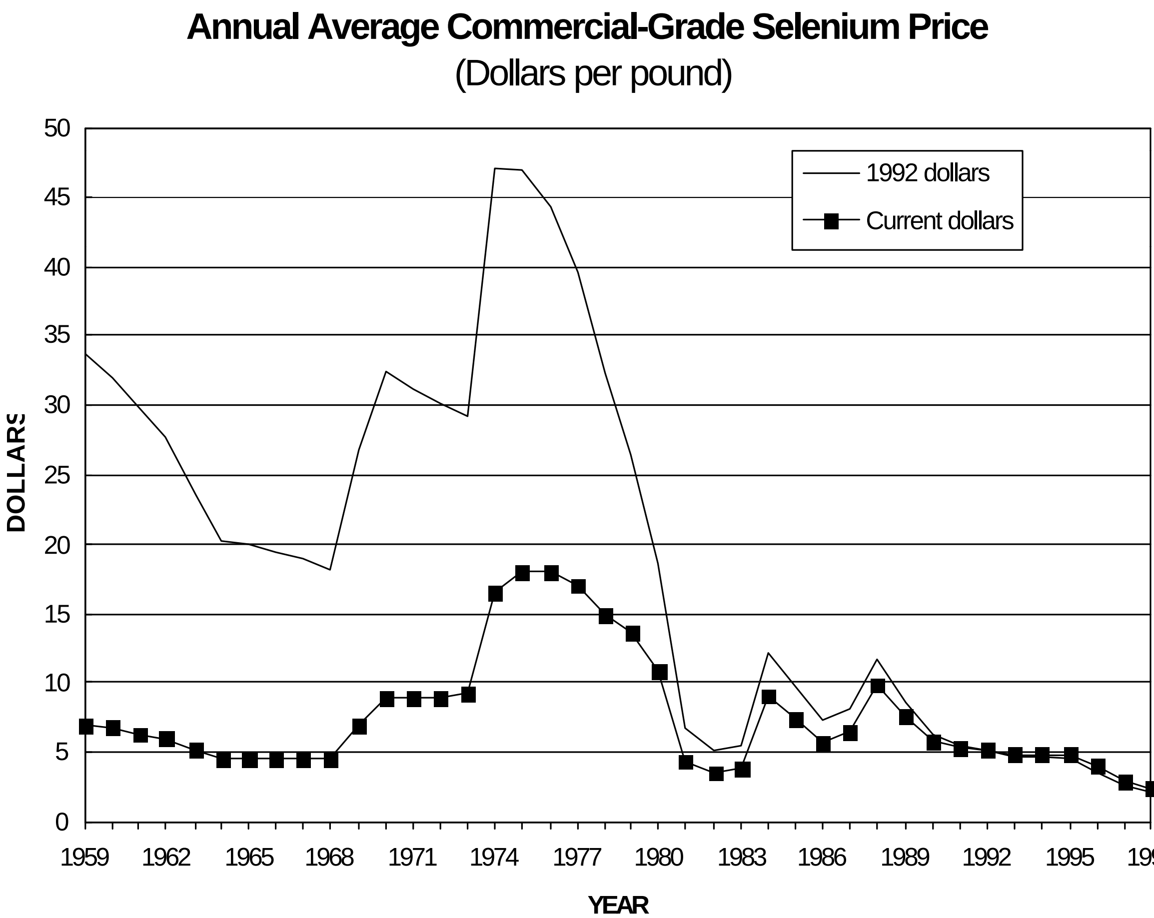
Year	Price	Year	Price	Year	Price	Year	Price
1959	2.26	1969	0.66	1979	0.61	1989	0.74
1960	0.86	1970	0.66	1980	0.74	1990	0.74
1961	1.00	1971	0.66	1981	0.74	1991	0.74
1962	1.00	1972	0.66	1982	0.74	1992	40.00
1963	0.90	1973	0.66	1983	0.74	1993	40.00
1964	0.90	1974	0.66	1984	0.74	1994	40.00
1965	0.63	1975	0.66	1985	0.74	1995	42.40
1966	NA	1976	NA	1986	0.74	1996	42.40
1967	0.63	1977	0.61	1987	0.74	1997	45.40
1968	0.63	1978	NA	1988	0.74	1998	79.70

NA Not available

Note: The data in the table above were compiled from information in various U.S. Bureau of Mines Minerals Yearbooks, U.S. Bureau of Mines Mineral Commodity Summaries, and U.S. Geological Survey Mineral Commodity Summaries. It is believed that the data in the previously mentioned publication represents, and/or were obtained from the following sources:
1959, Average of the price for purities ranging from 99.0% to 99.8% attributed to American Potash & Chemical Corp. & Penn Rare Metals Co.
1960, 99+% Rubidium metal, 10-pound lots.
1961-62, MSA Research Corp. 99.0% rubidium metal, 50-gram lots.
1963-64, Average of the range of prices for 99+% rubidium metal, *in* American Metal Market.
1965, Average of the range of prices for 99.5% rubidium, 1- to 9-pound lots attributed to the Penn Rare Metals Division of Kawecki Chemical Co.
1967-68, Average of the range of prices for 99.5% rubidium, 1- to 9-pound lots attributed to the Penn Rare Metals Division of Kawecki Chemical Co.
1969-75, U.S. Bureau of Mines Minerals Yearbook citation for 99.5+% rubidium metal.
1977, Average of the range of prices for 99.5% rubidium metal attributed to unidentified industry sources.
1979, Average of the range of prices for 99.5% rubidium metal attributed to unidentified industry sources.
1980-85, KBI Division, Cabot Corp., average of the yearend price for technical- and high-purity-grade rubidium metal.
1986-88, KBI Division, Cabot Corp., average of the yearend price for technical- and high-purity-grade rubidium metal in lots under 50 pounds.
1989-91, KBI Division, Cabot Corp.
1992-98, Alfa Aesar and other chemical catalogs. Prices for purchases of 99.8% rubidium metal in 1-gram ampoules.

Selenium

by Robert D. Brown, Jr.



Significant events affecting selenium prices since 1958

1963-67	Commercial stocks rise to 1.3 million pounds before declining, U.S. Government stocks reach 400,000 pounds in 1963, imports increasing
1968-72	Vietnam War, production and demand surge to record highs of 1.2 million and 1.8 million pounds, respectively, in 1969, stocks decline rapidly, civilian demand growth from single-use bottles and xerography
1974-76	Government stocks liquidated by 1974, low commercial inventories, reduced domestic production from recession and copper industry strike, increased import dependence, continued growth in xerography
1977-80	Stock buildup and reduced demand following 1977 recession, production level is established at about one-half of 1969 peak
1981-83	Demand surges, stocks remain high, xerography and glass manufacturing dominate demand
1984-89	World stocks decline as demand outstrips production, speculation encourages price fluctuations, domestic demand averages 1.3 million pounds
1990-91	World production rises, demand slackens owing to recession, stock decline is reversed
1995-98	Increasing use in lead-free brasses
1996-98	Large-scale research on supplementation for cancer prevention in humans

The discovery of selenium is credited to J.J. Berzelius, who isolated it in 1817 from the red residue found in sulfuric acid prepared at the pyrite mining operation at Fahlun, Sweden (Carapella, 1984, p. 842). For almost a century, selenium was merely a scientific curiosity, until its use as a pigment in the manufacture of red glass, ceramics, and glazes was established by 1910 (Hess, 1911). Prices for selenium prior to that time are not generally available. Commercial quantities of selenium were and still are recovered as a byproduct of the electrolytic refining of copper where it accumulates in anode residues (Hoffman, 1984, p. 495-516).

During World War I, selenium production and demand grew rapidly owing to the increased demand for red glass and the development of selenium as a replacement for manganese dioxide as a decolorizer in clear glass. Domestic production rose rapidly from about 5 metric tons in 1910 to about 50 tons in 1918. Although the production of selenium fluctuated markedly from year to year, it continued to increase, reaching a peak of 565 tons in 1969, during the Vietnam War. Disruptions to copper production, changing technology, and variable demand contributed to year-to-year fluctuations in production. From 1970 through 1980, domestic production fell markedly, with imports accounting for an increasing share of domestic demand. Domestic production of selenium was about 140 tons in 1980 and increased to roughly 250 tons in 1985, 275 tons in 1990, 375 tons in 1995, and 380 tons in 1996.

As calculated from domestic shipments plus net imports, apparent consumption also fluctuated markedly from year to year owing to economic cycles, military engagements, technical developments, and consumer stockpiling. Growth in consumption was driven by the development of new uses, including applications in rubber compounding, steel alloying, and selenium rectifiers. Consumption generally increased through 1969 when it peaked at almost 900 tons owing mainly to defense requirements. By 1970, selenium in rectifiers had largely been replaced by silicon, but its use as a photoconductor in plain paper copiers had become its leading application. By 1974, U.S. Government stocks, which had reached a peak of 400,000 pounds in 1963, were liquidated. Apparent consumption fell to less than 350 tons in 1980 but rose to a fairly stable range just above or below 500 tons from 1990 through 1996. During the 1980’s, the photoconductor application declined (although it was still a large end use) as more and more copiers using organic photoconductors were produced. In the late 1980’s, demand outstripped supply, thus causing an increase in price and a decrease in stocks. Since 1990, worldwide production has exceeded or matched demand. When demand has increased, so has production, but when demand has decreased, production has remained about the same. This fairly constant oversupply situation has kept prices low (Brown, 1998, p. 13-17). In 1996, continuing research showed a positive correlation between selenium supplementation and cancer prevention in humans (Clark, 1996, p. 1957-1963). Although this could be very important from a public health viewpoint, direct application of this finding would not add significantly to demand owing to the small doses required. In the late 1990’s, the use of selenium (usually with bismuth) as an additive to plumbing brasses to meet no-lead standards became important (King and Li, 1997); this application could add significantly to demand. In 1996, total domestic consumption was about 500 tons. Demand data from 1997 and 1998 are withheld to prevent publication of proprietary information.

References Cited

Brown, R.D., Jr., 1998, Selenium and tellurium—Supply demand relationship: International Symposium on the Uses of Selenium and Tellurium, 6th, Scottsdale, AZ, May 10-12, 1998, Proceedings, 314 p.

Carapella, S.C., Jr., 1984, Selenium (4th ed.): New York, Van Nostrand Reinhold Encyclopedia of Chemistry, 1082 p.

Clark, L.C., and others, 1996, Effect of selenium supplementation for cancer prevention: Journal of the American Medical Association, v. 276, no. 24, December 25, 129 p.

Hess, F.L., 1911, Selenium, *in* Mineral resources of the United States 1910: U.S. Geological Survey, pt. I, Metals, p. 731.

Hoffman, J.E., 1984, Recovery of selenium from electrolytic copper refinery slimes, *in* Precious metals—Mining, extraction, and processing: Warrendale, PA, Mining, Minerals, and Materials Society, 621 p.

King, M.G., and Li, Taie, 1997, Method for making machinable lead-free copper alloys with additive: U.S. Patent 5,614,038, assigned to ASARCO Incorporated, 4 p.

Annual Average Commercial-Grade Selenium Price[1]

(Dollars per pound[2])

Year	Price	Year	Price	Year	Price	Year	Price
1911	3.00	1933	1.90	1955	7.50	1977	17.12
1912	2.50	1934	1.90	1956	11.25	1978	15.00
1913	1.68	1935	2.00	1957	9.75	1979	13.65
1914	1.50	1936	1.88	1958	7.25	1980	10.95
1915	NA	1937	1.88	1959	7.00	1981	4.38
1916	1.35	1938	1.80	1960	6.75	1982	3.53
1917	2.15	1939	1.80	1961	6.38	1983	3.87
1918	3.00	1940	1.75	1962	6.00	1984	9.02
1919	2.38	1941	1.75	1963	5.13	1985	7.44
1920	2.00	1942	1.75	1964	4.50	1986	5.70
1921	2.13	1943	1.75	1965	4.50	1987	6.51
1922	1.96	1944	1.75	1966	4.50	1988	9.84
1923	1.86	1945	1.75	1967	4.50	1989	7.61
1924	1.86	1946	1.75	1968	4.50	1990	5.82
1925	1.70	1947	1.88	1969	7.00	1991	5.41
1926	1.95	1948	2.00	1970	9.00	1992	5.13
1927	1.95	1949	2.00	1971	9.00	1993	4.90
1928	2.13	1950	2.75	1972	9.00	1994	4.90
1929	1.65	1951	3.25	1973	9.25	1995	4.89
1930	1.90	1952	3.25	1974	16.53	1996	4.00
1931	1.90	1953	3.63	1975	18.00	1997	2.94
1932	1.90	1954	4.63	1976	18.00	1998	2.50

NA Not available

[1] 99.5%-pure selenium powder.

[2] To convert to dollars per kilogram, multiply by 2.20462.

Note:

1911-20, Domestic price, *in* U.S. Geological Survey, Mineral Resources of the United States.

1921-36, Domestic price, *in* Engineering & Mining Journal.

1937-66, Domestic price, *in* E&MJ Metal and Mineral Markets.

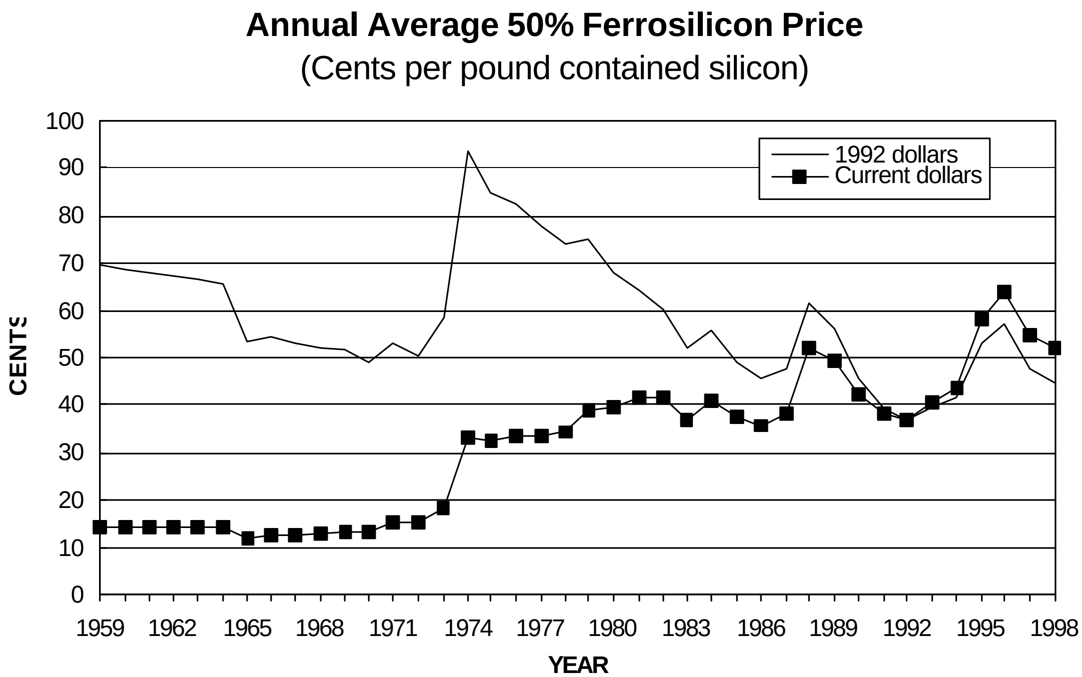
1967-93, New York dealer price, *in* Metals Week [through June 14, 1993].

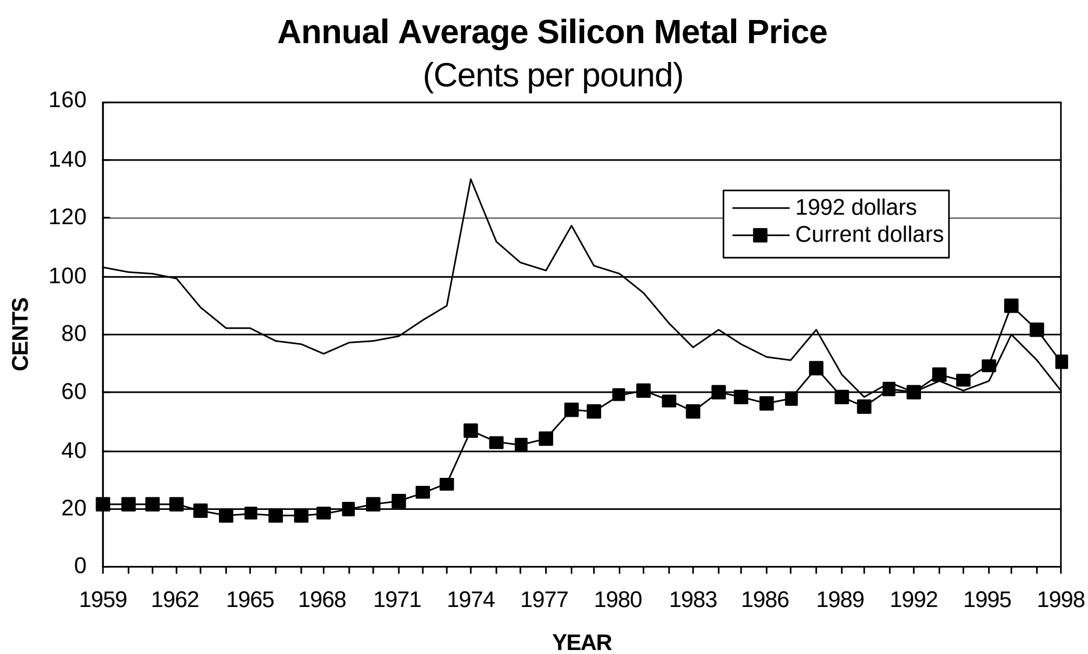
1993-98, New York dealer price, *in* Platt's Metals Week.

(This page intentionally left blank.)

Silicon

by Thomas S. Jones





Significant events affecting silicon prices since 1958

1974	Lifting of price controls
1980's	Imports of silicon materials capture a growing share of U.S. market
1988	Strength in steel production
1991	Antidumping duties assessed on U.S. silicon metal imports
1993-94	Antidumping duties assessed on U.S. ferrosilicon imports
1996	Period of strong demand

Silicon is a light chemical element with metallic and nonmetallic characteristics. It is second in importance to manganese in overall steelmaking. In the form of ferrosilicon, silicon is used for deoxidizing and as a strengthening alloy in the production of iron and steel. Silicon metal is used primarily in the aluminum and chemical industries.

Principal elements in the cost of silicon and ferrosilicon production are the delivered costs of the ore (quartz or quartzite) and the costs of energy, reductant coke or low ash coal, iron in the form of steel scrap (if required), and labor. These costs, and particularly that of energy, have increased rapidly since 1970. In addition, new capital costs for pollution control equipment have been incurred. Bulk ferroalloys produced in submerged-arc furnaces are extremely power intensive, especially silicon metal and silicon-containing alloys, which can require up to 14,000 kilowatt-hours of electric energy per metric ton of silicon contained in the final product (Dosaj, 1997). Energy is the largest cost component in the production of silicon metal and silicon-containing alloys and can account for one-fifth or more of total costs (de Linde, 1995).

Specifications for silicon metal used by the primary aluminum and chemical industries generally are more stringent than those for metal used by the secondary aluminum industry. Price trends for the small quantities of high-purity, high-value silicon produced for electronic uses are not addressed in this chapter. Data for U.S. exports in 1997 indicate that the cost of silicon for manufacture into the chips upon which modern computer technology is based averages as much as 30 times that for metallurgical and chemical uses.

Based on usage and nominal silicon content, the main varieties of silicon ferroalloys have been 50% ferrosilicon, 75% ferrosilicon, and specialty ferrosilicons. The price trends discussed here are for 50% ferrosilicon, simply referred to as "ferrosilicon" in the following text. Trends for 75% ferrosilicon have been much the same since at least 1980. Of the specialty ferrosilicons, the most important is perhaps magnesium ferrosilicon. For that ferroalloy, Metals Week has not listed a price since 1978, but American Metal Market has published prices with an effective date as recent as July 21, 1995.

The customary basis for quoting prices for silicon materials is in terms of silicon content, so that for the United States the price unit has been cents per pound of contained silicon. On this basis, the silicon units in silicon metal, because of their higher energy content, are more costly than those in ferrosilicon, for which no allowance is made for iron content. From 1959 through 1998, the ratio for the price of silicon contained in metal to the price of silicon contained in ferrosilicon fluctuated considerably, averaging about 1.45 overall.

E&MJ Metal and Minerals Markets and its successors (Metals Week in 1967 and Platt's Metals Week in 1993) are believed to have been the source of most, if not all, of the price data tabulated. In these publications, updating of U.S. producer prices ended about 1991, and their listing was formally suspended in 1996. The price basis throughout has been bulk lots, free on board (f.o.b.) shipping point for producers and f.o.b. warehouse, duty-paid, for dealer quotes for imports. In recent years, the prices in Platt's Metals Week have been exclusive quotations based on canvassing. The price tabulated for silicon metal generally has been for metal with a typical iron content of 1%.

Demand for metallurgical-grade silicon alloys and metal is little determined in the short term by their prices but rather by the level of activity in the steel, ferrous foundry, aluminum, and chemical industries. As a result, prices tend to vary widely with changes in demand and supply. The price versus time curves for silicon and ferrosilicon are quite similar for the period from 1959 through 1998. For both materials, prices rose steeply in 1974 and peaked markedly in 1988 and 1996. Since 1974, prices have grown at a compound annual rate of about 2.2%. This rate is much lower than the general rate of inflation as given by the Consumer Price Index, which advanced during the 1970's at about 8.6% per year and since the early 1980's at about 3.6% per year.

From 1959 through 1969, the price of silicon alloys and metallurgical-grade metal remained reasonably stable. During this period, the domestic producer price fluctuated between 12 and 14.5 cents per pound for ferrosilicon and between 18.1 and 21.9 cents per pound for metal.

Prices began to rise in the early 1970's owing to higher costs of scrap iron, metallurgical-grade coal, and electric power and the cost of newly installed pollution control devices to comply with governmental standards, which became effective in 1975 (Murphy and Brown, 1985). Prices for silicon materials increased sharply after Government controls imposed on ferroalloy prices were lifted in early 1974. Prices increased to 32.5 cents per pound for domestically produced ferrosilicon and to 47 cents per pound for metallurgical-grade metal; these prices were more than double those of 1970. Prices rose steadily from 1977 through 1981 in response to increased demand, rising inflation, and higher energy costs.

Prices peaked in 1988 owing to stronger demands from the aluminum, iron and steel, and silicon-base chemical industries, and by the end of the year, domestic producers were operating at close to capacity (Gambogi, 1990). Increased demand and rising prices persuaded some producers throughout the world to restart existing facilities and to make plans for future expansion. By yearend 1990, however, the then-record high prices of 1988 had declined significantly. The sudden decline in prices was caused mainly by oversupply of material resulting from the reactivation of idle capacity, development of new capacity in South America, and escalation of low-cost imports from China, South America, and the then-U.S.S.R. Consequently, in response to a continuing soft world market, several domestic producers scheduled production cutbacks.

Subsequently a number of domestic producers of silicon materials were alleged to have engaged in price fixing during 1989 through 1991. As a result of the investigation of these charges by the U.S. Department of Justice, two firms pled guilty and received fines in 1995-96 for price fixing of ferrosilicon (Jones, 1998). In 1997, a third firm was found guilty of price fixing of ferrosilicon (Megregian, Babbitz, and Kress, 1998).

In the 1990's, prices for silicon materials were influenced by the imposition of protective tariffs. Starting in 1980, imports of silicon metal and silicon ferroalloys captured an increasingly large share of the U.S. market, with a resultant decline in use of U.S. productive capacity. By the late 1980's, domestic producers had petitioned the U.S. Department of Commerce and the U.S. International Trade Commission for relief against alleged dumping of silicon metal imports from Argentina, Brazil, and China. In mid-1991, the two agencies concluded their investigations and made affirmative determinations that resulted in imposition of antidumping duties. For ferrosilicon, a similar sequence of events resulted in the imposition of antidumping duties in 1993-94 for a number of foreign sources. In subsequent years, at least some of these duties have been the subject of annual administrative reviews and court challenges that led, in certain cases, to revisions of the duties.

The 1996 price peaks for ferrosilicon and silicon metal, which are the highest on record, appeared to have been related to supply-demand conditions. These peaks, as well as those in 1988, roughly coincided with upturns in world steel production indicating a period of strong demand. Prices subsequently decreased in 1998, at least partly as a result of the deteriorating economic conditions in Asia and Russia.

References Cited

Dosaj, Vishu, 1997, Silicon and silicon alloys—Chemical and metallurgical, *in* Kroschwitz, J.I., and Howe-Grant, Mary, eds., Kirk-Othmer encyclopedia of chemical technology (4^{th} ed.): New York, John Wiley & Sons, v. 21, p. 1104-1122.

Jones, T.S., 1998, Silicon, *in* Minerals Yearbook 1996: U.S. Geological Survey, v. I, p. 783-791.

Gambogi, Joseph, 1990, Silicon, *in* U.S. Bureau of Mines 1988 Minerals Yearbook, v. I, p. 845-853.

de Linde, J.P., 1995, Ferroalloy markets, *in* Tuset, J.K., Tveit, H., and Page, I.G., eds., INFACON 7—Proceedings of the Seventh International Ferroalloys Congress, Trondheim, Norway, June 11-14, 1995: Trondheim, Norwegian Ferroalloy Research Organization, p. 39-62.

Megregian, S.S., Babbitz, Todd, and Kress, Carl, 1998, Antitrust and trade developments in the metals and mining industries: Ryan's Notes 1998 Ferroalloy Conference, Boca Raton, FL, October 25-27, 1998, handout of talk presented, unpaginated.

Murphy, G.F., and Brown, R.E., 1985, Silicon, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 713-728.

Annual Average 50% Ferrosilicon Price

(Cents per pound contained silicon[1])

Year	Price	Year	Price	Year	Price	Year	Price
1959	14.5	1969	13.5	1979	38.8	1989	49.6
1960	14.5	1970	13.6	1980	39.8	1990	42.4
1961	14.5	1971	15.3	1981	41.5	1991	38.3
1962	14.5	1972	15.0	1982	41.4	1992	36.9
1963	14.5	1973	18.5	1983	37.1	1993	40.8
1964	14.5	1974	33.0	1984	41.2	1994	43.9
1965	12.0	1975	32.5	1985	37.5	1995	57.9
1966	12.6	1976	33.5	1986	35.6	1996	64.0
1967	12.6	1977	33.5	1987	38.5	1997	54.8
1968	13.0	1978	34.5	1988	52.1	1998	52.1

Annual Average Silicon Metal Price

(Cents per pound[1])

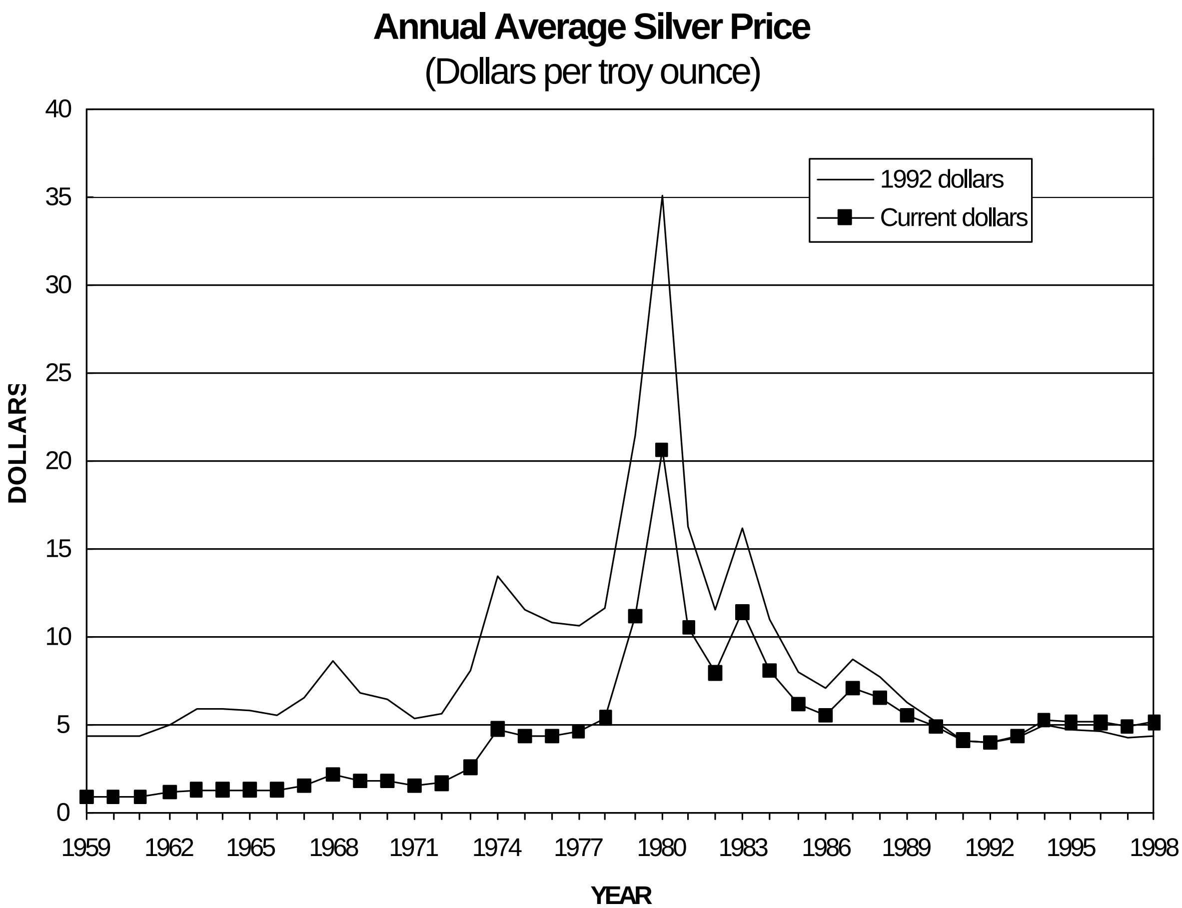
Year	Price	Year	Price	Year	Price	Year	Price
1959	21.4	1969	20.1	1979	53.7	1989	58.8
1960	21.4	1970	21.5	1980	59.2	1990	54.8
1961	21.4	1971	22.9	1981	61.0	1991	61.5
1962	21.4	1972	25.4	1982	57.4	1992	60.0
1963	19.5	1973	28.4	1983	53.8	1993	66.4
1964	18.2	1974	47.0	1984	60.4	1994	64.1
1965	18.5	1975	43.0	1985	58.8	1995	69.5
1966	18.0	1976	42.5	1986	56.3	1996	89.7
1967	18.1	1977	44.0	1987	58.1	1997	81.4
1968	18.3	1978	54.5	1988	68.7	1998	70.5

[1] To convert to cents per kilogram, multiply by 2.20462.

Note:
1959-66, U.S. producer price, *in* E&MJ Metal and Mineral Markets.
1967-79, U.S. producer price, *in* Metals Week.
1980-93, U.S. dealer import price, *in* Metals Week.
1993-98, U.S. dealer import price, *in* Platt's Metals Week.

Silver

by Henry E. Hilliard



Significant events affecting silver prices since 1958

1950-68	Huge U.S. Government silver holdings largely depleted
1963	Silver Purchase Act and various other legislation repealed; U.S. Treasury authorized to print Federal Reserve Notes, which were not redeemable for silver, for circulating currency
1965	Silver eliminated from all U.S. coins except the half dollar, which has its silver content reduced from 90% to 40%
1967	Announcement by U.S. Government that all silver coins would be withdrawn from circulation
1968	Redemption of silver certificates for silver could only be made until June 24; thereafter, silver certificates would be exchanged for Federal Reserve Notes
1979-80	Attempt to corner the silver market
1985	U.S. Mint authorized to begin minting a silver bullion coin

Silver has been used for thousands of years as ornaments and utensils, for trade, and as the basis for many monetary systems. Of all the metals, pure silver has the whitest color, the highest optical reflectivity, and the highest thermal and electrical conductivity. Also, silver halides are photosensitive. Owing to the above properties, silver has many industrial applications, such as in mirrors, electrical and electronic products, and photography, which is the largest single end use of silver. Silver's catalytic properties make it ideal for use as a catalyst in oxidation reactions; for example, the production of formaldehyde from methanol and air, catalyzed by silver screens or crystallites containing a minimum 99.95 weight-percent silver (Butts and Coxe, 1967, p. 1-15).

The most common occurrences of silver are in association with base metals and other precious metals. About 75% to 80% of the silver mined today is produced as a byproduct of mining operations directed mainly at the production of copper, gold, lead, or zinc. A large part of silver production is, therefore, relatively insensitive to the price of silver.

There are two types of markets for silver—physical markets and futures exchanges. It is possible for these markets to overlap if the buyers of futures contracts take delivery of silver metal when the contracts mature. A notable example of this was in the early 1980's when two buyers and their associates took delivery of millions of ounces of silver when their futures contract matured. Physical markets are operated by bullion dealers, banks, and commodity dealers. Silver is bought from mines and refineries and sold to consumers and brokers to supply industrial and investment demand. The London Bullion Market, which had its origins in the 17th century, was the leading physical market until about 1960 when it was overtaken in importance by the New York Market. The London Market fixes a daily price, at which all orders to buy or sell silver can be matched. The New York Market price for silver is the Handy & Harman quote for unfabricated silver, which the company announces daily at noon. That is the lowest price at which offers can be obtained by Handy & Harman for silver in commercial bar form. The Handy & Harman price and the London fixing are for 99.9 %-pure silver.

Prior to World War II, the major uses for silver, other than in coinage, were for jewelry and sterlingware. During the war, however, technological advances were made in electronics and photography. After the war, this technology was used to develop new consumer products. As the demand for consumer goods increased, so did the demand for silver, and, as a result, the market price increased. The higher market price, however, did not result in increased mine production. The Silver Act of 1946 authorized the U.S. Treasury to purchase domestically mined silver at $0.905 and to sell its silver holdings at $0.91 per ounce. Through the first half of the 1950's, the market price remained below $0.91, so domestic mine operators sold their silver to the Treasury. In the second half of the 1950's, the continued increase in industrial demand for silver and static mine production resulted in the market price increasing to $0.91 and Treasury silver sales being the largest source of silver for industrial consumers (National Academy of Sciences, 1968).

In the late 1950's and early 1960's, a second component was added to the demand side of the supply-demand equation—the investor-speculator. The silver certificates authorized by the Silver Purchase Act of 1934 were redeemable for silver held by the Treasury. At a market price above $1.29, a profit could be made by redeeming the silver certificates, receiving 0.77 ounce of silver from the Treasury, and then selling the silver. In addition, at a market price above $1.38, a profit could be made by melting U.S. circulating coinage for its silver content. Realizing that it could not continue to supply industrial consumers with silver, mint coinage, and maintain a stock of silver for redemption of silver certificates, the Government began a program to demonetize silver. Public Law 88-36, which repealed the Silver Purchase Act of 1934 and authorized the printing of Federal Reserve Notes not redeemable in silver, was passed in mid-1963. The Coinage Act of 1965 eliminated the use of silver in dimes and quarters and reduced the silver content of half dollars. In 1967, silver coins were withdrawn from circulation, and holders of silver certificates were given 1 year, until June 24, 1968, to redeem the certificates for silver (Silver Institute, 1990, p. 6-7).

With the ending of the relation between silver and the U.S. monetary system in 1968, investor-speculator activities and industrial demand became the main determinants of movement in the silver market price. From 1968 through 1971, the price declined, owing, in part, to an economic recession in the United States and an attempt by the Government to stabilize the price of silver. From 1972 through 1975, the average price increased, owing to such factors as the devaluation of the U.S. dollar and an embargo of oil exports by the Organization of Petroleum Exporting Countries. Prices also increased from 1976 through 1980. Analysts attributed this 5-year period of higher average prices to such factors as a high domestic inflation rate combined with slow growth in U.S. economic activity, another "oil crisis," a U.S. economic recession that began in 1979, and an attempt by a group of investors to "corner" the silver market (Roskill Information Services Ltd., 1984, p. 190-203). By early 1981, the silver market was beginning to adjust to the upward pressure placed on prices in 1979 through 1980. Owing to worldwide recession and reaction to higher silver prices, industrial demand for silver was in decline, and investment demand for silver fell sharply. Supply also fell as the surge of secondary recovery from old scrap and coin remelt subsided. Silver prices reached a cyclical low of $4.88 per ounce in June 1982, 10% of the $48 peak 30 months earlier. Because of panic in the financial markets and fear of inflation, investment demand for silver increased sharply in late 1982 and the first quarter of 1983. This influx of investor buying helped push silver prices from the low of $4.88 in June 1982 to a peak of $14.74 in February 1983. In March, this rapid rise in price (the price nearly tripled in 9 months) was reversed as investors took profits, industrial users developed new methods that reduced their per-unit use of silver and substituted lower priced materials for silver. Prices recovered during the summer, but the trend was downward from the fourth quarter of 1983 through 1986. Lower prices discouraged the secondary recovery of silver and forced less-efficient mines to close. On the demand side, lower prices relieved the pressure to use less silver or to use lower cost substitutes for silver in products. After starting 1987 at $5.44 per ounce, prices reached a low of $5.36 on January 7. Prices increased though the remainder of the year, reaching a high of $10.20 on April 27 but closing out the year at $7.20. The annual average price for 1987 was $7.01 per ounce, the first increase in 4 years.

Owing to various market and economic conditions, the annual average price of silver declined from $7.01 per ounce in 1987 to a low of $3.94 in 1992 before increasing slightly to $4.30 in 1993. Prices began to increase in the first quarter of 1994, reaching $5.75 per ounce on March 28, 1994. The upward momentum was caused by political unrest in Mexico, the world's largest producer, and reports of large shipments to India. In April, prices slipped rapidly to around $5.00 per ounce as Indian demand slowed and large supplies from Russia and other East European countries appeared in the market. In September, prices increased again to $5.71 per ounce before collapsing to $4.90 on November 30. Prices in 1995 were not quite as volatile as in 1994, but the downward trend that began in April 1994 continued (Silver Institute, 1995, p. 8-15).

For centuries, the price of silver has been closely coupled with the price of gold, but the demonetization of both metals in much of the world has weakened the link. Throughout most of 1996, the price of silver was adversely affected by the poor performance of gold. Toward the end of 1996, however, the price of silver began to deviate from the price of gold, owing to investors' and speculators' adoption of distinctly different positions in the two markets. This decoupling process continued into 1997, and although the gold market continued to influence the price of silver, the trend in the metals' prices indicated that a total decoupling may have been in the making.

In the first 2 months of 1997, the price of gold fell by 2%. Initially, the price of silver followed gold down to a 2-year low of $4.65 per ounce in the first week of January. During the next 6 weeks, the price began to rebound, rising by 14% to reach $5.32 on March 3. The higher price proved to be unsustainable as technical selling entered the market. Silver prices dropped to $4.64 on April 29. Early in July, gold fell to $315, a 12-year low. Subsequently, silver fell to $4.21 on July 17, its low for the year. On October 27, the Dow Jones Industrial average dropped more than 500 points, Asian equity markets were in turmoil, and gold fell to a 12-year low of $308 per ounce. Surprisingly, silver held its ground, closing above $4.60. After the U.S. Thanksgiving holiday, gold fell below $300 while silver climbed to more than $5.30. By the 1st of December, the price of silver had increased by $0.53, to $5.83, as above-ground stocks of silver declined to the lowest level in many years. The price of silver reached its high for 1997 on December 24 at $6.24 and closed out the year at $5.95 per ounce; the price ratio of silver to gold was 48:1.

Silver prices averaged $4.94 per ounce in the fourth quarter of 1998, down from $6.25 in the first quarter. In February, prices rose to a 9-year high after it became known that a U.S. investment firm had purchased 3,978 metric tons of the metal. The investment firm made its first purchase in July 1997 when the price was below $4.50 per ounce. The price rose to a high of $7.13 in the first week of February before falling back to $6.15 by the end of the month. Prices fell even further in May, June, and July to a low of about $4.70 at the end of August. Prices traded within the narrow range $5.203 to $4.963 for the remainder of the year and closed out the year at $5.05 per ounce.

References Cited

Butts, A., and Coxe, C.D., 1967, Silver—Economics, metallurgy, and use: Princeton, NJ, D.Van Nostrand, 488 p.

National Academy of Sciences, 1968, Trends in usage of silver: National Academy of Sciences Publication MAB-24, 15 p.

Roskill Information Services Ltd., 1984, The economics of silver (3d ed.): London, Roskill Information Services Ltd., 203 p.

Silver Institute, 1990, World silver survey, 1950-1990: Washington, DC, Silver Institute, 81 p.

———1995, World silver survey, 1995: Washington, DC, Silver Institute, 64 p.

Annual Average Silver Price

(Dollars per troy ounce[1])

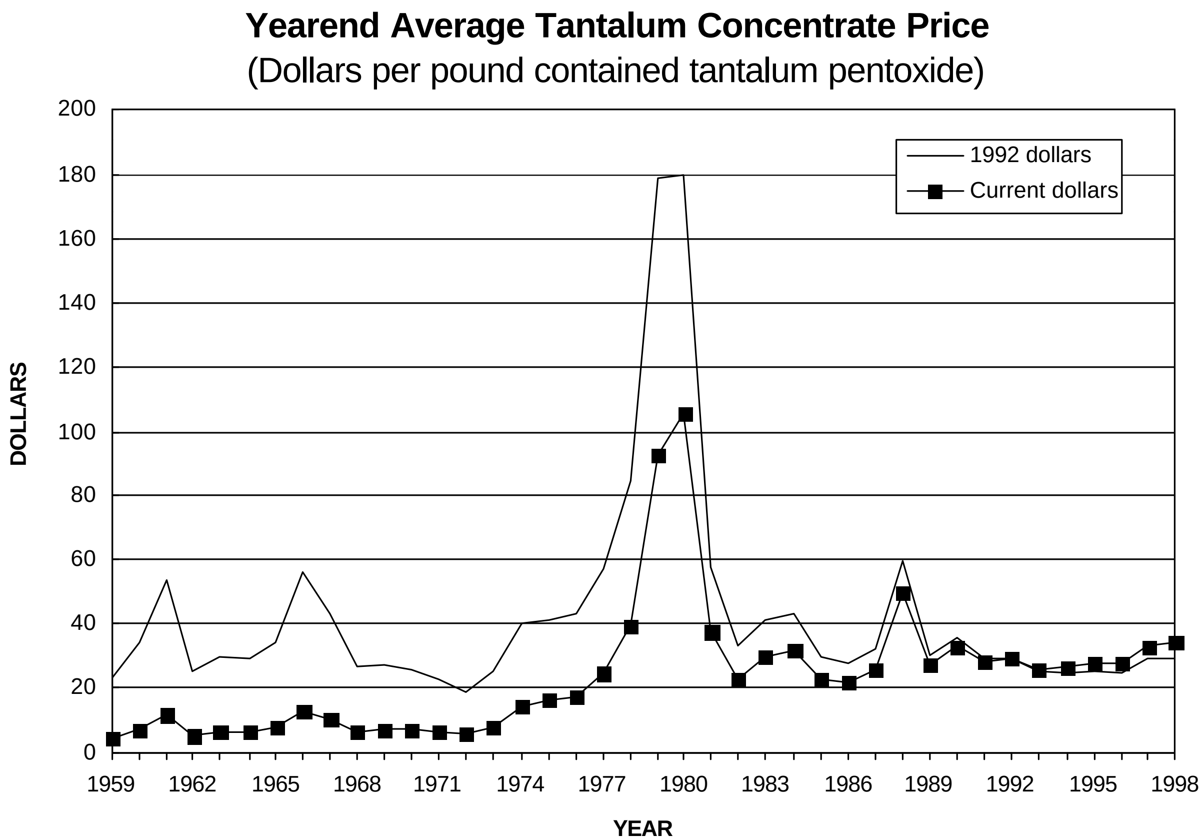
Year	Price	Year	Price	Year	Price	Year	Price
1900	0.62	1925	0.69	1950	0.74	1975	4.42
1901	0.60	1926	0.62	1951	0.89	1976	4.35
1902	0.53	1927	0.57	1952	0.85	1977	4.62
1903	0.54	1928	0.58	1953	0.85	1978	5.40
1904	0.58	1929	0.53	1954	0.85	1979	11.09
1905	0.61	1930	0.38	1955	0.89	1980	20.63
1906	0.67	1931	0.29	1956	0.91	1981	10.52
1907	0.66	1932	0.28	1957	0.91	1982	7.95
1908	0.53	1933	0.35	1958	0.89	1983	11.44
1909	0.52	1934	0.48	1959	0.91	1984	8.14
1910	0.54	1935	0.64	1960	0.91	1985	6.14
1911	0.54	1936	0.45	1961	0.92	1986	5.47
1912	0.62	1937	0.45	1962	1.09	1987	7.01
1913	0.61	1938	0.43	1963	1.28	1988	6.53
1914	0.56	1939	0.39	1964	1.29	1989	5.50
1915	0.51	1940	0.35	1965	1.29	1990	4.82
1916	0.67	1941	0.35	1966	1.29	1991	4.04
1917	0.84	1942	0.38	1967	1.55	1992	3.94
1918	0.98	1943	0.45	1968	2.14	1993	4.30
1919	1.12	1944	0.45	1969	1.79	1994	5.29
1920	1.02	1945	0.52	1970	1.77	1995	5.15
1921	0.63	1946	0.80	1971	1.55	1996	5.19
1922	0.68	1947	0.72	1972	1.68	1997	4.89
1923	0.65	1948	0.74	1973	2.56	1998	5.10
1924	0.67	1949	0.72	1974	4.71		

[1] To convert to dollars per kilogram, multiply by 32.1507.

Note:
1900-74, New York price of 99.9%-pure silver, *in* Silver, U.S. Bureau of Mines Minerals Yearbook 1974.
1974-93, New York price of 99.9%-pure silver, *in* Metals Week (through June 14, 1993).
1993-98, New York price of 99.9%-pure silver, *in* Platt's Metals Week.

Tantalum

by Larry D. Cunningham



Significant events affecting tantalum prices since 1958

1979-80	Tantalum price accelerates to record levels
1982	Industry's accumulation of large tantalum material inventories
1988	Drawdown of tantalum material inventories by processors
1990	Purchase of tantalum materials for the National Defense Stockpile (NDS)
1991	Long-term tantalum supply contracts between major producer and processors
1998	Sales of tantalum minerals from the NDS

Tantalum is a refractory metal that is easily fabricated, has a high melting point, is highly resistant to corrosion by acids, and is a good conductor of heat and electricity. Tantalum's first commercial usage was as filament material in incandescent electric lamps in the early 1900's (Miller, 1959). Currently, the major use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. Alloyed with other metals, tantalum is also used in making carbide tools for metalworking equipment and in the production of superalloys for jet engine components. Substitutes, such as aluminum, rhenium, titanium, tungsten, and zirconium, exist for tantalum but are usually made at either a performance or economic penalty.

Tantalum mineral concentrates (tantalite) are the main primary source of tantalum, and the price for tantalum products is affected most by events in the supply of and demand for tantalite. The price for tantalum metal products generally follows the pattern for that of tantalum concentrates. The price for tantalum metal products is also affected by the size of the order/contract and material specification. The yearend 1998 price for tantalum concentrates was about \$41.50 per pound of contained tantalum compared with the most recent industry source for the selling price for the following tantalum metal products (per pound of contained tantalum)—vacuum-grade metal for superalloys, $75 to $95; sheet, $100 to $150; capacitor-grade metal powder, $135 to $240; and capacitor-grade wire, $180 to $250.

Australia is the major producer of tantalum mineral concentrates. U.S. tantalum-mining has not been significant since 1959. The United States satisfies its tantalum requirements primarily by importing tantalum concentrates from Australia and Brazil and quantities of metal and powders from various countries. Many of the applications for tantalum are either directly or indirectly defense related because of its use in the aerospace, communications, energy, and transportation industries. Thus, tantalum is classified as critical and strategic, and over the years, various tantalum materials have been purchased for the NDS.

A significant activity during the 1950's was the U.S. Government's worldwide program for the purchase of about 6,800 metric tons (t) of combined columbium and tantalum oxides contained in columbium-tantalum ores and concentrates. The purchase program was terminated in 1958 (Cunningham, 1985a, b). The program, which was initiated to encourage increased production of columbium-tantalum ores and concentrates of domestic and foreign origin, largely governed the market price for tantalum ores and concentrates. It also resulted in the discovery of large low-grade domestic and foreign deposits of tantalum minerals. The program, however, was less successful in developing domestic tantalum mineral production. The low grade of the discoveries precluded their development at current or expected future prices.

By 1960, tantalum demand for use in capacitors, high-temperature alloys, corrosion-resistant chemical and nuclear applications, machine cutting tools, and aerospace applications had increased substantially. Price peaks in 1961 and 1966 were occasioned by a sudden increase in demand for tantalum, which outstripped the supply, thus driving prices up. Increased demand stimulated tantalum production. After a leveling off of demand, however, overproduction ensued, resulting in a decline in tantalum prices. The higher cost operations, which had opened in response to the increased demand, closed down, and supply reverted back to customary levels.

The 1970's was a decade of increasing tantalum demand, ore shortages, escalating prices, and substitution. The record price levels during this period were attributed, in part, to a state of panic buying influenced by anticipated increases in tantalum demand amidst concerns of shrinking world tantalum supply. As demand for tantalum increased, some processors foresaw the coming production shortfall and began to stockpile inventories. The net effect was very competitive buying of tantalum feed materials to meet customer needs with associated spiraling prices. The high prices brought about substitution for tantalum and more-widespread search for and development of new tantalum supply sources.

In 1979 to 1980, the price for tantalum source materials exploded. Tantalum source material production could not meet market demand, resulting in sustained inventory reduction. With optimistic forecasts of market growth, processors found themselves locked into a bidding contest for available tantalum source materials. By yearend 1982, large high-cost inventories of tantalum source materials were accumulated as a hedge against perceived future shortages.

During the late 1970's and early 1980's, processors, faced with runaway source material prices, were forced to pass along a large part of the price increases to end users, which had the effect of a decrease in the use of tantalum. Because of escalating tantalum prices, consumers began to substitute alternate products, to decrease tantalum content in products, and to increase recycling to substitute for virgin tantalum products. These demand-reducing activities were accelerated by the price volatility and resulted in increased stock inventories. In the consumer electronics sector, tantalum was designed out of some circuits and replaced primarily with aluminum-bearing electronic components.

The tantalum concentrate price was at its highest level at midyear 1980, about $118 per pound of contained tantalum oxide. By yearend 1980, prices began declining and, by yearend 1986, were the lowest since yearend 1976. The downturn in prices was hastened by weak tantalum demand and the overhang of the large inventories of tantalum source materials built up during the early 1980's. Industry sources estimated that these inventories were as high as about 5,000 t of contained tantalum oxide in 1982 (Tantalum-Niobium International Study Center, 1986). By 1988, price increases for tantalum source materials were again of major concern in the tantalum industry. The yearend 1988 price for tantalite ore, $50 per pound of contained tantalum oxide, nearly doubled the yearend 1987 price. The price escalation was attributed to increased demand for tantalum source materials following a drawdown of the tantalum inventories that had been built up.

The price for tantalum ore continued its cyclic pattern through 1993; thereafter, the price was steady with some moderate increases. From 1990 to 1998, the demand for tantalum remained strong, with increased consumption in most years. Demand was robust in the electronics sector for tantalum capacitors in such products as portable telephones, pagers, video cameras, personal computers, and automotive electronics. Overall growth in this sector, however, was slowed owing to the industry's continued emphasis on the miniaturization of electronic components, resulting in less tantalum used per unit.

In 1990, the Defense Logistics Agency (DLA) purchased about 91 t of tantalum oxide contained in tantalum minerals for the NDS. The price of the material purchased ranged from about $36.62 to $37 per pound of contained tantalum oxide. At about the time of material purchase, the price quote for tantalite ore ranged from about $27 to $28.50 per pound of contained tantalum oxide (Cunningham, 1993).

In 1991, Australia's largest tantalum minerals producer entered into contracts with the world's two largest tantalum processors for the long-term supply of tantalum ore. Under the terms of the contracts, tantalum ore would be supplied to the processors at fixed volumes and prices for a period of 5 years (Gwalia Consolidated Ltd., 1991). Subsequently, the producer contracted with the processors for the sale of all its budgeted production of tantalite ore through 2003 (Sons of Gwalia Ltd., 1998).

In 1998, the DLA initiated the sale of tantalum minerals from the NDS. In September and December, the DLA sold about 90 t of tantalum contained in tantalum minerals valued at about $11.6 million (Defense National Stockpile Center, 1998a, b). The overall average unit price for the sales, about $48 per pound of contained tantalum oxide, was significantly higher than that being quoted for tantalum minerals, about $34 per pound of contained oxide.

References Cited

Cunningham, L.D., 1985a, Columbium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 185-196.

———1985b, Tantalum, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 811-822.

———1993, Columbium and tantalum, *in* Minerals Yearbook 1990, v. I: U.S. Bureau of Mines, p. 339-357.

Defense National Stockpile Center, 1998a, Stockpile awards tantalum minerals: Fort Belvoir, VA, Defense National Stockpile Center news release, September 24, 1 p.

———1998b, Stockpile awards tantalum minerals: Fort Belvoir, VA, Defense National Stockpile Center news release, December 4, 1 p.

Gwalia Consolidated Ltd., 1991, Gwalia Consolidated Ltd. annual report 1991: West Perth, Western Australia, Gwalia Consolidated Ltd., 63 p.

Miller, G.L., 1959, Tantalum and niobium, *in* Metallurgy of the rarer metals: London, Butterworths Scientific Publications, p. 2.

Sons of Gwalia Ltd., 1998, Sons of Gwalia Ltd. annual report 1998: West Perth, Western Australia, Sons of Gwalia Ltd., 92 p.

Tantalum-Niobium International Study Center, 1986, Perspectives on the development of the tantalum industry: Tantalum-Niobium International Study Center No. 48, October, p. 2-5.

Yearend Average Tantalum Concentrate Price
(Dollars per pound contained tantalum pentoxide[1])

Year	Price	Year	Price	Year	Price	Year	Price
1940	2.50	1955	3.40	1970	7.13	1985	22.75
1941	2.25	1956	3.40	1971	6.50	1986	21.75
1942	1.93	1957	3.40	1972	5.63	1987	26.00
1943	2.50	1958	3.40	1973	8.00	1988	50.00
1944	2.50	1959	4.80	1974	14.00	1989	27.00
1945	2.50	1960	7.25	1975	16.00	1990	33.00
1946	NA	1961	11.50	1976	17.63	1991	28.25
1947	2.50	1962	5.50	1977	24.63	1992	29.00
1948	2.38	1963	6.50	1978	39.50	1993	26.00
1949	2.25	1964	6.50	1979	92.50	1994	26.25
1950	2.25	1965	7.75	1980	105.50	1995	27.75
1951	2.25	1966	13.00	1981	37.50	1996	27.75
1952	3.40	1967	10.25	1982	22.50	1997	33.00
1953	3.40	1968	6.50	1983	29.50	1998	34.00
1954	3.40	1969	7.13	1984	32.00		

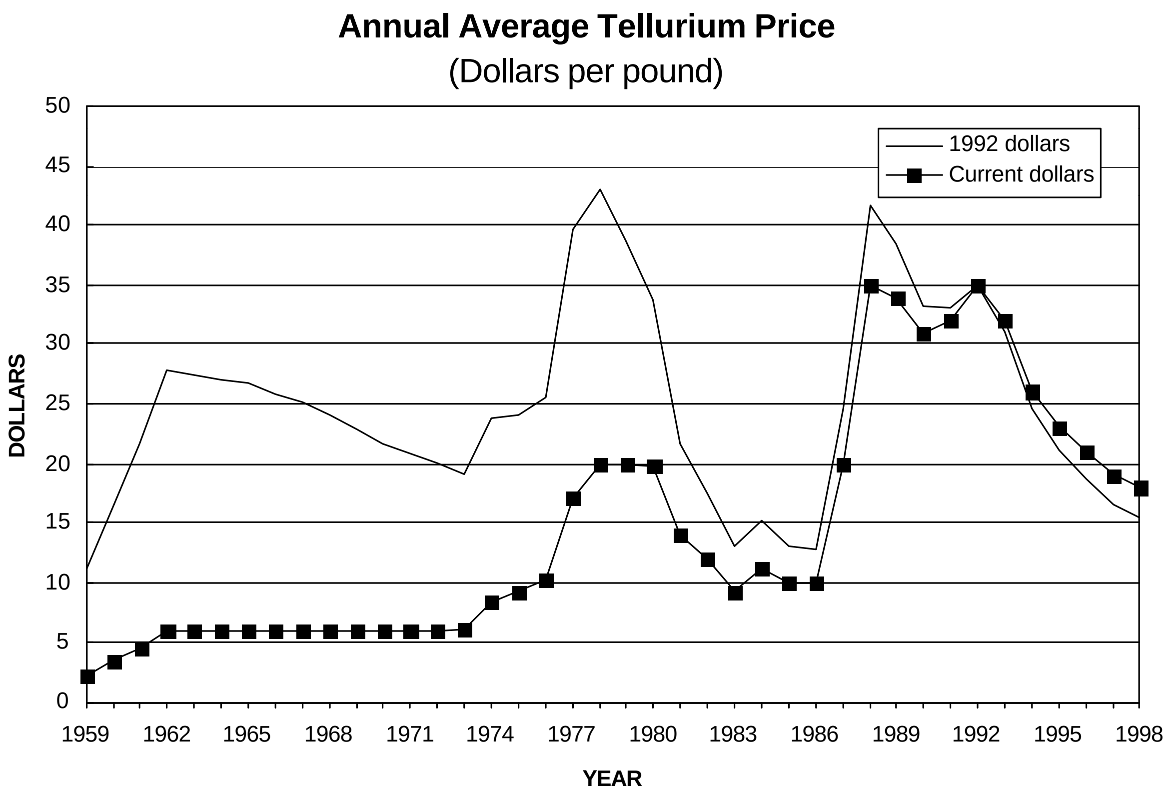
NA Not available
[1] To convert to dollars per kilogram, multiply by 2.20462.

Sources: E&MJ Metal and Mineral Markets (E&MJ M&MM) (1940-41), U.S. Government purchase (1942-43), E&MJ M&MM (1944-51) U.S. Government purchase (1952-58), E&MJ M&MM (1963-66), Metals Week (1967-92), and Platt's Metals Week (1993-98). Prices for the period 1959-62 were published by the U.S. Bureau of Mines, but origin is unknown.

(This page intentionally left blank.)

Tellurium

by Robert D. Brown, Jr.



Significant events affecting tellurium prices since 1958

1959-62	Price rise coincides with growth in demand for thermoelectric devices
1962-73	Price remains invariant, high inventories, demand averages about 200,000 pounds per year, free-machining steel becomes dominant use
1973-80	Price controls during 1973 lifted in December, annual demand doubles stimulated by catalytic uses, reduced production from fall-off in copper production and tellurium content of ores, speculation affects prices
1980-86	Demand plummets, major catalytic use ends and consumer inventories return to marketplace, depressed domestic steel industry
1987-88	Demand for free-machining steel increases, reduced tellurium production, inventory depletion, price doubles
1989-93	Domestic and world demand weakens; production declines faster than consumption, resulting in a moderate fall-off in stocks and sustained high prices
1993-98	Oversupply situation develops as demand decreases faster than production, high-efficiency cadmium telluride solar cells fail to increase demand significantly

Tellurium is a relatively rare element, tied for 71st place with platinum and palladium in rank of crustal abundance. It is in the same chemical family as oxygen, sulfur, selenium, and polonium: oxygen and sulfur are nonmetals, polonium is a metal, and selenium and tellurium are semiconductors, although they are often referred to as metals when in elemental form. Tellurium was first identified in 1782 in Transylvanian gold ore (Azimov, 1994, p. 260). For more than a century, tellurium was an experimental material having little commercial value. Small quantities of tellurium were produced from anode muds generated during the electrolytic refining of copper. World tellurium production is still mainly a byproduct of copper processing. This byproduct nature has led to supply/demand imbalances that have had significant impacts on price (Elkin, 1985, p. 1,158).

By 1920, a small commercial demand had developed for tellurium in electronic equipment, electroplating, and chemical production (Heikes, 1922). Despite a consumption of only about 1,000 pounds per year, production of tellurium rose to more than 11,000 pounds per year by 1929 following the rise in electrolytic copper production (Heikes, 1933).

Additional significant commercial uses for tellurium were developed during the 1930's, and demand and production rose sharply, with production exceeding demand. Major uses included the purification of zinc-refining solutions, alloying with lead to improve its tensile strength and corrosion resistance, and rubber compounding to improve resistance to aging and abrasion.

Production and demand for tellurium fluctuated markedly between 1940 and 1958, but generally supply outstripped demand. A demand peak in 1941, attributed to World War II, corresponded to the increased use of tellurium as a carbon stabilizer in cast iron, and a peak in 1951-52, attributed to the Korean Conflict, corresponded to tellurium's expanded use in copper alloying. Price-driven substitution of tellurium for selenium in some applications helped boost demand from 1955 through 1958.

Beginning in 1959, the byproduct nature of tellurium, with production being essentially independent of demand, and the small and specialized uses of tellurium combined to create volatility in the market. Prices rose from \$1.70 per pound in 1958 to \$6.00 per pound in 1962 before stabilizing at the higher level (Lansche, 1963, p. 148). This period was marked by increased shipments and speculative interest. The rise in price also corresponded to the growth in thermoelectric applications for tellurium, as well as its use in free-machining steel, which became the dominant use (Holowaty, 1964; Rathke and Morgan, 1965).

Prices remained stable at about \$6.00 per pound until the early 1970's when growing demand for ferrous alloy applications was followed by a rapid growth in the catalytic applications of tellurium in petrochemicals processing. When a large domestic consumer of tellurium catalyst closed its plant in late 1979, reducing demand and returning large quantities of consumer stocks to the market, and tellurium consumption in steel fell abruptly 2 years later as steel production slumped, tellurium prices fell sharply from 1980 through 1983. Production also decreased owing to a decline in the tellurium content of domestic copper ores (Wills, 1982). By 1983, only one domestic producer of tellurium remained. Domestic production decreased in 1985 when imported high-tellurium copper concentrates were no longer processed. By 1987, with increasing demand in free-machining steels and low production of tellurium, inventories became critically low, and prices rose substantially and remained fairly stable until 1993, when a steady decline began that lasted through 1998. During this period, an oversupply situation developed owing to the fact that although production decreased, demand decreased more (Brown, 1998, p. 13-17).

The use of high-purity tellurium in cadmium telluride solar cells is very promising. Some of the highest efficiencies for electric power generation have been obtained by using this material, but this application has not yet caused demand to increase significantly.

Metal prices can be affected by national and international regulations. Tellurium scrap and that of certain other metals were banned from shipment from Europe to African, Pacific, and Caribbean (APC) nations in response to Basel Convention deliberations in 1997 which attempted to stop the "dumping" of toxic materials in APC countries (Metal Bulletin, 1997). This was in spite of many cases where APC countries were already importing scrap for processing by their metal industries, not merely for disposal. Actually, tellurium metal is not toxic. It was removed from the U.S. Environmental Protection Agency's most-hazardous materials list when its insolubility was pointed out to agency officials (U.S. Environmental Protection Agency, 1996).

Commercial-grade tellurium is usually marketed as minus 200-mesh powder but is also available as slabs, ingots, sticks, or lumps.

References Cited

Azimov, Isaac, 1994, Azimov's chronology of science and discovery: New York, Harper Collins Publishers, 800 p.

Brown, R.D., Jr., 1998, Selenium tellurium supply-demand relationship: International Symposium on the Uses of Selenium and Tellurium, 6th, Scottsdale, AZ, May 10-12, 1998, Proceedings, p. 13-17.

Elkin, E.M., 1985, Tellurium and tellurium compounds, *in* Kirk-Othmer concise encyclopedia of chemical technology: New York, John Wiley, 1318 p.

Heikes, V.C., 1922, Selenium and tellurium, *in* Mineral resources of the United States 1920: U.S. Geological Survey, pt. I—Metals, p. 71-72.

———1933, Arsenic, bismuth, selenium, and tellurium, *in* Mineral resources of the United States 1930, Part I—Metals: U.S. Bureau of Mines, p. 25-30.

Holowaty, M.O., 1964, Free-machining steels: U.S. Patents 3, 152,889 and 3,152,890, assigned to Inland Steel Co., October 13.

Lansche, A.M., 1963, Tellurium, *in* Minerals and Metals Commodity Data Summaries: U.S. Bureau of Mines, p. 148-149.

Metal Bulletin, 1997, EU environmental ministers move to extend export ban: Metal Bulletin, no. 8239, December 22, p. 12.

Rathke, A.E., and Morgan, A.T., 1965, Free-machining steels: U.S. Patent 3, 169,857, assigned to Inland Steel Co., February 16.

U.S. Environmental Protection Agency, 1996, Rules and regulations: Federal Register, v. 61, no. 89, May 7, p. 20477.
Wills, Frank, 1982, Inventories grow despite lower output of this copper byproduct: Engineering and Mining Journal, v. 183, no. 3, March, p. 122-123.

Annual Average Tellurium Price
(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1917	3.00	1938	2.00	1959	2.33	1980	19.77
1918	NA	1939	2.00	1960	3.50	1981	14.00
1919	NA	1940	1.75	1961	4.63	1982	12.00
1920	NA	1941	1.75	1962	6.00	1983	9.25
1921	NA	1942	1.75	1963	6.00	1984	11.25
1922	2.25	1943	1.75	1964	6.00	1985	10.00
1923	2.00	1944	1.75	1965	6.00	1986	10.00
1924	NA	1945	1.75	1966	6.00	1987	20.00
1925	NA	1946	1.75	1967	6.00	1988	35.00
1926	2.02	1947	1.75	1968	6.00	1989	34.00
1927	1.91	1948	1.75	1969	6.00	1990	31.00
1928	1.91	1949	1.75	1970	6.00	1991	32.00
1929	2.07	1950	1.75	1971	6.00	1992	35.00
1930	1.70	1951	1.75	1972	6.00	1993	32.00
1931	2.00	1952	1.75	1973	6.05	1994	26.00
1932	2.00	1953	1.75	1974	8.34	1995	23.00
1933	2.00	1954	1.75	1975	9.28	1996	21.00
1934	2.00	1955	1.75	1976	10.33	1997	19.00
1935	2.00	1956	1.63	1977	17.15	1998	18.00
1936	2.00	1957	1.75	1978	20.00		
1937	2.00	1958	1.70	1979	20.00		

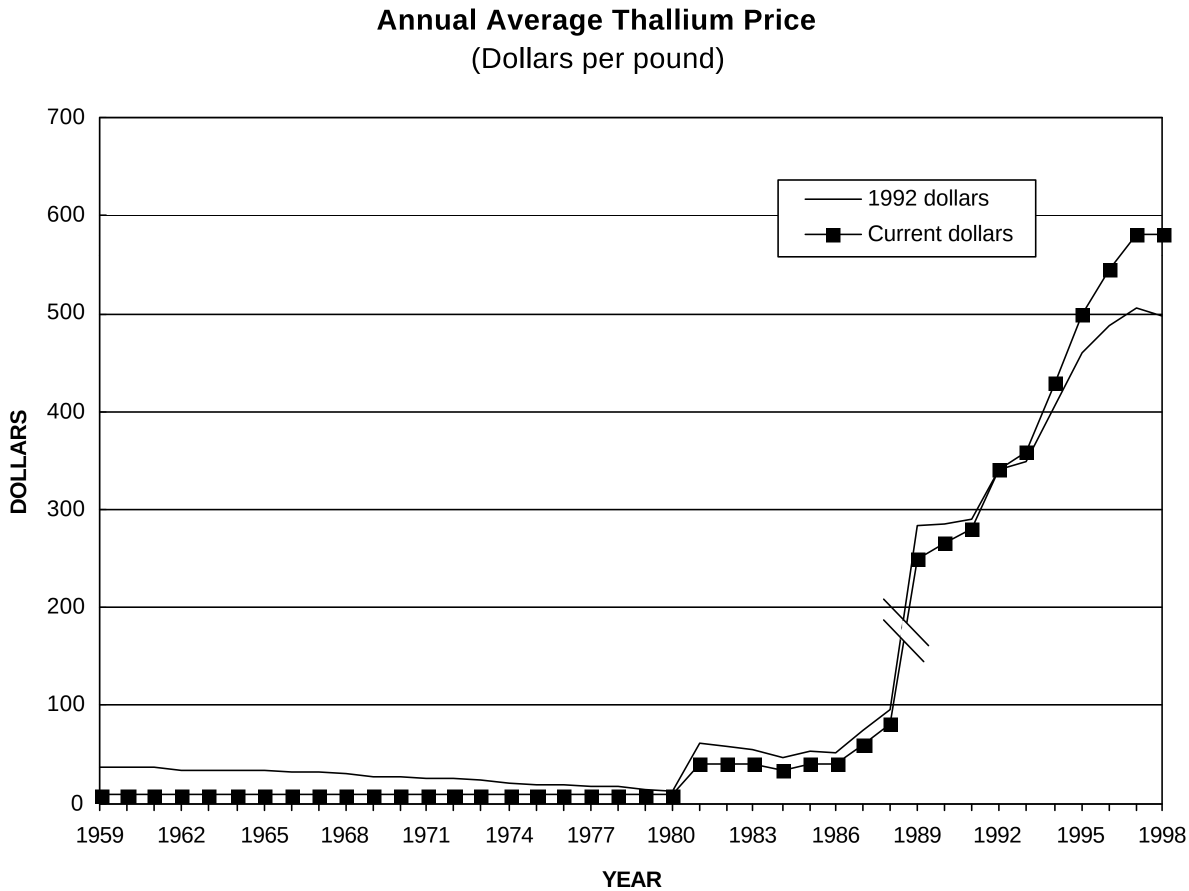
NA Not available
[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:
1917-22, U.S. producer price for 99%-pure tellurium, *in* U.S. Geological Survey Mineral Resources of the United States.
1923-29, Domestic price for 99%-pure tellurium, *in* Engineering and Mining Journal.
1930-36, New York price for 99%-pure tellurium, *in* Engineering and Mining Journal.
1937-39, New York price for 99%-pure tellurium, *in* E&MJ Metal and Mineral Markets.
1940-66, New York price for 99.7%-pure tellurium, *in* E&MJ Metal and Mineral Markets.
1967-80, New York price for 99.7%-pure tellurium, *in* Metals Week.
1981-94, U.S. producer price quotes for 99.7%-pure tellurium, *in* U.S. Bureau of Mines Minerals Yearbook.
1995-98, U.S. producer price quotes for 99.7%-pure tellurium, *in* U.S. Geological Survey Minerals Yearbook.

(This page intentionally left blank.)

Thallium

by Gerald R. Smith



Significant events affecting thallium prices since 1958

1959-73	Continued use for rodenticides and insecticides
1981	Domestic production was terminated; dependence on imports
1989-98	Used in superconductivity research and new medical applications; traditional uses continued

Thallium, a soft, bluish-gray, malleable heavy metal, was discovered by Sir William Crookes in 1861 while he was making spectroscopic determinations for tellurium on residues from a sulfuric acid plant. Although the metal is reasonably abundant in the Earth's crust at a concentration estimated to be about 0.7 part per million, it exists mostly in association with potassium minerals in clays, soils, and granites and, thus, is generally considered to be commercially unavailable in this form. Several thallium minerals, containing 16% to 60% thallium, occur in nature as sulfide or selenide complexes with antimony, arsenic, copper, lead, and silver but are rare and have no commercial importance as sources of this element. The major source of commercial thallium is the trace amounts found in copper, lead, zinc, and other sulfide ores. Thallium is recovered as a byproduct from the flue dust and residues generated during the roasting and smelting steps in the processing of these ores.

From 1912 to 1930, thallium compounds were used extensively for medicinal purposes; for example, in the treatment of ringworm, dysentery, and tuberculosis. The narrow margin between toxicity and therapeutic benefit, however, eventually eliminated the practical use of these compounds. The use of thallium salts as poison for rodents and later as insecticide led to increased use of thallium from 1925 to 1965; significant quantities of the rodenticide were used by the U.S. military to control rat infestation in World War II operations (Lee, 1971; Smith and Carson, 1977).

The postwar price of thallium metal reached $18.00 per pound after the wartime allocation and price control system imposed on thallium chemicals was lifted by the War Production Board in 1946. In 1965, the U.S. Government issued regulations prohibiting the household use of thallium-containing rodent poisons and insecticides because of their extreme toxicity to humans, resulting in a significant decline in thallium consumption. By 1973, all retail sales of these chemicals had been banned in the United States. Although thallium consumption declined sharply as a result of the loss of these markets, the decline was offset to some extent by increases in the uses of thallium in electronic applications, chemical synthesis, and such minor uses as components for solders, low-melting alloys, low-temperature thermometers, and optical glasses. During this period of transition in the end-use sectors, the published domestic producer price remained at $7.50 per pound through 1980. In 1981, ASARCO Incorporated, the only domestic producer of thallium and thallium compounds, stopped production. From 1981 through 1988, the price of thallium metal was based upon information obtained from import dealers. By 1988, thallium prices had risen to $80.00 per pound.

In the 1990's, consumption of thallium metal and compounds has continued in most of the established end uses; for example, semiconductor material for selenium rectifiers, an activator in gamma radiation detection equipment, an electrical resistance component in infrared radiation detection and transmission equipment, a crystalline filter for light diffraction in acousto-optical measuring devices, an alloy with mercury for low-temperature measurements, an addition to glass to increase its refractive index and density, a catalyst or intermediate in the synthesis of organic compounds, and a high-density liquid for sink-float separation of minerals. In addition, research activity has been ongoing to develop high-temperature superconducting materials for such applications as magnetic resonance imaging, storage of magnetic energy, magnetic propulsion, and electric power generation and transmission. Since 1989, numerous patents have been issued for and reports have been published on the preparation of high-temperature superconductor compounds containing thallium. In 1993, one U.S. company joined the International Superconductivity Technology Research Center, a 46-member superconductivity consortium based in Japan. As a member of this consortium, the company now sends two scientists to the Center to conduct research on its newly discovered thallium compounds that superconduct at high temperatures. The use of radioactive thallium compounds for medical purposes in cardiovascular imaging to detect heart disease has also increased steadily since the early 1980's.

With the advent of these newer and potential safe uses for thallium, the demand for higher purity thallium metal, either in research or practical application, has increased. Consistent with the greater need for high-purity thallium and the lack of published or otherwise available producer or dealer quotations for thallium metal of any purity since 1988, the price of thallium metal has been based upon the metal price listed in retail supplier catalogues. The price of 99.999%-pure thallium granules has risen steadily from $250.00 per pound in 1989 to $580.00 per pound in 1998. This price increase, an average of about 15% per year, reflects an increase in the retail price, but this increase is higher than the rate of inflation. To some extent, the price increase is probably the result of a greater demand for high-purity thallium.

References Cited

Lee, A.G., 1971, The chemistry of thallium: Amsterdam, Elsevier, p. 1-4.

Smith, I.C., and Carson, B.L., 1977, Thallium, v. 1 *of* Trace metals in the environment: Ann Arbor, MI, Ann Arbor Science, p. 9-16.

Annual Average Thallium Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1942	10.00	1957	12.50	1972	7.50	1987	60.00
1943	10.00	1958	7.50	1973	7.50	1988	80.00
1944	11.00	1959	7.50	1974	7.50	1989	250.00
1945	12.50	1960	7.50	1975	7.50	1990	265.00
1946	14.00	1961	7.50	1976	7.50	1991	280.00
1947	18.00	1962	7.50	1977	7.50	1992	340.00
1948	15.00	1963	7.50	1978	7.50	1993	360.00
1949	14.00	1964	7.50	1979	7.50	1994	430.00
1950	12.50	1965	7.50	1980	7.50	1995	500.00
1951	12.50	1966	7.50	1981	40.00	1996	545.00
1952	12.50	1967	7.50	1982	40.00	1997	580.00
1953	12.50	1968	7.50	1983	40.00	1998	580.00
1954	12.50	1969	7.50	1984	35.00		
1955	12.50	1970	7.50	1985	40.00		
1956	12.50	1971	7.50	1986	40.00		

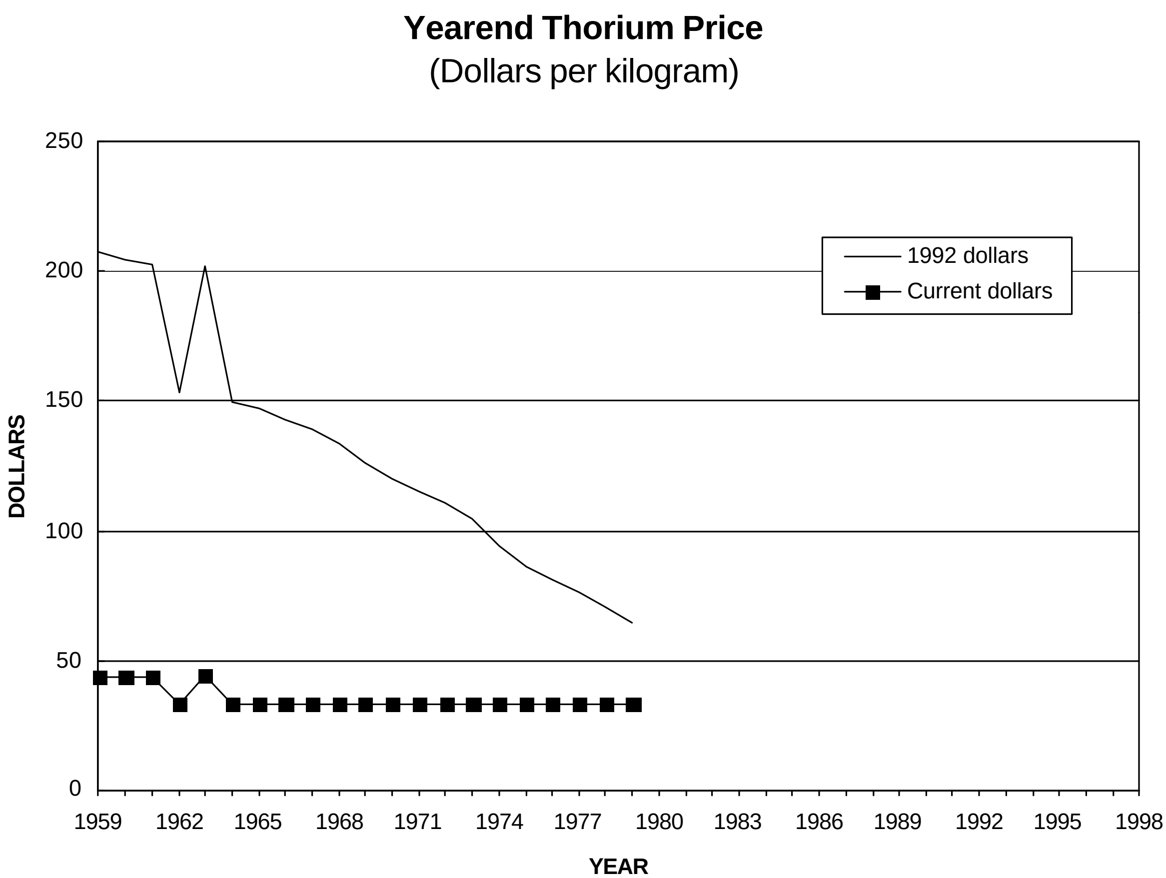
[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:
1942-66, U.S. producer price (99.90% pure thallium), *in* E&MJ Metal and Mineral Markets.
1967-80, U.S. producer price (99.90% pure thallium), *in* Metals Week.
1981-88, Imported dealer price (99.90% pure thallium), private communications with suppliers.
1989-98, Retail supplier price (99.9990% pure thallium granules), *in* Aldrich and Alfa Aesar chemicals catalogues.

(This page intentionally left blank.)

Thorium

by James B. Hedrick



Significant events affecting thorium prices since 1958

1958	Technology improved
1977	Vietnam War increased demand
1980	Decrease in demand, prices for commercial quantities of pure thorium no longer quoted

In 1828, Jöns Jakob Berzelius, a Swedish chemist and mineralogist, discovered thorium in the mineral thorite (Söderbaum, 1929-31), which had been collected by the Reverend Hans M.T. Esmark from a syenite on the island of Lövö, Norway (Weeks and Leicester, 1968, p. 532). Berzelius prepared the impure metal by reducing potassium thorium fluoride with potassium in a glass tube (Weeks and Leicester, 1968, p. 534). In 1884, commercial use of thorium began with the invention and development of the incandescent gas light "Welsbach mantle," or "Auerlicht," by Austrian chemist Carl Auer von Welsbach. Patented the following year, the mantle used the luminescent properties of a thorium nitrate mixture containing small amounts of cerium, beryllium, and magnesium nitrates to adjust the brightness and strength of the lamp mantle (Auer von Welsbach, 1902). World production initially came from Sweden and Norway, but the United States (1893), Brazil (1895), and India (1911) followed, as larger and more-economic deposits were developed (Parker and Baroch, 1971, p. 17).

Recovered almost exclusively as a residue or waste during processing of the rare-earth-thorium phosphate mineral, monazite, thorium is used in small amounts in alloying magnesium, emitting electrons at microwave frequencies, and welding electrodes to provide a stable and continuous arc (Hedrick, 1997).

Fluctuations in the price of thorium have been minimized by its byproduct status and a supply that far exceeds demand. Because of the small size of the thorium industry, quoted prices are those of individual companies. The thorium price, which is variable, depends on the material's purity and the quantity purchased. Its use as a pure metal has been limited, with essentially all thorium applications using either a thorium compound or a thorium-containing master alloy. Therefore, the price history of the individual metal is limited. The annual prices presented in the graph and table may not be comparable from year to year, owing to differences in purities, quantity of material to be purchased, and source of the price.

The price of thorium metal was quoted in dollars per pound beginning in 1958. The previous year, the Atomic Energy Commission (AEC) released information on an improved process for preparing high-purity (99.9% purity) thorium metal (U.S. Atomic Energy Commission, 1957). AEC's new technology reportedly reduced the per pound production cost of the metal from the $15 to $20 ($33 to $44 per kilogram) range to $2 ($4.41 per kilogram). Increased costs in the late 1960's and early 1970's were related to increased demand for aviation alloys during the Vietnam War (Baroch, 1968). After the war, demand for thorium-containing alloys declined about 50%, and only minor quantities have been used since (Kirk, 1981).

Environmental issues and concerns related to thorium's natural radioactivity have impeded its commercial development. The impact of these environmental concerns escalated in the 1980's, causing the principal consumers to seek nonradioactive substitutes. By the end of the decade, most thorium materials generated as a byproduct of rare-earth production were disposed of in tailing ponds or shipped to U.S. Government approved low-level radioactive disposal sites (Hedrick, 1990).

After 1979, thorium was primarily sold in small research quantities or alloyed as a master or finished alloy. As a result, prices for the pure metal were no longer quoted for commercial quantities. Research in the late 1980's led to the development of suitable substitutes for thorium alloys, and demand decreased. In the 1980's and 1990's, prices for commercial quantities were only available for a few thorium-containing alloys, including magnesium-thorium master alloy (80% magnesium-20% thorium), the magnesium alloy HZ-32, and the magnesium-zinc alloy ZH-62. During the mid-1990's, most domestic companies ceased using thorium-bearing metal and alloys in their products, the result of concerns and costs related to its natural radioactivity (Hedrick, 1996).

References Cited

Atomic Energy Commission, 1957, Atomic energy facts—A summary of atomic activities of interest to industry: U.S. Atomic Energy Commission, September, p. 72.

Auer von Welsbach, Carl, 1902, History of the invention of incandescent gas-lighting: Chemical News, v. 85, May 30, p. 254-256.

Baroch, C.T., 1968, Thorium, *in* Minerals Yearbook 1967, v. I-II: U.S. Bureau of Mines, p. 1113-1117.

Hedrick, J.B., 1990, Thorium, *in* Minerals Yearbook 1989, v. I: U.S. Bureau of Mines, p. 1063-1966.

———1996, Thorium, *in* Minerals Yearbook 1995, v. I: U.S. Bureau of Mines, p. 847-850.

———1997, Thorium, *in* Minerals Yearbook 1996, v. I: U.S. Geological Survey, p. 899-902.

Kirk, W.S., 1981, Thorium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 671, p. 937-945.

Parker, J.G., and Baroch, C.T., 1971, The rare-earth elements, yttrium, and thorium: U.S. Bureau of Mines Information Circular 8476, 92 p.

Söderbaum, H.G., 1929-31, Jac. Berzelius levnadsteckning [Jacob Berzelius—A portrait of his life]: Uppsala, Sweden, Almquist & Wiksells Boktryckeri A.-B., v. 2, p. 66-68.

Weeks, M.E., and Leicester, H.M., 1968, Discovery of the elements (7th ed.): Journal of Chemical Education, 896 p.

Yearend Thorium Price
(Dollars per kilogram)

Year	Price	Year	Price	Year	Price	Year	Price
1959	43.10	1969	33.07	1979	33.07	1989	NA
1960	43.10	1970	33.07	1980	NA	1990	NA
1961	43.10	1971	33.07	1981	NA	1991	NA
1962	33.07	1972	33.07	1982	NA	1992	NA
1963	44.09	1973	33.07	1983	NA	1993	NA
1964	33.07	1974	33.07	1984	NA	1994	NA
1965	33.07	1975	33.07	1985	NA	1995	NA
1966	33.07	1976	33.07	1986	NA	1996	NA
1967	33.07	1977	33.07	1987	NA	1997	NA
1968	33.07	1978	33.07	1988	NA	1998	NA

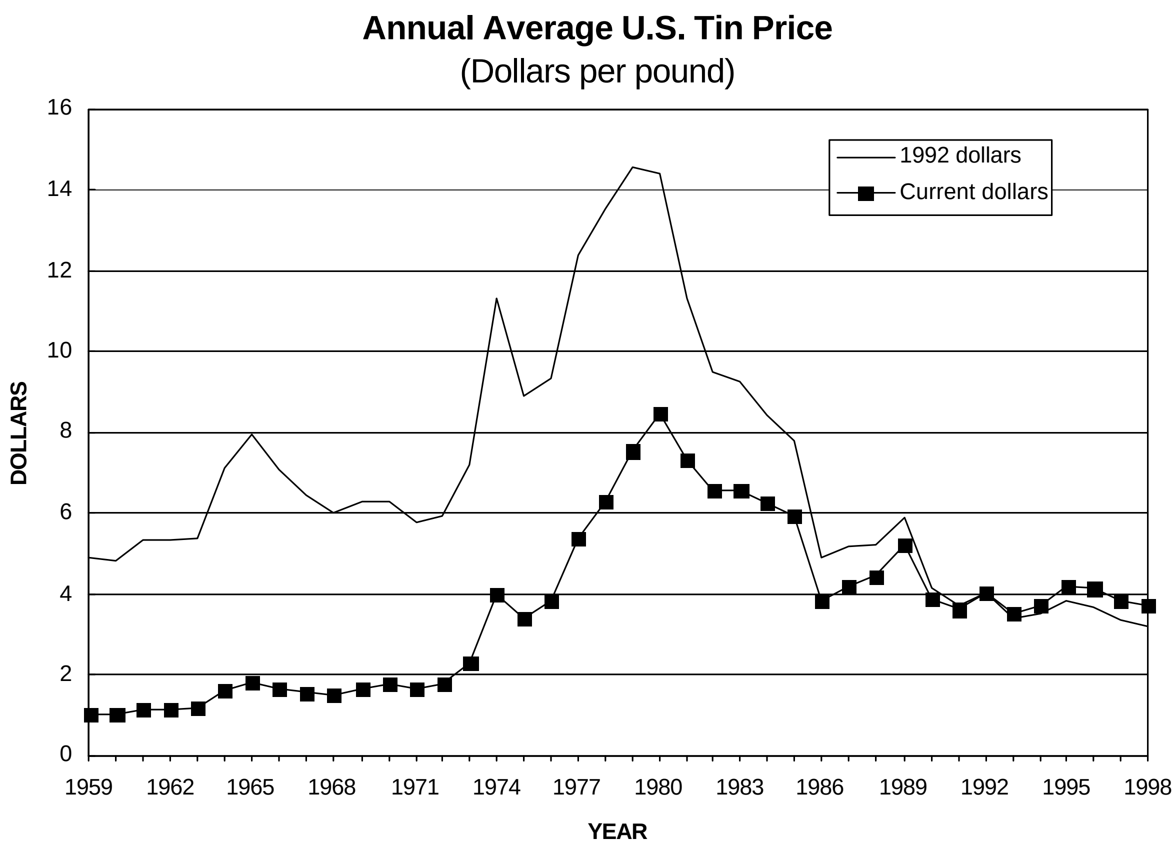
NA Not available

Note:
1959-61, Nuclear grade from the U.S. Atomic Energy Commission.
1962, 1964-79, Commercial grade for pellets, *in* American Metal Market.
1963, 99.9+% purity, *in* Thorium, U.S. Bureau of Mines Minerals Yearbook 1963.
1980-98, Price no longer quoted because of decreased demand.

(This page intentionally left blank.)

Tin

by James F. Carlin, Jr.



Significant events affecting tin prices since 1958

1956-85	International Tin Agreements (a continuous series of complex, global, 4-year pacts)
1973-80	Rampant inflation
1981-82	Sharp recession

Unique to tin has been its long history of commodity "agreements" dating back to 1921. These agreements were usually structured between producer countries and consumer countries on a complex global basis. The earlier agreements tended to be somewhat informal and sporadic; they led to the "First International Tin Agreement" in 1956, the first of a continuously numbered series that essentially collapsed in 1985. Through this series of agreements, the International Tin Council (ITC) had a considerable effect on tin prices during that 29-year period. The ITC was able to support the price of tin during periods of low prices by buying tin for its buffer stockpile and was able, to some degree, to restrain the price during periods of high prices by selling tin from the stockpile. This was an anti-free-market approach, designed to assure a sufficient flow of tin to consumer countries and a decent profit for producer countries. During the 29-year run of the tin agreements, however, it was apparent that the buffer stockpile was not sufficiently large, especially to defend the artificial ceiling prices. Consequently, during most of those 29 years, tin prices rose, sometimes sharply, especially from 1973 through 1980 when rampant inflation plagued the American and many foreign economies.

During the late 1970's and early 1980's, the U.S. Government tin stockpile was in an aggressive selling mode, partly to take advantage of the historically high tin prices. The sharp recession of 1981-82 proved to be quite harsh on the tin industry, as well as on the other metal-using industries of the United States and most industrialized countries. Tin consumption declined dramatically. The ITC was able to avoid truly steep declines through accelerated buying for its buffer stockpile; this activity required the ITC to borrow extensively from banks and metal trading firms to augment its resources. The ITC continued to borrow until late 1985, when it reached its credit limit. Immediately, a major "tin crisis" followed—tin was delisted from trading on the London Metal Exchange for about 3 years, the ITC dissolved soon afterward, and the price of tin, now in a free-market environment, plummeted sharply to the $4 per pound level (Roskill Information Services Ltd., 1995, p. 283-290). The price of tin has remained in that lower range since 1985, except for an excursion to the $5 level in 1989.

Reference Cited

Roskill Information Services Ltd., 1995, The economics of tin: London, Roskill Information Services Ltd., 299 p.

Annual Average U.S. Tin Price
(Dollars per pound[1])

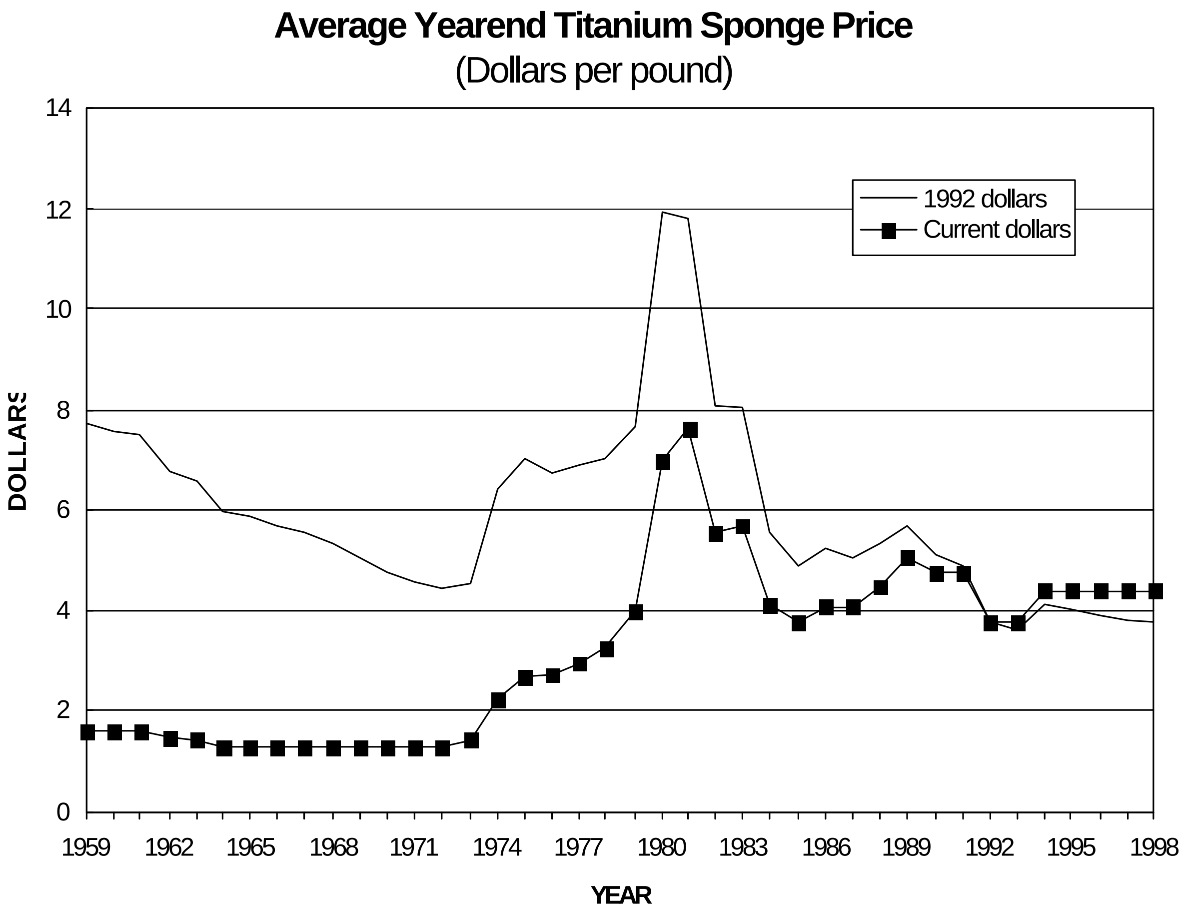
Year	Price	Year	Price	Year	Price	Year	Price
1880	0.208	1910	0.341	1940	0.498	1970	1.741
1881	0.208	1911	0.423	1941	0.520	1971	1.673
1882	0.234	1912	0.461	1942	0.520	1972	1.775
1883	0.208	1913	0.443	1943	0.520	1973	2.276
1884	0.181	1914	0.343	1944	0.520	1974	3.963
1885	0.195	1915	0.386	1945	0.520	1975	3.398
1886	0.216	1916	0.435	1946	0.545	1976	3.798
1887	0.249	1917	0.618	1947	0.779	1977	5.346
1888	0.262	1918	0.888	1948	0.993	1978	6.296
1889	0.209	1919	0.633	1949	0.993	1979	7.539
1890	0.214	1920	0.483	1950	0.955	1980	8.460
1891	0.208	1921	0.299	1951	1.271	1981	7.331
1892	0.206	1922	0.326	1952	1.205	1982	6.539
1893	0.201	1923	0.427	1953	0.958	1983	6.548
1894	0.181	1924	0.502	1954	0.918	1984	6.238
1895	0.141	1925	0.579	1955	0.947	1985	5.960
1896	0.132	1926	0.653	1956	1.014	1986	3.832
1897	0.136	1927	0.644	1957	0.963	1987	4.188
1898	0.157	1928	0.504	1958	0.951	1988	4.414
1899	0.251	1929	0.452	1959	1.021	1989	5.202
1900	0.299	1930	0.317	1960	1.014	1990	3.863
1901	0.167	1931	0.245	1961	1.133	1991	3.628
1902	0.268	1932	0.220	1962	1.146	1992	4.024
1903	0.281	1933	0.391	1963	1.166	1993	3.498
1904	0.280	1934	0.522	1964	1.577	1994	3.691
1905	0.314	1935	0.504	1965	1.782	1995	4.156
1906	0.398	1936	0.464	1966	1.640	1996	4.124
1907	0.382	1937	0.543	1967	1.534	1997	3.815
1908	0.295	1938	0.423	1968	1.481	1998	3.733
1909	0.297	1939	0.503	1969	1.644		

[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:
1880-1936, New York price for Grade A Straits (Malaysian) tin (99.85% pure), *in* Engineering and Mining Journal.
1937-66, New York price for Grade A Straits (Malaysian) tin (99.85% pure), *in* E&MJ Metal and Mineral Markets.
1967-76, New York price for Grade A Straits (Malaysian) tin (99.85% pure), *in* Metals Week.
1976-98, Metals Week composite price, *in* Metals Week (through June 14, 1993) and Platt's Metals Week.

Titanium

by Joseph Gambogi



Significant events affecting titanium prices since 1958

1971	Research for Supersonic Transport terminated
1975-76	Military aircraft production peak (F-14 and F-15)
1977-81	Rapid increase in orders for commercial aircraft
1982-84	Collapse of the commercial aircraft market
1984-86	Production of B1-B bombers
1985-89	Renewed strength in the commercial aircraft market
1988-89	Increases in U.S. sponge production capacity
1990-94	Reductions in military and commercial aerospace
1992	Sodium-reduction sponge plant closed at Ashtabula, OH
1993	Magnesium-reduction sponge plant commissioned at Henderson, NV
1994-97	Surge in consumer goods and commercial aerospace orders
1997-98	Cancellation of some commercial aircraft orders

Discovered in 1790, titanium is well known as a light metal with excellent corrosion resistance (Barksdale, 1966, p. 3). Titanium sponge is the most basic form of titanium metal and can be produced from the minerals rutile, leucoxene, and ilmenite. Titanium metal is consumed primarily in the commercial and military aerospace industries. Large-scale production capacity of sponge exists in China, Japan, Kazakhstan, Russia, Ukraine, and the United States. Unlike some metals, titanium is not sold on any market exchanges. Although often unspecified, sponge prices are normally based on a minimum 93.3-percent titanium content with a Brinell hardness of less than 120.

Although commercial production of titanium pigments began in the early 1900's, commercially produced titanium metal was not available until 1948. During the first two decades of the commercial development of titanium metal, the price per pound declined significantly. Cancellation of the SST program in 1971 tended to keep demand and prices for titanium sponge low through 1973. From 1973 through 1981, however, prices rose along with generally increasing orders for commercial aircraft and other industrial uses. The historic high price in 1981 and the subsequent price collapse were believed to have been accentuated by an overestimation of aircraft orders that did not materialize or were later canceled as the aircraft market deteriorated, leaving some producers with large inventories of titanium metal products to be drawn from during a period of lower demand (National Materials Advisory Board, 1983, p. 7-22). From 1985 through 1989, titanium metal prices were again on the rise, reflecting renewed strength in the commercial aircraft and other industrial markets. Military aircraft programs, such as the B-1B bomber program, also contributed to the rise in demand during this period. Owing to this increased demand, two of the domestic sponge producers made moderate expansions to their existing capacity during 1988 and 1989 (Titanium Development Association, 1990, p. 3).

The early 1990's marked the end of the Cold War and the beginning of sharp cuts in defense spending. Concurrently, commercial aircraft and engine producers were reducing raw material inventory levels causing a significant fall in titanium metal demand and prices. Domestic consumption of titanium sponge fell by 42% in 1991.

Owing to decreased demand and the availability of imported material, RMI Titanium Co. closed its 10,900-metric-ton-per-year sponge production plant at Ashtabula, OH, in 1992 (RMI Titanium Co., 1992, p. 11). The closure left two remaining producers in the United States.

In 1993, Titanium Metals Corp. commissioned a 10,000-ton-per-year sponge plant at its Henderson, NV, facility. The expansion was based on a derivation of the Kroll process called Vacuum Distillation Process (VDP). According to industry reports, the new plant produced a higher quality sponge at lower operating costs. Following the commissioning of the VDP plant, much of the old Kroll plant capacity was idled (American Metal Market, 1993a).

Imports of titanium sponge rose sharply during the mid-1990's. Although it is not apparent from published prices of domestic sponge, imports were available at substantially less than the domestic published price (American Metal Market, 1993b). In 1994, the average unit value of imports reached a record low of $1.58 per pound. A new use of titanium metal in golf club heads led to a resurgence in consumption for titanium in 1995 (American Metal Market, 1996). In addition, new commercial aircraft orders rose sharply from 1995 to 1997 (Aviation Week & Space Technology, 1997). By 1997, domestic consumption of titanium sponge reached a record high of 32,000 metric tons. Also in 1997, the total value of sponge imports reached a record high. According to U.S. Customs statistics, the average unit value of sponge imports was $3.42 per pound.

The instabilities in Asian economies caused a cancellation of aircraft orders in 1998 (ISRI Commodities Report, 1998). These cancellations resulted in a moderate fall in consumption of titanium during 1998. Although prices for titanium metal products were also affected, long-term supply agreements between aircraft producers and titanium producers helped stabilize prices for some titanium products (Metal Bulletin, 1998).

References Cited

American Metal Market, 1993a, Greater penalty sought against CIS's titanium: American Metal Market, v. 101, no. 174, September 9, p. 1.

———1993b, Titanium prices drop as Timet strike continues: American Metal Market, v. 101, no. 247, December 27, p. 1.

———1995, Titanium tees off to a birdie: American Metal Market, v. 104, no. 147, September 9, p. 1.

Aviation Week & Space Technology, 1997, Boeing suppliers warn of protracted delays: Aviation Week & Space Technology, v. 147, no. 13, p. 22.

Barksdale, Jelks, 1966, Titanium—Its occurrence and technology: New York, The Ronald Press Company, 691 p.

Institute of Scrap Recycling Industries, Inc., 1998, Titanium—A titanic slide: ISRI Commodities Report, v. 4., no. 24, December 16, p. 1-2.

Metal Bulletin, 1998, RMI secures new long-term aerospace contracts: Metal Bulletin, no. 8253, February 16 , p. 13.

National Materials Advisory Board, 1983, Titanium—Past, present, and future: Washington, DC, National Academy Press, 209 p.

RMI Titanium Co., 1992, Annual report 1992: Niles, OH, RMI Titanium Co., 33 p.

Titanium Development Association, 1990, Statistical review 1980-1989: Dayton, OH, Titanium Development Association, 27 p.

Average Yearend Titanium Sponge Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1941	5.25	1956	2.75	1971	1.32	1986	4.10
1942	5.25	1957	2.25	1972	1.32	1987	4.10
1943	5.25	1958	1.82	1973	1.44	1988	4.50
1944	5.25	1959	1.60	1974	2.25	1989	5.05
1945	5.25	1960	1.60	1975	2.70	1990	4.75
1946	5.25	1961	1.60	1976	2.73	1991	4.75
1947	6.50	1962	1.46	1977	2.98	1992	3.75
1948	5.50	1963	1.44	1978	3.28	1993	3.75
1949	5.00	1964	1.32	1979	3.98	1994	4.38
1950	5.00	1965	1.32	1980	7.02	1995	4.38
1951	5.00	1966	1.32	1981	7.65	1996	4.38
1952	5.00	1967	1.32	1982	5.55	1997	4.38
1953	5.00	1968	1.32	1983	5.70	1998	4.38
1954	4.50	1969	1.32	1984	4.13		
1955	3.45	1970	1.32	1985	3.75		

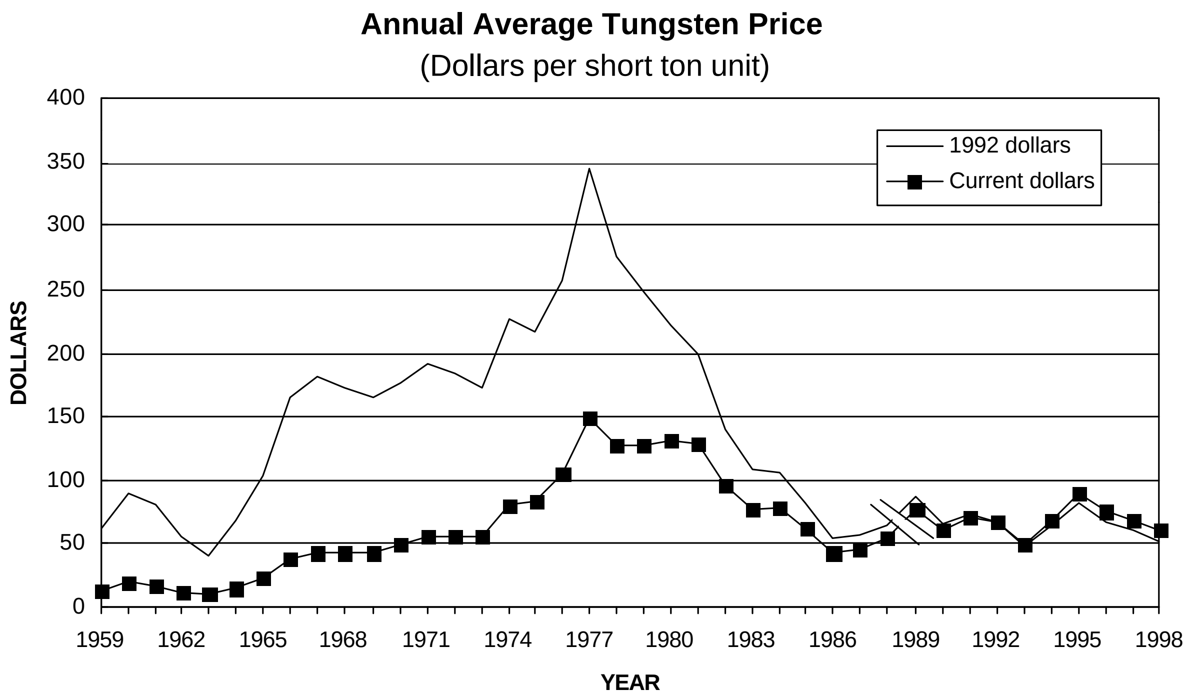
[1] To convert to dollars per metric ton, multiply by 2,204.62.

Sources: E&MJ Metal and Mineral Markets (1941-51),(1952-65, 72-82), Metals Week (1967-71), American Metal Market (1983-98). Prices for the periods from 1952 through 1965 and 1972 through 1982 were published by the U.S. Bureau of Mines, but origin is unknown.

(This page intentionally left blank.)

Tungsten

by Kim B. Shedd



Significant events affecting tungsten prices since 1958

1963	Sudden decrease in exports from China, North Korea, and Russia
1965-89	Disposal of tungsten concentrates from the U.S. Government stockpiles
1979-93	Increasing dominance of China in the world market
1981-82	Sharp recession
1991	U.S. antidumping duty imposed on Chinese concentrates and dissolution of the Soviet Union
1992-98	Exports of tungsten from Russia and other countries of the former Soviet Union to the world market

Tungsten has a wide range of industrial uses. The largest use is as tungsten carbide in cemented carbides. Cemented carbides (also called hardmetals) are wear-resistant materials used by the metalworking, mining, and construction industries. Tungsten metal wires, electrodes, and/or contacts are used in lighting, electronic, electrical, heating, and welding applications. Tungsten is also used to make tool steels, wear-resistant alloy parts and coatings, superalloys for turbine blades, and heavy metal alloys for armaments, heat sinks, and high-density applications, such as weights and counterweights. Chemical uses of tungsten include catalysts, inorganic pigments, and high-temperature lubricants.

Tungsten prices and many tungsten statistics are quoted in units of tungsten trioxide (WO_3). The short ton unit, used in the United States, is 1% of a short ton (20 pounds) and tungsten trioxide is 79.3% tungsten. Therefore, a short ton unit of WO_3 equals 20 pounds of WO_3 and contains 7.19 kilograms (15.86 pounds) of tungsten. The metric ton unit, used in most other countries, is 1% of a metric ton (10 kilograms). A metric ton unit of WO_3 contains 7.93 kilograms (17.48 pounds) of tungsten.

Until recently, the main reference price for tungsten was the price of tungsten concentrates. In the early 1990's, the trade in tungsten concentrates decreased, and the market shifted towards the price of the intermediate product ammonium paratungstate as a reference price (International Tungsten Industry Association, 1997, p. 32). Prices of tungsten concentrates and ammonium paratungstate generally follow similar trends. One would expect the price of ammonium paratungstate to exceed that of concentrate by an amount equivalent to the processing costs to convert concentrate to ammonium paratungstate. In 1992, however, the Metal Bulletin price for ammonium paratungstate actually fell below that for concentrate. At that time, the normal premium for ammonium paratungstate was estimated to be between $23 and $32 per short ton unit. The following were cited as possible explanations for this unusual pricing situation: the availability of very inexpensive feedstock for Chinese ammonium paratungstate plants or Government subsidies for those plants (Maby, 1993).

The main forms of tungsten used by downstream consuming industries are tungsten carbide powder, tungsten metal powder, ferrotungsten, and various tungsten chemical compounds. With the exceptions of ferrotungsten and ammonium paratungstate, prices for these products are no longer published on a regular basis.

Historically, tungsten prices have fluctuated widely as the market alternated between periods of scarcity and oversupply. In addition to general economic conditions and industrial activity, the following factors have affected the tungsten market over time: China's position as the world's largest producer; changes in availability from Communist or formerly Communist countries; purchases for or sales from various Government stockpiles; trade controls; buildup of or reduction in inventories held by industry; fluctuations in production by a large number of widely dispersed small producers; differing political, social, and economic objectives of producing countries; industry fragmentation in that most countries that produce tungsten are not large consumers; rapid shifts in demand; and increases in demand in support of military activity (Engineering and Mining Journal, 1967; Burrows, 1971, p. 1-7 and 36-37; Rawlings, 1974; Lincoln, 1986).

From the late 1950's to early 1960's, the tungsten market was characterized by oversupply and low prices. This was a result of several factors. Following the Korean conflict, high prices combined with U.S. Government programs to stockpile tungsten and to encourage domestic production by purchasing tungsten concentrates from U.S. mines at a fixed price led to an increase in production (Geehan, 1952; Grainger, 1960). This was followed by reduced demand when the U.S. Government's tungsten acquisition program was completed and increased supply as a result of the disposal of stockpiled ore from the United Kingdom, the resumption of shipments from Korea, and increased offers of tungsten from China and Russia (Grainger, 1960, 1962).

In late 1963, exports of tungsten from China, North Korea, and Russia suddenly decreased significantly from those of previous years. The apparent withdrawal of these countries from the world market combined with an increase in demand from Eastern Europe resulted in a supply squeeze and a significant increase in prices by late 1964. The high prices led to an increase in mine production from non-Communist countries and increased recycling of tungsten-bearing scrap. In 1965, the U.S. Government began a long-term sales program of tungsten concentrates from Defense Production Act inventories. The increase in supply from these sources was not enough to balance the loss of tungsten from Communist countries during a period of strong worldwide demand (Grainger, 1965; Engineering and Mining Journal, 1967). As a result, the annual average U.S. price of tungsten concentrate in 1966 was more than four times greater than that of 1963.

Prices remained relatively high during the late 1960's owing to strong demand and only limited exports of tungsten from China. U.S. tungsten consumption was strong, at least in part, in support of the war in Vietnam and for increased production of tungsten carbide balls for ballpoint pens and studs for automobile snow tires. Sales of tungsten concentrates from the U.S. Government at fixed prices contributed to the stabilization of the U.S. market (Stevens, 1969). Between March 1966 and December 1973, the U.S. Government's General Services Administration (GSA) "off the shelf" fixed prices for tungsten concentrates were quoted as the price of concentrates in the U.S. market. Between October 1969 and February 1970, European prices for tungsten concentrates quoted in Metal Bulletin increased from approximately $46 per short ton unit to a high of approximately $80 per short ton unit (Ratzker, 1971). The increase in European prices was reported to be primarily the result of a continued high level of industrial activity in combination with the absence of significant quantities of tungsten shipments from China. In 1969, as a result of stable fixed prices in the United States, increasing market prices in Europe, and the availability of tungsten from the U.S. Defense Production Act inventories, the United States became a net exporter of tungsten concentrates for the first time in history (Stevens, 1970).

A worldwide economic slowdown in 1971 caused reduced demand for tungsten, particularly from the steel and machine tool industries (Mining Journal, 1972). During 1972 and 1973, economic conditions improved, and demand for tungsten increased. U.S. prices were quoted at the GSA "off the shelf" fixed price of $55 per short ton unit. European prices decreased to a low of approximately $30 per short ton unit by late 1972. The downward trend in European prices during a period of increasing demand was attributed to substantial inventories overhanging the market. By late 1972/early 1973, the rate of consumption had increased enough to cause a significant reduction in inventory levels, and European prices began to increase (Rawlings, 1974).

Toward the end of 1973, the GSA discontinued its "off the shelf" fixed-price sales of tungsten concentrates in favor of monthly sales on a sealed-bid basis (Stevens, 1973). From 1974 through 1976, awards of tungsten concentrates from U.S. Government stockpiles were at unit values close to the prevailing European prices quoted in Metal Bulletin. In 1974, high levels of tungsten consumption in the United States and Europe and the lack of large inventories resulted in an increase in the Metal Bulletin price to more than $100 per short ton unit (Rawlings, 1975). The Metal Bulletin price decreased in 1975 as a result of recessionary economic conditions in Western markets and a corresponding decrease in tungsten demand. During the next 2 years, tungsten prices increased sharply to record highs as a result of worldwide inflation, strong buying by Eastern European countries, a recovery in Western demand, and reports of decreased quantities of tungsten offered by China (Ho, 1977). Metals Week began publishing U.S. spot prices for tungsten concentrates in January 1977 after a hiatus of more than 10 years. By March 1977, this price exceeded $160 per short ton unit.

By late 1977-early 1978, the price of tungsten concentrates began to decline. Although Western mine production had steadily increased, exports of tungsten from China and releases from U.S. Government stockpiles balanced a shortfall between production and consumption. The decline in prices during 1978 was attributed to the following factors: an increase in Western tungsten inventories during 1977; reduced demand in Western Europe, particularly for ferrotungsten; increased Western mine production; and the absence of Eastern European buyers as a significant influence in the Western market (Thurber, 1979).

Between late February 1979 and late October 1981, the average of Metals Week prices for tungsten concentrate was relatively stable in the $120- to $140-per-short-ton-unit range. By late 1981, the worldwide recession began to affect tungsten demand. In addition, China was exporting steadily increasing amounts of tungsten concentrates and intermediate products to Western markets (Thurber, 1982; Ho, 1986). In the mid-1980's, the availability of low-priced intermediate products from China contributed to the downward trend in the price of tungsten concentrates. There was a marked change from concentrate prices governing the price of intermediate products to intermediate product prices governing concentrate prices (Ho, 1986). The price of concentrate trended downward to a low of $28 per short ton unit by late 1986, and then fluctuated between $30 and $65 per short ton unit during the next 2 years. From September 1988 to late 1990, the price steadily decreased to $31 per short ton unit. The decrease in price during a 3-year period of strong Western consumption was attributed to continued oversupply of Chinese tungsten (Bunting, 1991).

In mid-1991, the concentrate price increased to $67 per short ton unit following the imposition of a 151% antidumping duty against Chinese concentrates in the U.S. market. During the next 2 years, the price steadily fell to $28 per short ton unit. This price decline was attributed to continued exports of tungsten materials from China during a period of reduced demand as a result of the worldwide economic recession, a decrease in imports by former Soviet countries following the breakup of the Soviet Union in 1991, and destocking by consumers (Maby, 1993). By 1993, imports of Chinese tungsten concentrates and intermediate products had grown to 75% of Market Economy Countries' supply of primary tungsten (Bunting, 1994). Added to the increasing supply from China were exports of tungsten materials from Russia and other countries of the former Soviet Union.

By 1994, almost all of the tungsten mines in Market Economy Countries had ceased production, and Chinese mine production was also at a low level as a result of the persistent low prices of tungsten concentrates (Bunting, 1997). In 1994, the world economy and industrial activity improved, demand for tungsten increased, and prices began to rise (Maby, 1995). By mid-1995, the concentrate price rose to $70 per short ton unit. This led to large releases of tungsten from Government stockpiles in China, Kazakhstan, and Russia; releases of inventories from Russian mines; and an increase in mine production, particularly in China. By early 1996, an oversupply situation had developed. As a result, prices decreased and mine production was reduced. By late 1996, most of the inventories that had been overhanging the market had been drawn down (Bunting, 1997). In 1997, demand for tungsten increased, but supply was plentiful, and prices continued to decrease. Prices decreased again during 1998. Demand was strong during the first half of the year, but weakened during the second half. At yearend, the Metals Week price for tungsten concentrate was between $40 and $45 per short ton unit.

References Cited

Bunting, R.M., 1991, Tungsten—A strong year—But: Engineering and Mining Journal, v. 192, no. 3, March, p. 27-29.

———1994, Presentation to I.T.I.A. AGM—11/3/94, *in* International Tungsten Industry Association annual general meeting, 7th, Huntsville, AL, November 2-4, 1994, Proceedings: London, International Tungsten Industry Association, 16 p.

———1997, Tungsten—Can the industry meet future demand?: Engineering and Mining Journal, v. 198, no. 3, March, p. 37-41.

Burrows, J.C., 1971, Tungsten—An industry analysis: Lexington, MA, D.C. Heath and Co., 287 p.

Engineering and Mining Journal, 1967, Tungsten: Engineering and Mining Journal, v. 168, no. 2, February, p. 165-167.

Geehan, R.W., 1952, Tungsten, *in* Minerals Yearbook 1952, v. I: U.S. Bureau of Mines, p. 1066-1082.

Grainger, P.E., 1960, Tungsten, *in* Annual review 1960: Mining Journal, p. 41.

———1962, Tungsten, *in* Annual review 1962: Mining Journal, p. 41.

———1965, Tungsten, *in* Mining annual review 1965: Mining Journal, p. 48-49.

Ho, Eric, 1977, Tungsten, *in* Mining annual review 1977: Mining Journal, p. 82-83.

———1986, Tungsten, *in* Mining annual review 1986: Mining Journal, p. 73.

Lincoln, G.M., Jr., 1986, Tungsten—Bleak market environment:

Engineering and Mining Journal, v. 187, no. 3, March, p. 59-61.
International Tungsten Industry Association, 1997, Tungsten: London, International Tungsten Industry Association, 33 p.
Maby, Michael, 1993, Tungsten, *in* Metals and minerals annual review 1993: Mining Journal, p. 72-73.
———1995, Tungsten, *in* Metals and minerals annual review 1995: Mining Journal, p. 63-64.
Mining Journal, 1972, Tungsten, *in* Mining annual review 1972: Mining Journal, p. 80-83.
Ratzker, Menno, 1971, Tungsten: Engineering and Mining Journal, v. 172, no. 3, March, p. 149-150.
Rawlings, J.W., 1974, Tungsten—'73 market firmed, but GSA remains pricing key: Engineering and Mining Journal, v. 175, no. 3, March, p. 130-131.
———1975, Tungsten—Prices take off in '74 on good demand and lack of surplus inventories: Engineering and Mining Journal, v. 176, no. 3, March, p. 133-134.
Stevens, R.F., Jr., 1969, Tungsten: Engineering and Mining Journal, v. 170, no. 3, March, p. 130-133.
———1970, Tungsten: Engineering and Mining Journal, v. 171, no. 3, March, p. 106-109.
———1973, Tungsten, *in* Minerals Yearbook 1973, v. I: U.S. Bureau of Mines, p. 1245-1261.
Thurber, W.C., 1979, Tungsten—U.S. consumption at highest level since 1974: Engineering and Mining Journal, v. 180, no. 3, March, p. 139-143.
———1982, Tungsten—Production and consumption drop as economies weaken: Engineering and Mining Journal, v. 183, no. 3, March, p. 98-100.

Annual Average Tungsten Price
(Dollars per short ton unit[1])

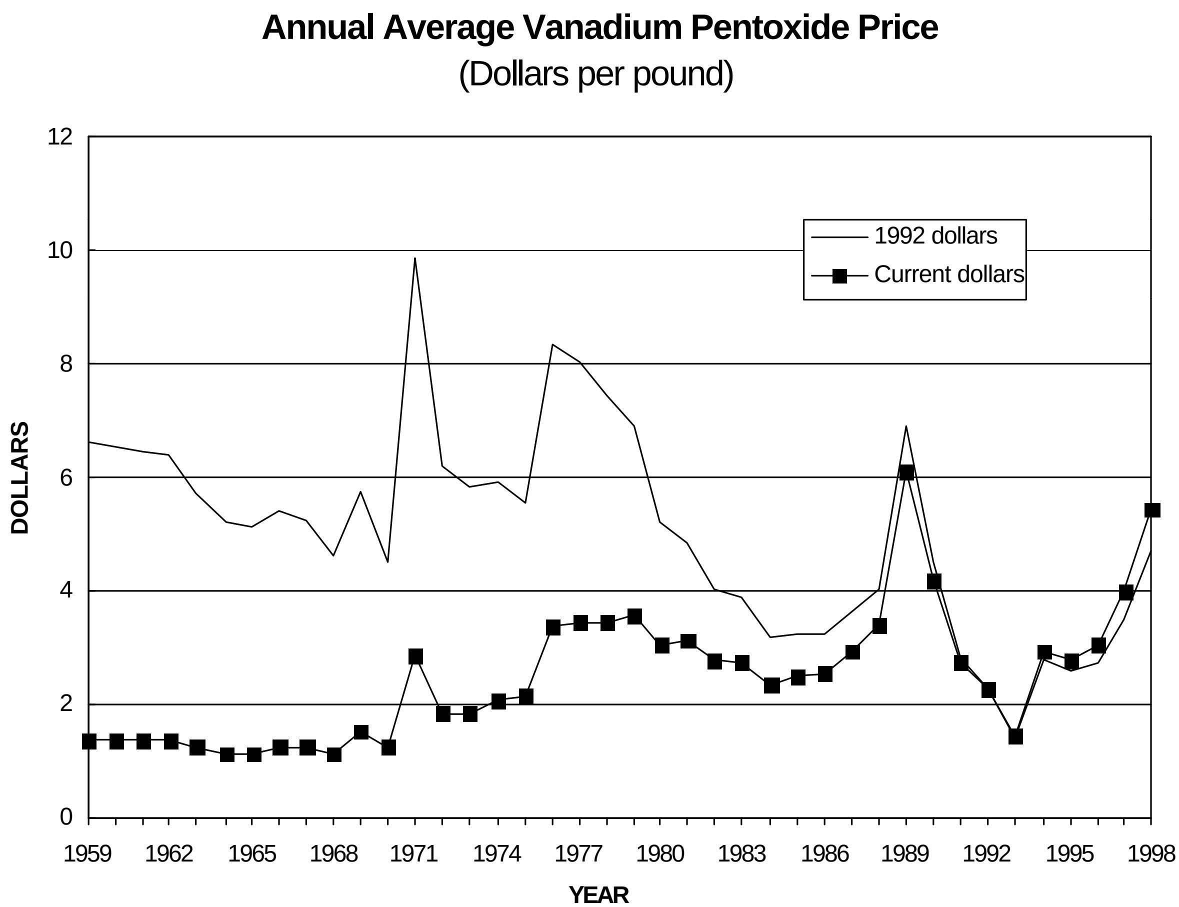
Year	Price	Year	Price	Year	Price	Year	Price
1959	13	1969	43	1979	128	1989	76
1960	19	1970	49	1980	130	1990	61
1961	17	1971	55	1981	129	1991	71
1962	12	1972	55	1982	97	1992	67
1963	9	1973	55	1983	77	1993	49
1964	15	1974	80	1984	78	1994	68
1965	23	1975	83	1985	62	1995	89
1966	38	1976	104	1986	42	1996	75
1967	43	1977	149	1987	46	1997	69
1968	43	1978	128	1988	54	1998	60

[1] To convert to dollars per metric ton unit, multiply by 1.10231. To convert to dollars per kilogram contained tungsten, multiply by 0.139.

Note: Annual average prices were derived from price changes reported in the following sources:
1959-66, tungsten ore (wolframite) in New York, "ordinary quality," excluding duty, *in* American Metal Market.
1967-73, tungsten ore, domestic quote reflecting the U.S. Government's General Services Administration price, *in* American Metal Market's Metal Statistics 1972 and Metal Statistics 1974.
1974-76, tungsten ore, minimum 65% tungsten trioxide, European market, excluding duty, *in* U.S. Bureau of Mines Minerals Yearbook, converted from pounds sterling per metric ton unit as reported in Metal Bulletin.
1977-88, tungsten ore, minimum 65% tungsten trioxide, U.S. spot price, c.i.f., excluding duty, *in* Metals Week.
1989-98, ammonium paratungstate, U.S. free market, *in* Metal Bulletin.

Vanadium

by Robert G. Reese, Jr.



Significant events affecting vanadium prices since 1958

1988-89	Short supply owing to technical problems at some producers, and to strong demand from steel and aerospace industries
1993	Market oversupply all year; price fell despite increase in consumption
1997	Disposal of last vanadium pentoxide holdings in the U.S. National Defense Stockpile (NDS)

Vanadium was first described by Andres Manuel del Rio in 1801. He had isolated it from lead ores from Zimapan, Mexico (Busch, 1961, p. 18). At the start of the 20th century, vanadium remained little more than a chemical curiosity with no commercial value because of its rarity and high cost. The supply and cost restrictions were significantly altered in the early years of the 20th century with the discovery of rich vanadium deposits in several countries, including the United States. In 1905, the American Vanadium Co. was established to extract vanadium from ores discovered in Colorado (Kuck, 1985, p. 985). Commercial production began shortly thereafter.

Two main prices are associated with vanadium—one is for the ferroalloy ferrovanadium, and the other for vanadium pentoxide; prices for vanadium metal are not published. Because much of the world's ferrovanadium is made from vanadium pentoxide, the price for vanadium pentoxide has been used.

Owing in part to its relative scarcity and the absence of free market trading, the vanadium pentoxide price has historically been a producer price. This has resulted in low volatility and relatively stable prices, showing a gradual upward trend, as can be seen in the graph above for the period from 1959 through 1988. Since the late 1980's, the vanadium pentoxide price appears to have become more volatile. This increased volatility is attributed to the availability of additional vanadium pentoxide supplies from such countries as China and Russia, sales of the remaining vanadium pentoxide from the NDS during the 1990's, and, to a very limited extent, the potential substitution of other metals for vanadium in certain alloys.

References Cited

Busch, P.M., 1961, Vanadium—A materials survey: U.S. Bureau of Mines Information Circular 8060, 95 p.

Kuck, P.H., 1985, Vanadium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 895-915.

Annual Average Vanadium Pentoxide Price[1]
(Dollars per pound[2])

Year	Price	Year	Price	Year	Price	Year	Price
1959	1.38	1969	1.51	1979	3.57	1989	6.10
1960	1.38	1970	1.25	1980	3.07	1990	4.21
1961	1.38	1971	2.85	1981	3.14	1991	2.75
1962	1.38	1972	1.85	1982	2.77	1992	2.28
1963	1.25	1973	1.85	1983	2.75	1993	1.45
1964	1.15	1974	2.08	1984	2.36	1994	2.95
1965	1.15	1975	2.14	1985	2.50	1995	2.80
1966	1.25	1976	3.38	1986	2.53	1996	3.07
1967	1.25	1977	3.47	1987	2.95	1997	4.00
1968	1.15	1978	3.47	1988	3.40	1998	5.47

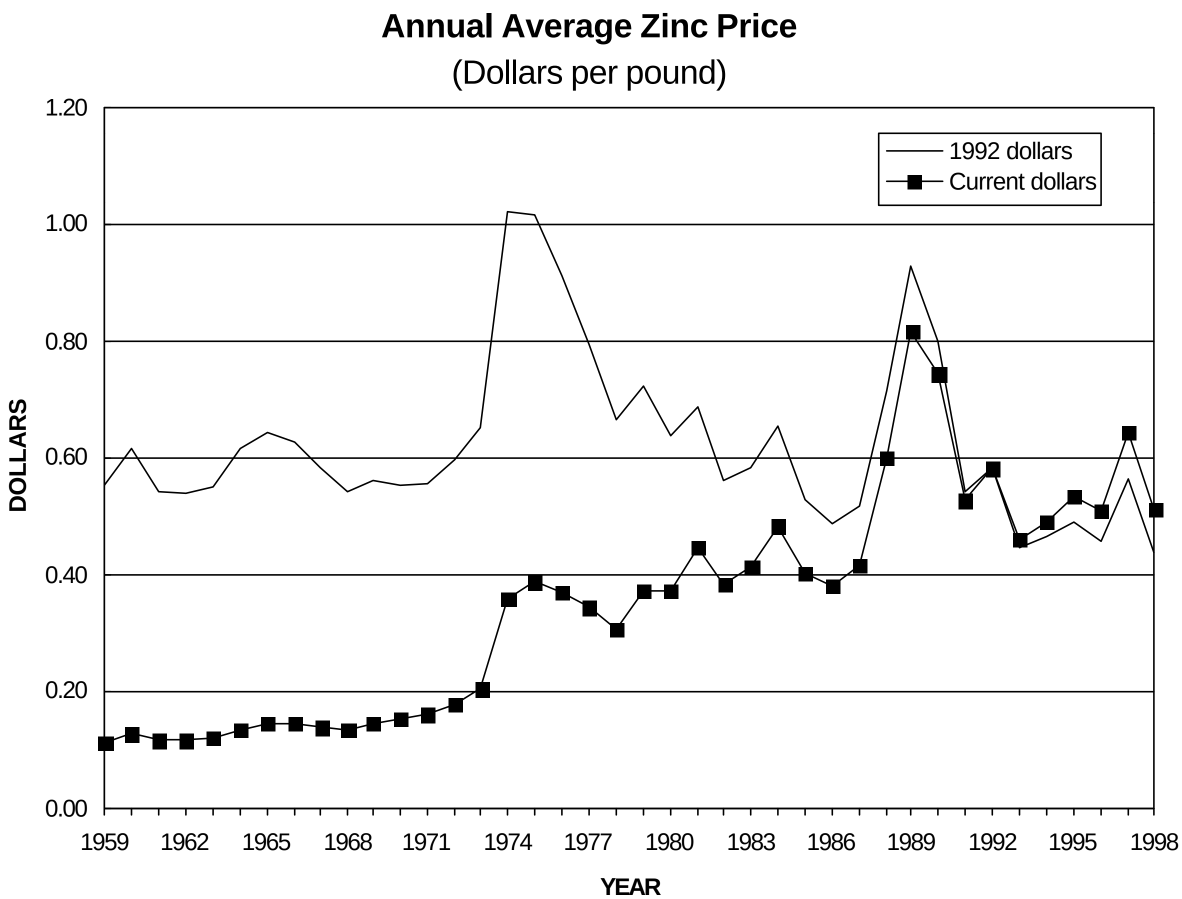
[1] Minimum 98% vanadium pentoxide anhydride.

[2] To convert to dollars per kilogram, multiply by 2.20462.

Source: Metal Bulletin (1959-98).

Zinc

By Jozef Plachy



Significant events affecting zinc prices since 1958

1954-64	Stockpile buildup; import quotas
1965-69	Vietnam conflict; import quotas terminate; stockpile releases
1971-73	Price control; slow price increase
1975-82	Stockpile sales terminate; declining production
1977	Recessions
1982	Recession; introduction of zinc penny
1983-89	Period of sustained economic growth; stagnating domestic production; high zinc imports and prices
1987-89	Short supply of zinc metal; strong world demand

The rapid development of the vast Joplin, MO, zinc mining district in the early 1870's was stimulated by the growing use of zinc by U.S. industry. During the first half of the 20th century, two pricing centers emerged—St. Louis, MO, and New York, NY. The New York price was usually higher because it included shipping charges. Because the prevailing method of production was pyrometallurgical, yielding Prime Western (PW) zinc, both prices were based on that grade. Higher grades of zinc cost more because of the expense of additional refining.

During 1960's, the East St. Louis, IL, price of zinc remained stable, which can be attributed partially to Government policies pertaining to stockpile programs and import quotas and tariffs. The price increase in this decade was about 13%. In 1965, import quotas were lifted, and Public Law 89-322, authorizing the first of the annual zinc disposals from the Government stockpile, was enacted. In 1971, the importance of the East St. Louis price diminished when a major producer began to include shipping charges in its price quotation. The emergence of the New York price coincided with Metals Week becoming the main pricing medium for zinc in the United States.

Because price controls were in force from 1971 through 1973 and any increase of price had to be approved by the U.S. Price Commission, zinc prices increased only gradually. After price controls were abolished, the price for high-grade zinc metal rose abruptly nearly doubling by mid-1975. For the next 11 years, the annual average price fluctuated within an $0.18-per-pound band (Jolly, 1993).

By 1980, more than a decade after electrolytic refining had become dominant in the production of domestic zinc, HG was made the base grade for pricing purposes, and Metals Week introduced its weighted average price, which it based on daily sales of HG. The largest increase in the history of the zinc price began with a small, $0.04-per-pound increase in November 1987 and escalated to a $0.20-cent increase in February 1989. The main impetus for this steep increase was tightness of supply brought about by strong world demand; strikes, technical problems at some smelters, and hurricane-related delays of zinc shipments from Mexico were also contributing factors. In the 1980's, U.S. refinery production supplied only about one-third of domestic demand. As a result, world price became the dominant factor in setting the domestic price.

Outside of the United States, the world pricing basis for zinc has essentially been the price quoted by the London Metal Exchange (LME), which introduced its first zinc contract in 1915. In order to stabilize the sometimes volatile LME prices, a group of non-U.S. zinc producers established the European Producer Price (EPP) in 1964. Later, dissatisfaction with the EPP pricing system, mainly as it related to the settlement price of zinc concentrate and the determination of smelter treatment charges, led to the reemergence of LME zinc quotations as the principal basis for world zinc pricing (Jolly, 1997, p. 218-221). The choice of an LME basis was further solidified when the LME switched from British pounds to U.S. dollars for all its transactions in 1998.

During the 1990's, the price for refined zinc remained rather uneventful, reflecting the supply and demand of the market.

References Cited

Jolly, J.H., 1993, Zinc, *in* Metal prices in the United States through 1991: U.S. Bureau of Mines, p. 191-195.

———1997, U.S. zinc industry: Baltimore, MD, American Literary Press, Inc., 312 p.

Annual Average Zinc Price

(Dollars per pound[1])

Year	Price	Year	Price	Year	Price	Year	Price
1875	0.070	1906	0.061	1937	0.065	1968	0.135
1876	0.072	1907	0.058	1938	0.046	1969	0.147
1877	0.060	1908	0.046	1939	0.051	1970	0.153
1878	0.049	1909	0.054	1940	0.063	1971	0.161
1879	0.052	1910	0.054	1941	0.075	1972	0.178
1880	0.055	1911	0.056	1942	0.083	1973	0.207
1881	0.052	1912	0.068	1943	0.083	1974	0.360
1882	0.053	1913	0.055	1944	0.083	1975	0.390
1883	0.045	1914	0.051	1945	0.083	1976	0.370
1884	0.044	1915	0.142	1946	0.087	1977	0.344
1885	0.043	1916	0.136	1947	0.105	1978	0.310
1886	0.044	1917	0.089	1948	0.136	1979	0.373
1887	0.046	1918	0.080	1949	0.122	1980	0.374
1888	0.049	1919	0.070	1950	0.139	1981	0.446
1889	0.050	1920	0.078	1951	0.180	1982	0.385
1890	0.055	1921	0.047	1952	0.162	1983	0.414
1891	0.050	1922	0.057	1953	0.109	1984	0.486
1892	0.046	1923	0.066	1954	0.107	1985	0.404
1893	0.040	1924	0.063	1955	0.123	1986	0.380
1894	0.035	1925	0.076	1956	0.135	1987	0.419
1895	0.036	1926	0.073	1957	0.114	1988	0.602
1896	0.039	1927	0.062	1958	0.103	1989	0.820
1897	0.041	1928	0.060	1959	0.115	1990	0.746
1898	0.046	1929	0.065	1960	0.130	1991	0.528
1899	0.058	1930	0.046	1961	0.116	1992	0.584
1900	0.044	1931	0.036	1962	0.116	1993	0.462
1901	0.041	1932	0.029	1963	0.120	1994	0.493
1902	0.048	1933	0.040	1964	0.136	1995	0.534
1903	0.054	1934	0.042	1965	0.145	1996	0.511
1904	0.051	1935	0.043	1966	0.145	1997	0.646
1905	0.059	1936	0.049	1967	0.139	1998	0.514

[1] To convert to dollars per kilogram, multiply by 2.20462.

Note:

1875-1904, New York price for Prime Western zinc (98% pure), *in* Ingalls, W.R., Lead and Zinc in the United States, McGraw-Hill, NY, 1980, p. 342.

1905-70, St. Louis/East St. Louis producer price for Prime Western zinc, *in* American Metal Market/Metal Statistics.

1971-79, U.S. Dealers Prime Western delivered price, *in* Metals Week.

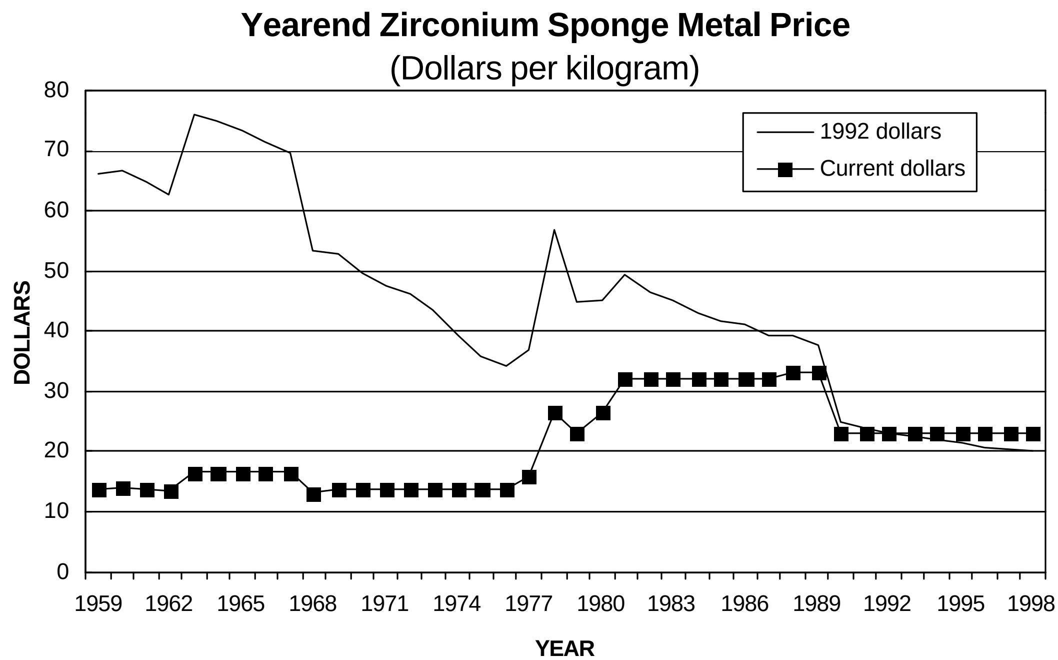
1980-93, U.S. Dealers High Grade zinc (99.9% pure) delivered price, *in* Metals Week.

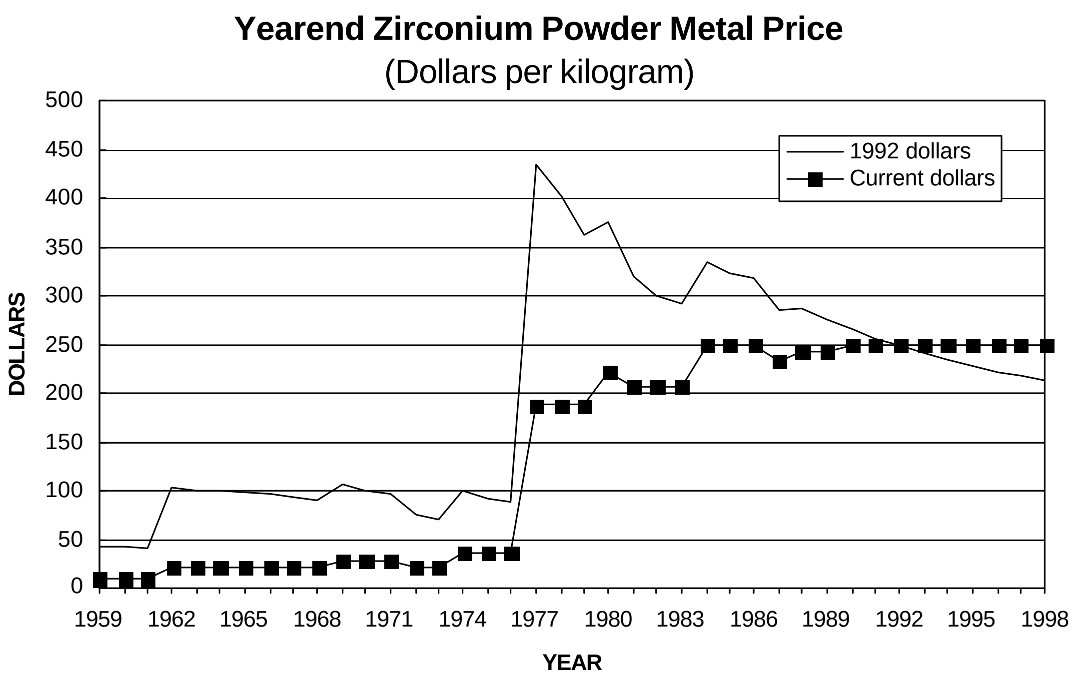
1994-98, U.S. Dealers Special High Grade zinc (99.99% pure) delivered price, *in* Platt's Metals Week.

(This page intentionally left blank.)

Zirconium

by James B. Hedrick





Significant events affecting zirconium prices

1957-62	Improved production methods and increased scale of operations and capacity led to declining prices
1977-78	Number of producers reduced to one; inflation, and lack of competition; demand increasing for high-purity specialty powders and metal

Zirconium metal is sold in three basic forms—powder, sponge, and crystal bar. Martin H. Klaproth discovered the element in Germany in 1789 by analyzing zircon (Weeks and Leicester, 1968). Production of the first impure zirconium metal was by Jöns Jakob Berzelius in 1824 (Berzelius, 1825). Commercial quantities of the ductile metal were not produced until 100 years later when Anton Eduard van Arkel and Jan Hedrik de Boer discovered the iodide, or crystal bar, process (van Arkel and de Boer, 1925). Powdered zirconium metal was available on domestic markets as early as 1930, when it was used primarily for its pyrophoric and alloying properties. Principal uses were for ammunition primers, vacuum-tube getters, flash powder used in photography, and corrosion-resistant steel alloys (Kalish, 1953). An economic process to produce zirconium metal sponge (Kroll, or magnesium-reduction, process) was developed in the mid-1940's and became commercially available in the early 1950's (Kroll, 1937; Kroll, Schlechten, and Yerkes, 1946; Kroll, Schlechten, and others, 1947; Kroll, Anderson, and others, 1948). Zirconium sponge is used in the production of zirconium metal and alloys, especially for use in nuclear fuel cladding, corrosion resistant piping in chemical processing plants, and heat exchangers. Crystal bar, which is a very high purity form of zirconium metal that is used mostly in research and special applications, is not covered in this report.

Zirconium Sponge

In January 1945, the U.S. Bureau of Mines (USBM) began research to develop a commercial process for making zirconium sponge metal (Etherington, Dalzell, and Lillie, 1955). By 1947, the USBM was operating a 27-kilogram (60-pound)-per-week pilot plant in Albany, OR, using the Kroll process. In response to the U.S. Navy's interest in zirconium for possible use in nuclear powered submarines, capacity at the pilot plant was expanded in 1949 (11,800 kilograms), 1950, and twice in 1951 (Shelton and others, 1956). By 1951, USBM capacity had reached about 136,000 kilograms (300,000 pounds) per year. That same year, commercial price quotations for zirconium sponge began at \$22 per kilogram (\$10 per pound). In 1952, the Atomic Energy Commission (AEC) contracted with Carborundum Metals Co., Akron, NY, to supply the metal for 5 years. By 1955, the Carborundum plant was producing more sponge than was needed for the U.S. Navy's nuclear submarine program. At this time, the USBM's zirconium plant was converted to a metallurgical research facility. From 1959 to 1977, the price of zirconium sponge remained fairly stable, averaging from about \$14 to \$17 per kilogram (\$31-\$37 per pound). The decline was also attributed to the slowing of the nuclear submarine program and the use of substitute materials for commercial powerplants. Beginning in 1978, prices for zirconium sponge increased, following the pattern of zirconium powder. The substantial price increase has been attributed primarily to the U.S. economy because lagging U.S. economic activity and double-digit inflation increased operating costs throughout the industry. The twofold price increase for zirconium sponge may have been associated with the 50% reduction in capacity by the sole domestic producer, the cost of implementing process environmental controls to regulate naturally occurring radioactive materials, and the continued demand for replacement fuel cladding and structural repairs at nuclear powerplants (Templeton, 1993).

In the 1980's and 1990's, the use of zirconium sponge in military and commercial nuclear powerplants, heat exchangers, and specialty chemical piping for corrosive environments eventually overshadowed the use of the metal in powder and crystal bar applications (Hedrick, 1989). With no new domestic construction of nuclear powerplants, demand for zirconium metal is expected to remain stable.

Zirconium Powder

In 1932, the price quoted for powdered metal of 98% purity was \$13.23 per kilogram (\$6 per pound) or less, depending on the quantity. The price remained stable throughout the next two decades, and the uses of the powder expanded to include applications in the ceramic, glass, and steel industries. The price for powdered zirconium declined to a record low of \$8.82 per kilogram (\$4 per pound) by 1957 as the Kroll process was commercialized and the demand and scale of operations increased. Increases in production and demand for zirconium sponge in the 1950's also probably contributed to the decline in the price of powder during this period. Beginning in 1977, prices for zirconium metal were tied to many factors, including the U.S. economy, as lagging U.S. economic activity and double-digit inflation increased operating costs throughout the industry. Increased energy costs were also a factor for the substantial price increases for zirconium powder and sponge. During the late 1970's, the number of zirconium powder producers declined to one for a short time, and requirements for high-grade powder started to increase. These events, including the development of the hydrogen embrittlement technique (hydride-dehydride process) to facilitate the conversion of sponge to powder and improved demand for replacement fuel cladding and structural repairs at nuclear powerplants, contributed to the increasing prices during this period.

Prices for zirconium powder stabilized during the 1980's and 1990's as market growth decreased and demand leveled off.

References Cited

Berzelius, J.J., 1825, Zirconium reducirt aus flusfspathfaurem Zirconkali, und einige Eigenschaften der Zirconerde [Zirconium obtained by the reduction of potassium-zirconium fluoride, and certain properties of zirconium earth (oxide)]: Leipzig, Germany, (Poggendorf), Annalen der Physik, v. 4, p. 121-156.

Etherington, H., Dalzell, R.C., and Lillie, D.W., 1955, Zirconium and its applications to nuclear reactors, chap. 1 *of* The metallurgy of zirconium: New York, McGraw-Hill, p. 1.

Hedrick, J.B., 1989, Zirconium and hafnium, *in* Minerals Yearbook 1988, v. I: U.S. Bureau of Mines, p. 1049-1057.

Kalish, H.S., 1953, The preparation of zirconium powder, chap. 5 *of* Zirconium and zirconium alloys: Cleveland, OH, American Society for Metals, p. 5-36.

Kroll, W.J., 1937, The formation of titanium and zirconium: Zeitschrift für Anorganishe Chemie, v. 234, p. 42.

Kroll, W.J., Schlechten, A.W., and Yerkes, L.A., 1946, Ductile zirconium from zircon sand: Transcripts of the Electrochemistry Society, v. 89, p. 263.

Kroll, W.J., Schlechten, A.W., Carmody, W.R., Yerkes, L.A., Holmes, H.P., and Gilbert, H.L., 1947, Recent progress in the metallurgy of malleable zirconium: Transcripts of the Electrochemistry Society, v. 92, p. 99.

Kroll, W.J., Anderson, C.T., Holmes, H.P., Yerkes, L.A., and Gilbert, H.L., 1948, Large scale laboratory production of ductile zirconium: Transcripts of the Electrochemistry Society, v. 94, p. 1.

Shelton, S.M., and others, 1956, Zirconium—Its production and properties: U. S. Bureau of Mines Bulletin 561, p. 1.

Templeton, D.A., 1993, Zirconium, *in* Metal prices in the United States through 1991: U.S. Bureau of Mines, p. 197-199.

van Arkel, A.E., and de Boer, J.H., 1925, Preparation of pure titanium, zirconium, hafnium, and thorium metal: Zeitschrift für Anorganishe und Allgemeine Chemie, v. 148, p. 345-350.

Weeks, M.E., and Leicester, H.M., 1968, Discovery of the elements (7th ed.): Easton, PA, Journal of Chemical Education, p. 517-520.

Yearend Zirconium Sponge Metal Price
(Dollars per kilogram[1])

Year	Price	Year	Price	Year	Price	Year	Price
1959	13.78	1969	13.78	1979	23.15	1989	33.07
1960	14.05	1970	13.78	1980	26.46	1990	23.15
1961	13.78	1971	13.78	1981	31.97	1991	23.15
1962	13.50	1972	13.78	1982	31.97	1992	23.15
1963	16.53	1973	13.78	1983	31.97	1993	23.15
1964	16.53	1974	13.78	1984	31.97	1994	23.15
1965	16.53	1975	13.78	1985	31.97	1995	23.15
1966	16.53	1976	13.78	1986	31.97	1996	23.15
1967	16.53	1977	15.98	1987	31.97	1997	23.15
1968	13.23	1978	26.46	1988	33.07	1998	23.15

[1] Prices are an average of a range and converted from dollars per pound.

Sources: American Metal Market (1959-62, 1969-98), Engineering & Mining Journal (1963-67), and Wah Chang Albany Corp., Albany, OR (1968).

Yearend Zirconium Powder Metal Price
(Dollars per kilogram[1])

Year	Price	Year	Price	Year	Price	Year	Price
1959	8.82	1969	27.56	1979	187.39	1989	242.51
1960	8.82	1970	27.56	1980	220.46	1990	248.02
1961	8.82	1971	27.56	1981	206.68	1991	248.02
1962	22.05	1972	22.05	1982	206.68	1992	248.02
1963	22.05	1973	22.05	1983	206.68	1993	248.02
1964	22.05	1974	35.27	1984	248.02	1994	248.02
1965	22.05	1975	35.27	1985	248.02	1995	248.02
1966	22.05	1976	35.27	1986	248.02	1996	248.02
1967	22.05	1977	187.39	1987	231.49	1997	248.02
1968	22.05	1978	187.39	1988	242.51	1998	248.02

[1] Prices are an average of a range and converted from dollars per pound.

Source: American Metal Market.

Appendix
Price Deflators, 1959-98[1]

Year	Price deflator[2]	Year	Price deflator[2]
1959	4.814	1979	1.933
1960	4.745	1980	1.703
1961	4.694	1981	1.543
1962	4.639	1982	1.454
1963	4.582	1983	1.409
1964	4.524	1984	1.351
1965	4.453	1985	1.304
1966	4.323	1986	1.280
1967	4.206	1987	1.235
1968	4.034	1988	1.187
1969	3.825	1989	1.132
1970	3.614	1990	1.074
1971	3.465	1991	1.030
1972	3.356	1992	1.000
1973	3.160	1993	0.971
1974	2.846	1994	0.947
1975	2.607	1995	0.921
1976	2.466	1996	0.895
1977	2.315	1997	0.874
1978	2.151	1998	0.860

[1]Derived from the Consumer Price Index-All Urban Consumers provided by the U.S. Department of Labor Statistics (1992=100). The method for computing the Consumer Price Index (CPI) before 1995 shows a slightly higher rate of inflation than that derived from the newer method used in recent years. According to the Bureau of Labor Statistics and the President's Council of Economic Advisers, the new method used from 1995 through 1998 has resulted in lowering the CPI inflation rate by 0.49 percentage point per year.
[2]To calculate price in constant 1992 dollars, multiply current price by price deflator. Each yearly price deflator is the ratio of 100 to the CPI.