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The U.S. Zinc Industry: A Historical Perspective

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THE U.S. ZINC INDUSTRY: A HISTORICAL PERSPECTIVE

by

A. D. McMahon,[1] C. H. Cotterill,[2] J. T. Dunham,[3] and W. L. Rice[4]

ABSTRACT

Changes in world mine and smelter supply sources of zinc have led to changes in zinc supply patterns in the United States during the past 3 years, 1970-72. The result has been a growing reliance on foreign sources of zinc metal to furnish an ever-increasing portion of expanding domestic requirements. This review of fundamentals and historical developments is intended to provide background in order to place the future of the U.S. zinc industry in perspective. The properties and uses of zinc are described. A new study on U.S. reserves is presented with description by geographical region and comparisons with older reserve data. The technology of the zinc industry from prospecting through refining is described with emphasis on the metallurgy involved in the various methods of smelting. Production, consumption, and imports are discussed and illustrated with graphs and tables to review the past and present patterns. Government actions affecting the industry are shown.

INTRODUCTION

Characterization of Developments in the U.S. Zinc Industry

The Mining and Minerals Policy Act of 1970 set forth and formally established for the first time the mineral policy of the United States. The Act states that the Congress declares that it is the continuing policy of the Federal Government in the national interest to foster and encourage private enterprise in (1) the development of economically sound and stable domestic mining, minerals, and metal and mineral reclamation industries; (2) the orderly and economic development of domestic mineral resources, reserves, and reclamation of metals and minerals to help assure satisfaction of industrial, security, and environmental needs; (3) mining, mineral, and metallurgical research, including the use and recycling of scrap to promote the wise and efficient use of our natural and reclaimable mineral resources; and (4) the study and development of methods for the disposal, control, and reclamation

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[1] Supervisory physical scientist.
[2] Physical scientist.
[3] Metallurgist.
[4] Geologist.

of mineral waste products, and the reclamation of mined land, so as to lessen any adverse impact of mineral extraction and processing upon the physical environment that may result from mining or mineral activities.

The Act requires the Secretary of the Interior to carry out the policy and to annually report to Congress on "the state of domestic mining, minerals, and mineral reclamation industries, including a statement of the trend in utilization and depletion of these resources, together with such recommendations for legislative programs as may be necessary to implement the policy of this Act."

Zinc is one of the major metals included in the First Annual Report of the Secretary of the Interior Under the Mining and Minerals Policy Act of 1970. The report, which was released in March 1972, emphasized that the combined output of the metal industries was valued at more than $150 billion annually, compared to the U.S. gross national product (GNP) of somewhat over $1,000 billion. It noted that development of domestic resources was not keeping pace with demand, and it identified some major problem areas including the following:

1. Foreign mineral supplies were becoming more costly, and some operations were being expropriated.

2. More competition was being encountered for foreign mineral supply.

3. Increased dependence on imports placed more constraints on U.S. foreign policy.

4. Investment in domestic mineral development was lagging.

5. Environmental regulations were limiting some production.

6. Demand for oil and gas exceeded domestic productive capacity.

7. Land withdrawals were adversely affecting exploration and development.

8. For some minerals, increased competition from imports was being felt.

9. There were increasing deficits in the mineral balance of trade.

10. Stockpile disposals overhung domestic mineral markets.

11. Mining suffered from a shortage of skilled manpower.

12. U.S. transportation facilities were not keeping pace with industrial requirements.

13. Fundamental research related to minerals was being cut back.

14. Government organization and information was antiquated.

15. Productivity of U.S. industry was inhibited by Government regulation.

Many of the problems enumerated are critical in attaining objectives set out in the Policy Act--some apply to the entire spectrum of the U.S. mineral industry.

The domestic zinc industry has been directly affected by several of the problems. As a result, of the some 1,290,500 tons of annual zinc smelting capacity in 1968, only 721,500 tons was operable at the beginning of 1973 and, based on announced plans, will be reduced to 647,000 tons by the end of 1973--a reduction of 50 percent in 5 years. This is the result of closing nine of the 14 smelters that were operating in 1968. By December 31, 1973, six smelters will be operating. This, because one smelter was closed by one operator, and purchased, rehabilitated, and reopened 2 years later by another firm.

Significant decreases in mine production in 1970, 1971, and 1972 resulted from the closing of 25 mines due to unprofitable operations and closing of smelting facilities. Many of the ore bodies in former productive areas have been worked out or have become too costly to mine. However, expansion at currently producing mines and future production from recently developed properties should maintain a level of domestic mine production at approximately 500,000 tons per year.

In spite of increased U.S. annual slab zinc consumption from 1,350,000 tons to 1,418,000 tons between 1968 and 1972, annual domestic smelter production decreased from 1,101,000 tons to 707,000 tons and annual domestic mine production declined from 529,000 tons in 1968 to 478,000 tons in 1972. Increased domestic needs were met in 1972 essentially by release of over 210,000 tons from the U.S. Government strategic stockpile. Greater dependence on foreign smelters developed to the extent of 220,000 tons during this 4-year period. Once the remaining surplus of stockpile metal is sold, reliance on foreign zinc smelting (and mining) will increase in lieu of the stockpile sources.

From a balance-of-payments standpoint and from value-added and maximum employment considerations, imports of metal are much less desirable than imports of the equivalent zinc content in ore. Either alternative is even less desirable, from the viewpoint of criteria set forth in the Mining and Minerals Policy Act of 1970, than the development and mining of domestic zinc reserves which are smelted domestically.

The purpose of this study is to provide a review of historical developments in the U.S. zinc industry to aid in evaluation of the present zinc supply situation.

The Department of the Interior, pursuant to the Mining and Minerals Policy Act, is considering "recommendations for legislative programs as may be necessary to implement the policy of this Act" and such recommendations as are made will consider the special problems of the zinc industry.

Review of Developments in the World and U.S. Zinc Industry

A useful time frame for examining the events leading to the current problems of the U.S. zinc industry is the 14-year period 1958-72. During the 5-year period, 1959-64, the free world zinc industry witnessed an increase in demand of 40 percent (6.6 percent per year 1959-64). For 2-1/2 years prices were comparatively stable (14.5 cents U.S. 1964-67). During the 7 years, 1959-66, world consumption was consistently greater than newly mined ore and smelter production. This gap was closed by drawing down large surpluses of both ore and metal which had accumulated after the Korean War.

Generally exploration and finding a commercial ore body, then developing it to a point of useful mine production involves 5 to 7 years. Although the first observation of marked increase in zinc consumption was in the late 1950's and early 1960's, production did not respond to this demand until the mid-1960's. This time span was required to establish the certainty of the rising consumption trend, initiate exploration, and finance and develop production facilities. Concurrently the demand growth rate fell to 1.7 percent during the period 1964-67. Characteristically mine production could not be rapidly adjusted to match demand and ore prices declined. Development of new mines was deferred.

In the meantime world zinc smelter operators, being in closer touch than the mine operators with the consumer, became firmly convinced of the potential growth in demand and set plans to expand smelting capacity. Also, the encouragement and assistance of several foreign governments, intent on realizing the benefits of the "value-added" increment, stimulated expansion of existing smelters and new smelter construction. Thus, large additions to smelting capacity began coming on stream in 1967. In late 1969 and in 1970, smelter demand for ores greatly exceeded mine production resulting in ore prices being bid up to a point where smelter margins worldwide, if not becoming actual losses, were drastically reduced (by as much as 1.5 cents per pound or $30 per ton of metal). Concurrently, the demand for metal declined with the slowdown in the economy and inflationary pressures increased with the result that labor and material costs rose rapidly, eroding smelting profits. This "cost-price squeeze" was not limited to U.S. smelters, but there were variations in the degree of inflation from country to country.

Those smelters that were newly built, more efficient, larger scale, more soundly financed, more favorably located, and often receiving governmental assistance in some form, tended to weather economic adversity while those not having such advantages were squeezed out. Three U.S. horizontal retort plants closed in the 1960's as well as several in Europe and Japan. In 1971-72, 38 percent of the total U.S. zinc smelting capacity was closed. The virtual certainty of future additional costs to meet environmental standards for particulate, gaseous, and waste water effluents increased the likely losses. This situation, coupled with the competition of new foreign smelters built on a largely nationalistic rationale, finally led to the decision by several companies to go out of business.

The remaining U.S. zinc smelting capacity in 1973 of about 750,000 tons annually is 50 percent greater than the 500,000 tons of recent and current annual mine production. It is possible that another 200,000 tons of smelter capacity may be forced to close permanently due variously to environmental controls, sharp increases in fuel costs, and foreign preemption of ore supply. Some 80,000 tons of electrolytic capacity previously closed will be partially reactivated in 1973, while 140,000 tons of retort capacity is expected to close in 1973-75. Aside from the imbalance of mine production and smelter capacity, geographical and technological factors close some smelter markets to some potential domestic mine production. However, some benefits accrue from smelting imported ore because foreign ores typically contain higher concentrations of cadmium, copper, silver, and gold than do many domestic ores. The importation of slab zinc instead of the ore increases U.S. reliance on foreign supply of such byproducts metals.

Processing foreign ores in this country is competitively disadvantaged by a tariff on ore imports, whereas most countries enter ore duty free, although metal imports are dutiable. Other forms of preferential treatment afforded foreign smelting industries by their governments include rapid amortization of facilities, long-term low-interest loans or loan guarantees, tax-free periods, reduced tax rates on profits, subsidy of exports, outright construction grants based on number of jobs to be created or other criteria, legal requirements for installation of smelting capacity as a precondition to opening a mining property, and sometimes direct government participation in and/or management of the smelting company.

PROPERTIES AND USES OF ZINC

Zinc serves the needs of mankind anonymously, in the main. Among the major metals of today's civilization (iron, aluminum, copper, lead, and zinc) all except zinc are easily recognized as such by the consumer. In virtually all cases, zinc loses its identity in the end products; the major consuming categories are galvanizing, brass, castings, rolled zinc, and chemicals. Zinc has been found to be beneficial and necessary in proper nutrition of humans, animals, and plants.

Zinc is a bluish white relatively soft metal having a density slightly less than iron (7.133 versus 7.86 g/cc). The atomic number is 30, atomic weight 65.37 and it is placed in Group II-B of the periodic table. Zinc is divalent in all its compounds.

Physical Properties

Physical characteristics include having a brittle hexagonal crystal structure, as cast, which is modified upon heating to about 120° C at which point it becomes ductile and is easily rolled or drawn. After mechanical working in this temperature range the metal does not become brittle again upon cooling. Thus wrought zinc is used to form roofing in building applications and as drawn cans for dry power cells. The high electrochemical activity of zinc, being surpassed among the common metals only by magnesium and aluminum in the electromotive series, accounts for one of its largest uses--galvanizing of iron and steel. In this application zinc undergoes sacrificial corrosion from the surface of the steel, protecting the substrate from structural degradation. Zinc readily alloys with other metals, imparting characteristics of workability at low temperature, corrosion resistance, and pleasing finishes for use in diecasting alloys, brass, and other common alloys. Table 1 sets forth some of the physical properties of zinc.

TABLE 1. - Physical properties of zinc

Atomic properties:	
Atomic number	30
Atomic weight	65.37
Zn isotopes, natural	64 (48.84 percent)
	66 (27.62 percent)
	67 (4.12 percent)
	68 (18.71 percent)
	70 (0.69 percent)
Zn isotopes, artificial (radioactive)	62
	63
	65
	69
	72
	73
Crystal structure	Hexagonal close-packed
Crystal lattice, A:	
a	2.664
c	4.9469
c/a	1.856
Atomic radius	1.31
Electron configuration	2-8-18-2
Mass properties: Density (solid at 25° C) g/cc	7.133
Thermal properties:	
Melting point ° C	419.5
Boiling point ° C	907
Combustion point (approx.) ° C	1,800
Heat of fusion cal/g	24.4
Heat of vaporization (907° C) cal/g	419.5

Chemical Properties

Pure zinc at ambient temperatures is highly resistant to attack by dry air, but above 225° C the rate of attack increases rapidly. In moist air, attack proceeds at room temperature and, in the presence of carbon dioxide, forms the hydrated basic carbonate. The latter forms a tightly adhering light-grayish film which tends to protect the zinc from further corrosion. Halogens react with zinc in the presence of moisture but not if dry. Reaction with steam above 350° C occurs rapidly. Mineral acids readily attack zinc, the strongest reaction being with sulfuric, followed by hydrochloric and nitric. Zinc displays a vigorous reducing power, liberating hydrogen from sulfuric and hydrochloric acids. This property forms the basis for the use of zinc dust or mossy zinc in many commercial organic chemical processes. With nitric acid, zinc liberates nitrogen oxides. The metal is amphoteric, reacting with hot caustic to evolve hydrogen and form zincates. Zinc is inert to petroleum derivatives and anhydrous alcohol but is oxidized by mixtures of alcohol and water.

Zinc Metal and Alloys

Commercial grades of zinc metal have been established by the American Society of Testing and Materials (ASTM) as set forth in table 2.

TABLE 2. - Grades of slab zinc and chemical composition[1]

Grade	Composition, percent			
	Lead, maximum	Iron, maximum	Cadmium, maximum	Zinc, minimum, by difference
Special High-Grade[2].....	0.003	0.003	0.003	99.99
High-Grade.............	.07	.02	.03	99.90
Intermediate...........	.20	.03	.40	99.50
Brass Special[3]..........	.60	.03	.50	99.00
Prime Western...........	1.60	.05	.50	98.00

[1] ASTM Standards, pt. 6, p. 1 (Specification B6-70).

[2] Tin in Special High-Grade shall not exceed 0.001 percent.

[3] When specified for use in the manufacture of rolled zinc or brass, aluminum shall not exceed 0.0005 percent.

Prime Western zinc was the specification first established for use in hot-dip galvanizing. Brass Special and Intermediate were largely used in alloying with copper to form brass. High-Grade, and later Special High-Grade, were established with the advent of alloys containing small amounts of aluminum, to be used in the diecasting of intricate functional parts cast to very close dimensional tolerances.

Basic alloying parameters are governed by the maximum solid solubilities of other metals in zinc; for example, gold is soluble to the extent of 10 to 15 percent, silver 8 percent, cadmium, palladium, and copper 2 to 3 percent, manganese and aluminum 0.5 to 1 percent. In forming intermetallic compounds higher percentages occur. The effects imparted by several metals to the physical and chemical properties of zinc in the form of either solid solubilities or intermetallic compounds are as follows:

1. Lead in small quantities in rolled zinc used for manufacture of dry cells promotes a desirable rate of chemical reaction for the proper release of electrochemical energy.

2. Cadmium in rolled zinc tends to increase strength, hardness, creep resistance, and recrystallization temperature.

3. Iron, when alloyed with zinc in the substrate of galvanized steel, is of paramount importance to a properly galvanized article. A cross section of the coating shows first a layer of pure iron overlain by a very thin layer of $FeZn_3$, over which is a thicker layer of $FeZn_7$, above which is a layer of essentially pure zinc with a few solid crystals of the $FeZn_7$. These various alloys are quite resistant to corrosion and form an adherent bond between the steel base and the zinc.

4. Tin is deleterious in very small quantities in zinc that is to be rolled as it causes ruptures during hot rolling. In castings also it promotes subsurface corrosion. On the other hand small amounts of tin will cause an esthetically desirable "spangle" on galvanized sheet.

5. Copper increases strength, hardness, creep resistance, and recrystallization temperature. It has undesirable effects on corrosion of zinc in dry cells.

6. Aluminum at levels of 3.5 to 4.5 percent reduces grain size and improves impact strength and castability of zinc. In galvanizing, diecasting, and protective galvanic anodes, aluminum beneficially inhibits formation of the zinc-iron alloy.

7. Magnesium counteracts subsurface corrosion effects of tin and lead in zinc alloys.

8. Titanium forms a zinc-rich compound tending to decrease grain size of cast zinc and restrain grain growth in rolled zinc at elevated temperatures. Used in newer rolled zinc applications, it greatly increases creep resistance.

One of the growing uses of high-purity zinc metal is in zinc-base alloys for diecasting. This process enables a dimensionally accurate equipment part to be produced in a diecasting machine in fractions of a minute with the advantage of requiring few finishing operations before use.

The diecasting alloys are widely used in producing automobile parts such as carburetors, grills, door handles, and ornaments; appliance control panels, home washer parts, television bezels, transistor radio and camera frames; and small control gears and many other applications.

A zinc-containing alloy in growing use is aluminum-base diecasting alloy incorporating from 2.7 to 8 percent zinc. Although involving higher die temperatures and requiring a slightly slower operating speed than that for zinc-base alloy, parts made of this alloy exhibit high tensile strengths.

Many solders, especially for use on aluminum, contain zinc along with other alloying metals. Silver and gold solders also are alloyed with zinc.

Alloys in which zinc is a minor constituent include perhaps the oldest known use of zinc. These are the copper-zinc alloys known as brass. Commercially, these range from 5 to 40 percent zinc with copper being the major component. Brass is useful for its superior strength, greater ductility, and corrosion resistance. It is widely used in hardware, plumbing accessories, instruments, and communication equipment as well as for its pleasing yellowish-gold color.

Wrought zinc in general is composed of commercial grades of zinc to which has been added only very small amounts of metal to alter the properties of the zinc. Important characteristics of these wrought zinc alloys for commercial use include resistance to corrosion; white and nonstaining corrosion products; desirable chemical characteristics for dry cells and photoengraving plates; mechanical properties for easy forming, machining, and spinning; and good solderability.

While not strictly an alloying application, use of zinc as galvanizing to coat iron and steel objects is a leading use of the metal. Dipping steel in a bath of molten zinc results in a coating of from 1 to 2 ounces of zinc per square foot of steel surface. The coating then galvanically protects the underlying steel from corrosion when put in use, by reason of the higher electromotive potential of zinc over iron. Thus the zinc coating must be entirely corroded off before the iron substrate begins to rust, so that the structural strength of the article is preserved by sacrificial corrosion of the zinc. These uses range from galvanized garbage cans to barbed and woven wire fencing, steel woven cable, highway guardrail, radio and electrical transmission towers, building structures, and bridges. A more recent process of continuous-line galvanizing using a precisely controlled minor alloying metal content in the zinc bath is used to provide superior, economical coating on continuous steel sheet for use in building siding, downspout and guttering, air ducts, automobile and appliance bodies, etc.

Zinc Compounds--Inorganic

Its high reactivity with other elements and its amphoteric character result in zinc forming a wide variety of salts--the sulfates and chlorides being water soluble while the oxides, carbonates, phosphates, silicates, and organic complexes are largely insoluble. From the standpoint of quantity used and value, zinc oxide is by far the most important compound formed by zinc.

Zinc Oxide

Zinc oxide crystallizes in a white hexagonal form and combustion control during formation can modify the particle size and shape to achieve desired properties. The largest use is in the compounding and vulcanizing of rubber wherein the properties of high heat capacity and heat conductivity serve to cool flexing rubber in belts and tires. Also in the vulcanizing of rubber this compound scavenges any free sulfur remaining in the article after processing.

The high refractive index of zinc oxide accounts for its use as a pigment in white paints giving high hiding power. On exterior paints the ability of a thin film of zinc oxide to completely absorb ultraviolet rays from the sun is useful, as well as its mildewcidal action to prevent staining.

Classification of zinc oxide is commonly by method of production. "American Process" is made by carbon reduction of roasted zinc ore, burning the resultant zinc vapor to form zinc oxide; "French Process" zinc oxide is produced by burning zinc metal in air; some "chemical process" oxide is made by precipitation of zinc hydroxide from solution and calcining to form oxide.

Zinc oxide is insoluble in water, organic solvents, and neutral oils. With organic and inorganic acids it forms simple and complex salts and soaps. Reaction with alkalies forms zincates. The oxide may be used to catalyze some chemical reactions. One of the oldest uses is pharmaceutically in treatment of burns, infections, and skin diseases. Uses relying on physicochemical properties include the rapidly growing photoconductivity field where a carefully produced zinc oxide is coated on paper and used in office photocopying applications. The ceramic industry produces frits and glazes in which zinc oxide provides color for pottery or improves the brilliance of glass.

Other Inorganic Zinc Compounds

Zinc acetate is used as a mordant in dyeing and in glazes for porcelain. It is used as an astringent and antiseptic in personal hygiene.

Zinc borates are useful for fire retardancy and as fluoborates for insecticides.

Zinc carbonate (and zinc oxide) is now in growing application as a nutritive supplement for many animals such as swine, sheep, and poultry.

Zinc chloride has a low melting point and is used in galvanizing fluxes, as a wood preservative and a fire-retardant agent for wood, in dry cells, as a disinfectant, a printing mordant, and for mercerizing cotton.

Zinc chromate has use as a wood preservative, algicide, and a primer for metal surfaces for corrosion protection.

Zinc cyanide serves as a zinc carrier for electroplating and for medicinal purposes in treating epilepsy, neuralgia, etc.

Zinc fluosilicate is used as a concrete hardener and as a wood preservative.

Zinc nitrate finds use as a mordant in dyeing.

Zinc permanganate finds some application as an antiseptic and astringent.

Zinc peroxide as a powder functions topically as a deodorant, astringent, and antiseptic for wounds and skin diseases.

Zinc phosphate is chiefly used in dental cements.

Zinc silicate is used as a phosphor in television screens.

Zinc sulfate is water soluble and finds use as a hardener in viscose rayon spinning baths, as a flotation reagent, and increasingly as a trace element to overcome zinc deficiencies in plants grown in certain areas.

Zinc sulfide may be used as a white paint pigment, most often as a component of barium lithopone for inside application. High-purity zinc sulfide also has wide use as a phosphor in cathode ray television tubes and fluorescent lamps.

Zinc Compounds--Organic

Most of the organic derivatives of zinc account for very small commercial quantities whereas many of the inorganic compounds are sold in thousand-ton quantities.

Zinc bacitracin is an antibiotic for human use in ointments, and is a growth factor in swine and poultry nutrition.

Zinc phenolsulfonate acts as an insecticide and is used for internal treatment of ulcers and wounds.

Zinc proprionate and caprylate function as fungicides in adhesive tape coatings, preparations to combat athletes foot and molds, fungi, and bacteria.

Zinc salicylate is used as an astringent and antiseptic.

Zinc soaps (stearates, palmitates, and oleates) are salts of fatty acids. They are white, fine, bulky, soft powders with a greasy feel. They repel water, but are generally soluble in benzene and petroleum derivates. They are used as a lubricant and mold release compounds in rubber and plastic forming, metal diecasting, and medicine tablet making. These soaps serve to waterproof concrete, paper, and textiles, and as flatting agents in lacquers.

Zineb and ziram (zinc ethylenebis[dithiocarbamate] and dimethyldithiocarbamate, respectively) are widely used as agricultural fungicides for which humans are much more tolerant than for the mercury, lead, and copper fungicides which the zinc salts replace. Some plants also receive added value from the contained zinc as a nutrient.

Many other organic zinc salts are used in medicinal applications based on the toxic effect of small quantities of zinc on many micro-organisms harmful to human, animal, and plant life.

Use Pattern

The construction industry is the most important market for zinc-coated material. Galvanizing accounts for over 90 percent of the total zinc used for protective covering of iron and steel used for structural steel, roofing, siding, guttering, and decking for concrete floors. Galvanized sheet is the standard duct material for air-conditioning, ventilating, and heating systems and is used for channels and conduits for electrical and telephone wires in large buildings. Zinc dust paints are growing in importance for primers and complete protective systems on structural steel. Zinc oxide has lost a substantial percentage of the paint market to titanium dioxide and to water-thinned paints that do not contain zinc oxide. Brass and zinc-bearing bronze find widespread use in the architectural field for construction of window walls, door and window frames, railings, panels, spandrels, and building hardware. Brass fittings as faucets, valves, traps, and pump bodies are important to the plumbing and heating industries, as are brass condenser and heat exchanger tubes. Rolled zinc sheet and strip is used extensively for rainwater gutters and pipes and for roof coverings and flashings in Western Europe, but very little is so used in other countries.

The transportation industry is the major consumer of zinc with particular requirements for galvanized steel sheet, diecasting alloys, brass, and zinc oxide. The automobile industry accounts for about one-third of total U.S. zinc consumption. The use of galvanized underbody parts to overcome corrosion problems caused from deicing salts used in winter has grown eighteenfold since 1950. The largest single use is in diecastings for automobile components. Brass is used for radiators, tubing, and decorative trim. About half the total consumption of zinc oxide is for rubber manufacture and the major use of the rubber is in automobile tires. Aircraft, ships, boats, buses, trucks, trailers, motor scooters, bicycles, railway rolling equipment, and massive belt conveyor systems account for over 10 percent of the zinc used for transportation.

Electrical equipment and supplies related to domestic appliances and office equipment account for more than 10 percent of total zinc consumption, where it is used for galvanized castings, die-cast parts, brass stampings and pressings, zinc sheet and strip, and zinc oxide in refrigerators, washers, dryers, stoves, dishwashers, bookkeeping machines, motorized files, radios, clocks, and other small appliances.

Machinery, including that for agriculture, roadbuilding, excavating, materials handling equipment, and the many types of mechanical equipment in manufacturing plants use nearly 10 percent of all zinc consumed.

The use of zinc oxide in the chemicals category increased remarkably since 1964 because of its use in sensitizing photocopying paper. This use now consumes about 52,000 tons of zinc per year.

Rolled zinc serves small but important markets for dry-battery shells, lithographic plates, and in construction as flashing, trim, and decorative panels. Approximately 10 percent of the zinc consumed is distributed between a number of miscellaneous uses. An important item is sacrificial anodes used to protect ship hulls, and submerged steelwork and pipes. Substantial quantities are used in aluminum and magnesium alloys, for desilverizing lead, extraction of gold, and for purification of zinc electrolytes.

ZINC RESOURCES

The average zinc content of the earth's crust has been estimated at 80 parts per million, although it varies widely in different types of rocks. There is usually more zinc in mafic igneous rocks and in carbonaceous shales and less in felsic intrusive rocks and in sedimentary rocks of carbonate composition. There is also far more iron, aluminum, and manganese in average rocks than there is zinc, whereas there is less copper and lead. Zinc is rarely found in the native metal state but in compounds with other elements. By far the most common of these compounds, is the mineral sphalerite. Zinc minerals are generally associated with other metallic minerals, the more common of which contain lead and copper. These anomalous concentrations are widely scattered over the continents but only in rather restricted localities and only in favorable geologic environs are they concentrated in sufficient quantity to be classed as ore deposits. In these deposits the zinc and lead minerals, sphalerite and galena, respectively, are mineralogically compatible and are found in combination throughout the world. Together with their oxidational products, they account for almost all of the zinc and lead that is mined.

Mineralogy and Geology

Many minerals contain zinc but the principal ore mineral is sphalerite, a zinc sulfide, sometimes referred to as "blende." Common varieties of this mineral are yellow or resinous brown, although it may occur in other colors, depending on the impurities present. Trace metals associated with and recovered from zinc sulfides include cadmium, germanium, gallium, indium, and thallium.

Zinc sulfides oxidize readily to a number of secondary minerals, the more common of which are the zinc carbonate, smithsonite, and the zinc silicate, hemimorphite. The latter commonly is known as calamine. Smithsonite and calamine frequently occur together in the same oxidized deposit and are referred to simply as oxidized zinc ore. The zinc minerals franklinite, willemite, and zincite are the ore minerals of the major zinc deposits at Franklin Furnace and Sterling Hill, N.J., but are rare elsewhere in the world. Some characteristics of the common zinc ore minerals are shown in table 3.

TABLE 3. - Properties of common ore minerals of zinc

Mineral	Composition	Specific gravity	Percent Zn
Sphalerite...........	ZnS	3.9 -4.1	63-67
Wurtzite.............	ZnS	3.98	59-67
Smithsonite..........	$ZnCO_3$	4.43	52
Hemimorphite.........	$H_2Zn_2SiO_3$	3.4 -3.5	54
Franklinite..........	$(Mn,Zn,Fe)O \cdot (Fe,Mn)_2O_3$	3.07-3.22	14
Willemite............	Zn_2SiO_4	3.89-4.18	51
Zincite..............	ZnO	5.43-5.70	75
Hydrozincite.........	$2ZnCO_3 \cdot 3Zn(OH)_2$	3.5 -3.8	59.5

Zinc and lead occur together in deposits of such differing habitat and origin that they have been classified and reclassified into many different types. For purposes of simplicity most of the zinc-lead deposits are classified according to their geologic environment as (1) stratabound deposits in carbonate rocks, (2) irregular deposits in carbonate and clastic rocks, (3) stratabound deposits in metamorphic rocks, (4) deposits in contact metamorphic rocks, and (5) deposits in veins.

One of the more common modes of occurrence of zinc-lead ore is as stratabound deposits in carbonate rocks. Many of the major zinc-lead deposits of the world are of this type. The ore bodies occur along and within selected stratigraphic units of limestone or dolomite; and if stratigraphically controlled they commonly are described as "bedded" or "stratified deposits." In the United States many of them are referred to as deposits of the Mississippi Valley type. The age of the host rocks varies but most of the deposits are in rocks of Paleozoic age. They may be in either flat-lying or folded strata, and in faulted or unfaulted strata. The mineralogy of these deposits is quite simple. Sphalerite and galena are the common primary ore minerals, sphalerite commonly being more abundant than galena. Barite and fluorspar are accessory ore minerals in many of these deposits, and dolomite, calcite, and jasperoid are common gangue minerals. In some deposits one of the principal sulfides may be much more prevalent than the other; for example, the galena-rich deposits in southeast Missouri as contrasted to the sphalerite-rich deposits in eastern Tennessee. The ores in the stratabound deposits are relatively deficient in gold, silver, and copper content. The grade of ore may be rich locally, but if the deposits are mined on a mechanized, large tonnage-low cost basis, the cutoff grade of ore is rather low. Typical deposits of this type are in the Tri-State district of Missouri, Kansas, and Oklahoma and in the East Tennessee district.

Irregular deposits in carbonate or clastic rocks generally are near intrusive igneous stocks of intermediate to acidic composition, to which they appear to be spatially and genetically related. Most are confined to zones where favorable strata are crossed by structural breaks. They may occur throughout the stratigraphic section as bedded deposits, associated with veins, or as replacement bodies in pipelike structures that transgress the section. Ore from these deposits is more like that of ore in veins and contains appreciable amounts of copper, silver, and gold. Typical of these are the silver-lead-zinc deposits of the Park City, Bingham, and Tintic districts in Utah, and the Eureka district in Nevada.

Stratabound deposits in metamorphic rocks are massive deposits of zinc-lead and zinc-copper ores found in metamorphic rocks throughout the world. They consist essentially of fine-grained aggregates of iron sulfides, sphalerite, galena, and commonly chalcopyrite, and they occur as massive, lenticular ore bodies that trend parallel to stratification of the enclosing metamorphosed sediments or volcanics. Although some deposits of this type tend to cross the bedding or foliation, there is evidence that many of these originally were bedded deposits subsequently metamorphosed and folded. These deposits include the largest concentrations of zinc-lead and zinc-copper ores known, including the Broken Hill and Mount Isa districts of Australia, the

Sullivan mine in British Columbia, the newly discovered ore bodies in Quebec, Ontario, and New Brunswick, Canada, and the Franklin-Sterling Hill deposits in New Jersey.

Contact metamorphic deposits are those contained in metamorphosed sedimentary rocks adjacent to an igneous intrusive. They are found in carbonate rocks that have been metamorphosed to various assemblages of silicated rocks commonly referred to as skarn, tactite, garnet rock, etc. Chalcopyrite, pyrite, pyrrhotite, sphalerite, and molybdenite are the common ore minerals. The ore may be in tabular bodies that parallel the bedding of the host rock, in irregular or pipelike deposits roughly conformable to the igneous contact, or in veins that transgress the metamorphosed host rock. Although there are many deposits of this type in the United States, only a few have been significant producers.

Veins are a common habitat for zinc-lead deposits, although a relatively small portion of the world's production of zinc comes from them. They are tabular structures, narrow in width compared to length and depth, and have sharply defined walls. The veins are not uniform in their metal content, and within them are enriched sections or ore shoots that are higher in grade than ore from stratabound deposits and contain more gold, silver, copper, and other metals. In the United States prominent zinc-producing veins include those in the Coeur d'Alene district of Idaho, Butte, Mont., and many in Colorado.

Table 4 shows the distribution of contained zinc estimated to occur in various environmental types of deposits for the world and the United States. As may be seen from the table, about two-thirds of the unmined zinc ore is in stratabound deposits, and it is likely that deposits of this type will continue to be most productive in future years.

TABLE 4. - Distribution of world measured and indicated reserves of zinc in various types of deposits

Type of deposit	Percent of total	
	United States	World
Stratabound deposits:		
Deposits in metamorphosed rocks	19	35
Deposits in nonmetamorphosed carbonate rocks	51	32
Irregular deposits in carbonate and clastic rocks	14	14
Veins in sedimentary, igneous, and metamorphic rocks	10	10
Deposits in contact-metamorphic rocks	5	8
Veins in Tertiary volcanic rocks	1	1
Total	100	100

Definition of Ore Reserves and Potential Resources

The aggregated mineral potential of an area is the summation of mineralized material quantities falling under the broad categories of ore reserves and potential resources.

The term ore reserves refers to material that in some degree has been measured in terms of commercial enterprise, and can be mined, processed and marketed at a profit. Potential resources include material of marginal and submarginal grade that may, with improved economic conditions, become ore reserves, and material that must await new technology to become exploitable. The U.S. Geological Survey and Bureau of Mines use the following reserve classification:

1. Measured, ore for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes, and for which the grade is computed from the results of detailed sampling.

2. Indicated, ore for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence.

3. Inferred, ore for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit, and for which there are few, if any, samples or measurements.

The categories of measured, indicated, and inferred ore may, for practical purposes, be equated to the commercially equivalent categories of proven, probable, and possible ore. The commercial system places more emphasis on phsyical measurement and sample data, and relies less on projection and extension based on geologic character of the deposit.

It must be emphasized that ore reserves and potential resources are in a sense ephemeral terms subject to change when applied to a particular mineral deposit. The term "ore reserves" is strictly tied to the economics of a mining-marketing situation. Minable ore reserves may revert to commercially unattractive potential resources for many reasons. A few of the more important are (1) a drop in the market price for mineral commodity, (2) a lack of demand, (3) increased mining or beneficiation costs, (4) increased transportations costs due to smelter closures or a change in market location, and (5) competition from foreign sources. Conversely, potential resources may be upgraded to ore reserves by (1) a price increase, (2) depletion of higher grade materials, (3) technological advances in mining or ore treatment, and (4) interruption of competition from other material sources.

Zinc Reserves of the United States

Zinc deposits in the United States have a wide geographical distribution. Zinc-bearing ores occur in 17 States that extend from northern New England, south to the southern Appalachian Mountain chain, west through the northern and central Mississippi Valley region, and include eight States in and west of the Rocky Mountains physiographic province. Figure 1 maps the zinc reserves by magnitude and table 5 lists the mining districts in which the deposits occur, using the index numbers of figure 1.

TABLE 5. - Location of U.S. zinc reserves

Region	State	Index No.[1]	District
Northeastern......	New York...........	1	Balmat-Edwards.
	Pennsylvania.......	2	Friedensville.
	New Jersey.........	3	Franklin.
	Maine..............	4	Southern Volcanic Belt.
South Appalachian.	Tennessee..........	5	Mascot-Jefferson City.
	.....do............	6	Copper Ridge.
	.....do............	7	Ducktown.
	Virginia...........	8	Austinville-Ivanhoe.
Central...........	Missouri...........	9	Southeast Missouri Lead District.
	Illinois-Wisconsin.	10	Upper Mississippi Valley.
	Illinois...........	11	Southern Illinois Fluorite.
Northwestern......	Washington.........	12	Metaline.
	.....do............	13	Northport.
	Idaho..............	14	Coeur d'Alene.
	.....do............	15	Bayhorse.
	Montana............	16	Philipsburg.
	.....do............	17	Barker.
	.....do............	18	Colorado.
	.....do............	19	Cataract.
	.....do............	20	Argenta.
	.....do............	21	Virginia City.
Southwestern......	Colorado...........	22	Leadville.
	.....do............	23	Gilman.
	.....do............	24	Ruby-Elk Mountain.
	.....do............	25	Telluride-Mt. Sneffels.
	.....do............	26	Silverton.
	.....do............	27	Creede.
	.....do............	28	Rico.
	Utah...............	29	East Tintic.
	.....do............	30	Park City.
	.....do............	31	Bingham.
	Arizona............	32	Jerome.
	.....do............	33	Bagdad.
	.....do............	34	Cedar Valley.
	.....do............	35	Aravaipa.
	New Mexico.........	36	Central.
	California.........	37	Darwin.
	.....do............	38	Lone Pine.

[1] As given in figure 1.

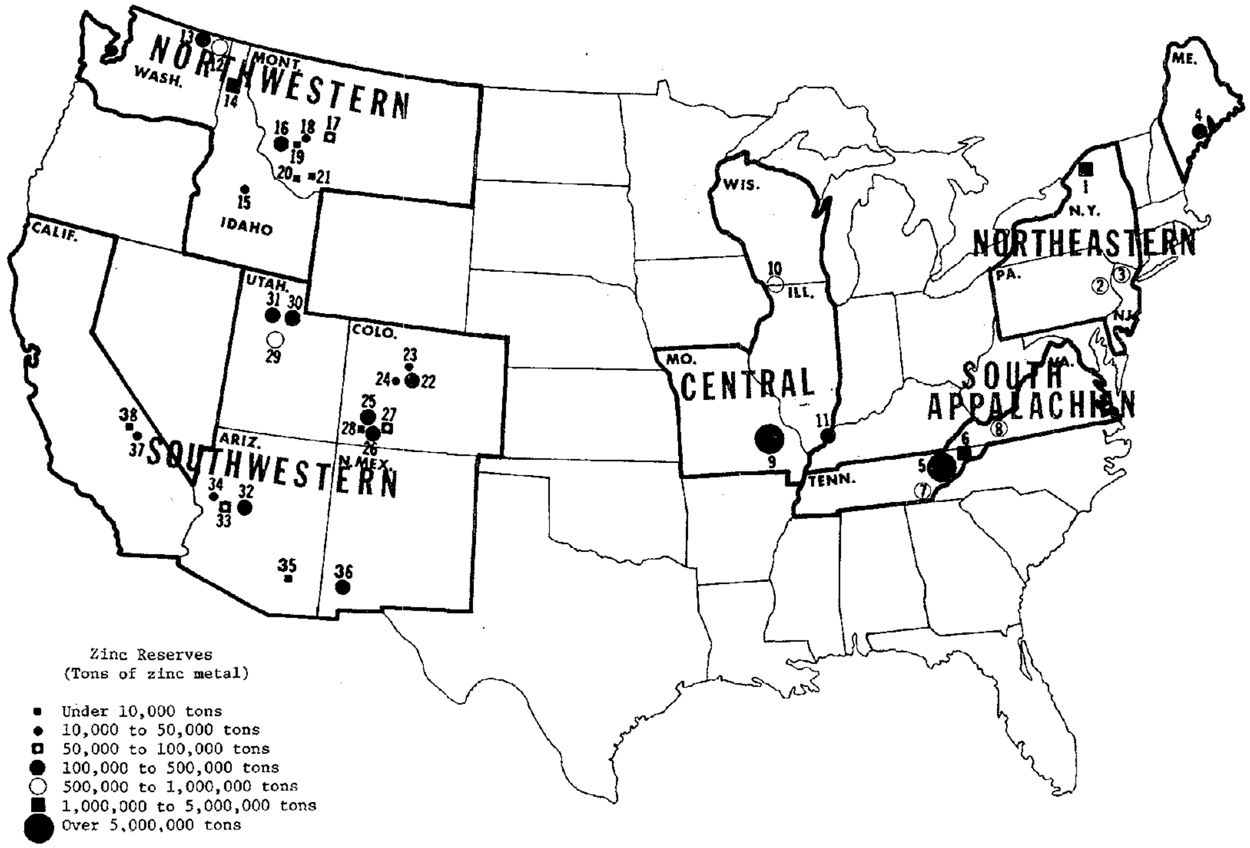

FIGURE 1. - Location map, U.S. reserve districts by geographical region.

The total U.S. zinc reserve is estimated at 1,156 million tons of ore containing 27 million tons of zinc, 37 million tons of lead, 2.8 million tons of copper, and 500 million ounces of silver. Table 6 lists domestic zinc reserves by geographical region.

Straight zinc ores account for 29 percent of the zinc in domestic reserves; exploitation of the remaining 71 percent is dependent to some degree on the recovery of one or more coproducts of byproducts. For example, nearly 37 percent of U.S. zinc reserve occurs as a relatively small percentage of the total contained metal in southeast Missouri lead deposits. Table 7 depicts estimated U.S. zinc reserves by metals to be recovered.

TABLE 6. - Estimated U.S. zinc reserves by geographical region

Region and metals recovered	Reserves[1] (thousand tons of ore)	Average grade			Contained metals				
		Zinc (percent)	Lead (percent)	Copper (percent)	Silver (ounces per ton)	Zinc (thousand tons)	Lead (thousand tons)	Copper (thousand tons)	Silver (thousand troy ounces)
Northeastern:									
Zinc-lead[2]	39,858	9.26	([2])	0	0	3,691	44	0	0
Zinc-copper-silver	1,200	16.75	0	0.55	0.37	201	0	6	444
Zinc-copper	1,000	7.60	0	1.13	0	76	0	11	0
Zinc-lead-silver	830	2.04	0.86	0	4.63	17	7	0	3,842
South Appalachian:									
Zinc	159,600	3.79	0	0	0	6,045	0	0	0
Zinc-lead	13,331	4.07	0.73	0	0	542	99	0	0
Zinc-copper	82,488	1.28	0	1.17	0	1,056	0	965	0
Central:									
Lead-zinc-copper	693,800	1.43	4.92	0.16	0	9,915	34,138	1,136	0
Zinc-lead	20,000	4.00	0.25	0	0	800	50	0	0
Zinc (fluorspar)	14,000	3.10	0.20	0	0	434	28	0	0
Northwestern:									
Zinc-lead-copper-silver	1,792	7.53	1.84	0.21	10.97	135	33	4	19,667
Zinc-lead-silver	58,387	2.98	2.71	0	5.21	1,742	1,584	0	304,235
Zinc-lead	2,357	3.98	0.43	0	0	94	10	0	0
Southwestern:									
Zinc-lead-copper-silver	14,786	5.39	2.98	0.55	6.03	796	437	81	89,144
Zinc-lead-silver	19,035	7.39	5.17	0	4.31	1,407	985	0	82,115
Copper-zinc	33,000	0.28	0	1.63	0	93	0	538	0
Zinc-lead	38	13.00	6.00	0	0	5	2	0	0
Zinc-copper-silver	325	7.94	0	3.45	1.20	26	0	11	390
Total	1,155,827	-	-	-	-	27,075	37,417	2,753	499,837

[1] No allowance made in tonnage or grade for dilution and pillars.

[2] Zinc-lead and straight zinc combined to preserve confidentiality.

TABLE 7. - Estimated U.S. zinc reserves by metal to be recovered

Contained metal	Reserves (thousand tons of ore)	Average grade				Contained metals			
		Zinc (percent)	Lead (percent)	Copper (percent)	Silver (ounces per ton)	Zinc (thousand tons)	Lead (thousand tons)	Copper (thousand tons)	Silver (thousand troy ounces)
Zinc	177,200	4.17	0	0	0	7,732	0	0	0
Zinc-lead	71,940	5.95	0.35	0	0	3,879	233	0	0
Zinc-lead-silver	78,250	4.05	3.29	0	4.99	3,166	2,576	0	390,193
Zinc-lead-copper-silver	16,600	5.62	2.84	0.51	6.56	932	470	85	108,811
Zinc-copper	116,490	1.05	0	1.30	0	1,225	0	1,514	0
Zinc-copper-silver	1,520	14.78	0	1.17	0.55	226	0	18	833
Lead-zinc-copper	693,800	1.43	4.92	0.16	0	9,915	34,138	1,136	0
Total	1,155,800	-	-	-	-	27,075	37,417	2,753	499,837

Description by Geographical Region

On the basis of geographical continuity, similarity of areal geology and modes of ore occurrence, the continental United States is divided into five regions containing zinc reserves. The regions are (1) Northeastern United States, encompassing New York, Pennsylvania, New Jersey, and Maine; (2) South Appalachian, consisting of Tennessee and Virginia; (3) Central United States, including Illinois, Wisconsin, and Missouri; (4) Northwestern United States, comprising Washington, Montana, and Idaho; and (5) Southwestern United States, composed of Utah, Colorado, Arizona, New Mexico, and California. Figure 1 outlines the regions, gives approximate locations of mining districts, and compares the magnitude of zinc reserves in different districts.

Northeastern United States

Zinc deposits in the States of New York, Pennsylvania, New Jersey, and Maine are estimated to have a total ore reserve of 43 million tons, containing 4 million tons of zinc, 51,000 tons of lead, 17,000 tons of copper, and 4.3 million ounces of silver. Important mining districts are (1) Balmat-Edwards district, New York; (2) Friedensville district, Pennsylvania; (3) Franklin district, New Jersey; and (4) Southern Volcanic Belt district, Maine.

New York

The Balmat-Edwards zinc deposits in northern New York are steeply plunging, lenticular, pod-shaped, or tabular replacement lodes that have the greatest dimension down the plunge. Sphalerite is the important sulfide ore mineral; a small amount of galena is present. Ore grades average a little over 9 percent zinc and about 0.20 percent lead.

Pennsylvania

The Friedensville zinc mining district is in southeastern Pennsylvania. The Friedensville zinc ores fill and replace the dolomitic matrix of a folded and faulted stratabound collapse breccia in lower Ordovician calcareous rocks. Metallic minerals are sphalerite and pyrite in a quartz and dolomite gangue. Zinc is the sole metal produced; the ore averages 6.7 percent zinc.

New Jersey

The Sterling Hill mine in the Franklin district, northern New Jersey, is located in a region of Precambrian gneiss and marble cut by pegmatite dikes.

The ore body has a hooklike configuration with the bent part of the hook plunging underground at about 45°. The host rock is marble; ore minerals are willemite, franklinite, and zincite occurring as disseminated grains and massive blocks in a calcite gangue. Zinc is the primary product, although a manganiferous zinc residuum is produced from the franklinite. The average grade is about 19.5 percent zinc; ores are shipped directly to the Palmerton, Pa., smelter.

Maine

Important zinc-bearing deposits are located in south-central Maine within the Southern Volcanic Belt geologic province. Ore occurrences, though restricted to a relatively small geographical area, differ widely in geological relations, ore grade, and metals present.

Sulfide minerals present in the district include pyrite, chalcopyrite, sphalerite, argentiferous galena, and minor pyrrhotite, although not all are necessarily present in a given ore body. Zinc grades vary between 1.17 percent and 16.75 percent and average 9.17 percent. Significant amounts of coproduct copper, lead, and silver are present.

South Appalachian States

The zinc-producing States of Tennessee and Virginia comprise this geographical division. Straight zinc deposits are the most important ore bodies, although one district produces zinc-copper coproduct ore, and one yields zinc ore with byproduct lead. Mines in the South Appalachian Region are estimated to hold reserves totaling 255 million tons of ore containing 7.6 million tons of zinc metal. Important zinc-producing districts in the region are (1) East Tennessee zinc district, (2) Ducktown district, Tennessee, and (3) Austinville-Ivanhoe district, Virginia.

Tennessee

Because of the close similarity in geology and mode of occurrence, zinc deposits in the Mascot, Jefferson City, and Copper Ridge districts are included together as the East Tennessee zinc district. Stratabound zinc ore found in lower Paleozoic carbonate sediments generally contain low-iron sphalerite deposited principally as open-space filling in solution and collapse breccia structures in interbedded dolomite and dolomitized limestone. Estimated average ore grade is 3.79 percent zinc; no other economically significant base or precious metals are present. The Copper Ridge deposits are included in potential resources rather than ore reserves.

Ore deposits in the Ducktown district in southeastern Tennessee are massive, tabular sulfide bodies that have been extensively folded. Ore minerals are phyrrhotite, pyrite, chalcopyrite, sphalerite, and magnetite; gangue minerals are quartz, calcite, actinolite, tremolite, hornblende, garnet, and schistose wall rock.

Copper is the primary product at Ducktown. Zinc is the most important byproduct; iron and various sulfur-based compounds are secondary byproducts. The ore has an average grade of 1.28 percent zinc and 1.17 percent copper.

Virginia

The Austinville-Ivanhoe lead-zinc district is located in southwestern Virginia. The ore bodies are chimney and mantolike replacement and open-space filling lenses that are elongated along strike of the enclosing rocks.

Sphalerite and galena are the important sulfide ore minerals; secondary zinc and lead oxide minerals are present and pyrite is abundant in places. The average ore grade is 4.0 percent.

Central United States

The zinc-producing States of Wisconsin, Illinois, and Missouri make up the geographical region that constitutes probably the most important lead-zinc metallogenic province in the United States. Zinc is the principal metal produced in one district, is an important byproduct of fluorspar mining in another, and is a significant byproduct of lead production in a third. Zinc-bearing deposits in the Central United States are estimated to contain 11.1 million tons of zinc, 34.2 million tons of lead, and 1.1 million tons of copper. Major mining districts are the Southeastern Missouri district, the Upper Mississippi Valley district, and the Southern Illinois district.

Missouri

The southeast Missouri lead district includes seven counties in the southeastern part of the State. A significant amount of zinc and a small percentage of copper occur in ores from the Viburnum Trend and Goose Creek sections of the district.

Ore deposits are laterally extensive carbonate replacement bodies measuring up to 200 feet thick. Galena is the principal ore mineral, with lesser amounts of sphalerite and chalcopyrite. Viburnum Trend ores average about 5 percent lead, 1.5 percent zinc, and nearly 0.2 percent copper; ores from Indian Creek-Goose Creek are about 2.7 percent lead, 0.4 percent zinc, and 0.1 percent copper.

Illinois and Wisconsin

Zinc-lead ore bodies in the Upper Mississippi Valley district in southwestern Wisconsin and northwestern Illinois, and fluorite-zinc deposits in the Southern Illinois district comprise (1) cavity fillings in solution breccias, (2) bedded replacement deposits, and (3) veins following faults, shear zones, and fractures.

A small amount of lead is a byproduct of zinc mining in the Upper Mississippi Valley district; the districtwide ore grade averages about 4 percent zinc and 0.25 percent lead. In Southern Illinois the zinc grade averages 3.1 percent; zinc is recovered as an important byproduct of fluorspar mining, and is thus dependent on the economics of the fluorspar industry. A small amount of lead is recovered as a second byproduct.

Northwestern United States

This geographical division comprises the zinc-producing States of Montana, Idaho, and Washington. Zinc deposits in the region are located in the northern Rocky Mountains or in immediately adjacent areas. Geological environments and modes of ore occurrence in the Northwestern United States are extremely diverse; zinc-bearing ores are found in sedimentary, metamorphic, and igneous rocks ranging from Precambrian to Late Mesozoic in age, and ore deposits vary from bedded replacement bodies to complex, deep-seated vein-type occurrences. Zinc-producing districts in the northwestern region have an estimated reserve of 62.5 million tons of ore containing nearly 2 million tons of zinc metal. Important mining districts, listed by State, are (1) Metaline and Northport, Washington; (2) Coeur d'Alene and Bayhorse, Idaho; and (3) Philipsburg and Barker, Mont.

Washington

The Metaline district is in the extreme northeast corner of the State. Ore deposits are irregular lenses, pods, and masses in carbonate sedimentary rocks in the upper part of the Cambrian Metaline limestone. Ore mineralogy is simple; the valuable minerals in most ore bodies are sphalerite and galena. The ore averages 2.36 percent zinc, 0.79 percent lead, and 0.04 ounce silver per ton.

The Northport district is a few tens of miles southwest of the Metaline district. The ore deposits are found in carbonate sediments in the Cambrian Metaline Formation, though ores at Northport occur in a lower stratigraphic interval. Ore bodies are replacement pods, stringers, and irregular lodes in dolomitic country rock. Important ore minerals are sphalerite and galena; the average district grade is 3.44 percent zinc and 0.97 percent lead.

Idaho

The Coeur d'Alene district in northern Idaho is one of the major lead-zinc-silver districts in the world. Base metal-silver ore occurs in an extremely complex series of steeply dipping replacement veins that contain randomly spaced oreshoots with highly variable dimensions.

Important ore minerals are galena, sphalerite, and silver-bearing tetrahedrite; the average districtwide ore grade is 3.40 percent zinc, 4.33 percent lead, and 9.80 ounces silver per ton.

The Bayhorse district is in south-central Idaho. Zinc-lead-silver ore bodies are replacement lodes and veins, and fissure veins with peripheral replacement of the country rock. Principal ore minerals in the district are sphalerite, galena, tetrahedrite, and lead-zinc carbonates. Ore grade at the producing property averages 2.7 percent zinc, 2.2 percent lead, and 4 ounces silver per ton.

Montana

Montana zinc reserves are distributed in six districts situated in the northern Rocky Mountains province in the western part of the State. Districts estimated to have a significant zinc potential are Philipsburg, Granite County; and Barker, Judith Basin County. The Colorado and Cataract districts, Jefferson County; the Virginia City district, Madison County; and the Argenta district, Beaverhead County, contain lesser tonnages of zinc. Geological environments and modes of ore occurrence in the Philipsburg and Barker districts are summarized as follows: (1) Philipsburg district--replacement veins and bodies in Paleozoic calcareous rocks and veins in granodiorite. Average grades are 9 percent zinc, 1 percent lead, 15 percent manganese, 0.25 percent copper, and 14 ounces silver per ton; (2) Barker district--fracture fillings and replacements along fractures in a syenite porphyry plug, ore grades average 5.97 percent zinc, 4.88 percent lead, and 6.99 ounces silver per ton.

Southwestern United States

The States of Utah, Colorado, Arizona, New Mexico, and California constitute this geographical division, which has an estimated zinc ore reserve of 67.2 million tons, containing 2.3 million tons of zinc, 1.4 million tons of lead, 630,000 tons of copper, and 171.7 million ounces of silver. Principal potential zinc mining areas listed by State are (1) central Colorado and San Juan Mineral Belt in Colorado; (2) Bingham, Tintic, Park City, Ophir, Mt. Baldy, and San Francisco districts in Utah; (3) Cedar Valley, Bagdad, Jerome, and Aravaipa districts, Arizona; (4) Central district, New Mexico; and (5) Darwin and Lone Pine districts, California.

Colorado

The zinc-producing districts of Leadville, Gilman, Ruby, and Elk Mountain are located in the central Colorado Mineral Belt. Ore deposits are fissure vein fillings, vein intersection replacement lodes in limestone, and massive sulfide manto and chimney replacement bodies in carbonate rocks. Primary sulfide ore minerals are sphalerite and galena; zinc ore grades range between 4 and 13 percent, lead varies from 1.2 to nearly 9 percent, and silver ranges between 1.4 and 6 ounces per ton.

Arizona and New Mexico

Zinc-bearing ore bodies occur in the Cedar Valley, Bagdad, and Jerome districts in west-central Arizona, in the Aravaipa district in southeast Arizona, and in the Central district in southwestern New Mexico.

Important Arizona zinc deposits are massive tabular, pipelike, and irregular sulfide replacements in schistose country rock; veins in a brecciated fault zone in rhyolite and limestone occur in one district.

Zinc and zinc-lead ore bodies in New Mexico's Central district are largely limestone replacement mantos, chimneys, and irregular ore masses, though veins in fault and fracture zones cutting intrusive rocks occur in the southwest part of the district. Copper ores with byproduct zinc occur in large, irregular pyritic replacement masses in limestone, bordering a granodiorite stock.

Grades in zinc, zinc-copper, and zinc-lead ore bodies vary between 5.6 and 13 percent zinc, from 0.6 to 6 percent lead, and between 0.6 and 3.65 percent copper. Up to 2 ounces of silver per ton are present in some Arizona zinc-lead deposits. A large copper deposit in the Central district contains 1.6 percent copper and 0.2 percent byproduct zinc.

The San Juan Mineral Belt of southwestern Colorado contains the zinc-lead-silver mining districts of Mt. Sneffels-Telluride, Creede, Silverton, Eureka, and Rico. Copper is also recovered at Creede and Mt. Sneffels-Telluride. Principal ore bodies are fault-controlled fissure veins, chimneys and irregular replacement bodies in limestone, and braided vein-type lodes. Common sulfides of the base metal ores are pyrite, sphalerite, galena, chalcopyrite, and tennantite. Ore grades range between 2.2 and 8 percent zinc, from 2.2 to 6 percent lead, and between 1.5 and 21 ounces of silver per ton. Byproduct copper grading between 0.6 and 0.99 percent is recovered from mines in two districts, and byproduct gold is produced in some instances.

California

Zinc-lead-silver deposits are located in the Darwin and Lone Pine districts in southeastern California. Ore deposits are fissure fillings, bedded replacements, and irregular, pipelike replacements controlled by fracturing and faulting.

Ores at Lone Pine are a mixture of oxide and sulfide minerals; the ore minerals are cerussite, hemimorphite, galena, and sphalerite. Major primary sulfide minerals at Darwin are argentiferous galena and sphalerite, lead and zinc oxide minerals are present in small amounts. Ore grades range from 5 to 7 percent zinc, between 3.5 and 11 percent lead, and from 5 to 12 ounces silver per ton.

Utah

The preponderance of the State's zinc reserves are in north-central Utah, in the Bingham, East Tintic, and Park City districts.

Bedded replacement ore bodies in limestone constitute the prevalent mode of ore occurrence, although irregular replacement lodes and fissure filling deposits are locally important. Zinc-lead-silver ore bodies contain the largest part of Utah's zinc reserves; byproduct copper is recovered in one district. Sulfide ores make up most of the reserves, although high-grade oxide and mixed sulfide-oxide ores are important in two districts. Sulfide ore grades range between 3.5 and 8.6 percent zinc, from 2 to 8 percent lead, and between 0.5 and 8 ounces silver per ton. High-grade oxide ores average about 12 percent zinc, 15 percent lead, and over 10 ounces of silver per ton.

Potential Zinc Resources of the United States

In addition to domestic zinc ore reserves, large tonnages of potential resources occur in four districts in the United States; a total of 35 million tons of zinc metal is present in these deposits. Table 8 depicts tonnage, grade, and contained metals in the four districts. Two areas, the Metaline district in northeastern Washington and the southeast Missouri lead district, have operating mines, although potential zinc metal included in the

35-million-ton total is in nonoperational or undeveloped parts of the districts. The Central Tennessee district comprises a newly discovered area with no producing mines. In the Butte, Mont., district, zinc occurs in developed mines shut down for economic reasons. Brief descriptions of individual potential districts follow.

TABLE 8. - Potential zinc resources of the United States

State and district	Zinc-bearing material (thousand tons)	Zinc (percent)	Lead (percent)	Copper (percent)	Silver (ounces per ton)	Zinc (thousand tons)	Lead (thousand tons)	Copper (thousand tons)	Silver (thousand troy ounces)
Tennessee:									
Central..........	160,000	5.75	0	0	0	9,200	0	0	0
East.............	51,750	3.77	0	0	0	1,950	0	0	0
Montana:									
Butte (high-grade)[1].........	66,250	8.00	1.00	0.12	3.00	5,300	662	79	198,750
Butte (low-grade)[2].........	20,000	2.50	0.38	0.35	0.37	500	76	70	7,400
Washington:									
Metaline[3].........	500,000	2.60	0.8	0	0.03	13,000	4,000	0	15,000
Missouri: Southeast Missouri lead district..........	325,000	1.69	5.40	0.19	0	5,490	17,550	618	0
Total.........	1,123,000	-	-	-	-	35,440	22,288	767	221,150

[1] Contains 4 percent manganese.

[2] Contains 1.5 percent manganese.

[3] Contains estimated 1 pound cadmium to 400 pounds zinc.

Central Tennessee District

A 16-county area totaling over 750,000 acres is being explored for zinc deposits in north-central Tennessee. As many as eight mineral exploration companies have been active in the region at one time.

Zinc mineralization occurs in flat-lying, stratabound collapse breccia structures buried to depths of at least 1,000 feet. Much of the exploration has been by surface methods and by drilling; one company has sunk a shaft and has completed several thousand feet of exploration--development crosscutting and drifting.

Zinc is the principal metal found. A little lead occurs, and enough fluorite is present in places to warrant recovery. The present resource estimate was based on limited company information and geological inference. The Central Tennessee district is estimated to have a resource of at least 160 million tons of zinc-bearing material having a grade of 5.75 percent zinc, for a total of 9.2 million tons of zinc metal (table 8).

Butte District, Montana

The Butte district, Montana, has extremely large tonnages of zinc-lead-silver-manganese-bearing material once classified by the operating company as ore reserves. An additional large tonnage of lower grade zinc-bearing mineralized material exists that the company assigned to the unmeasured or resource category. At the present time no zinc is mined at Butte.

High-grade submarginal zinc resources at Butte are estimated to total 66.25 million tons, containing 5.3 million tons of zinc, 662,500 tons of lead, 79,500 tons of copper, 198.75 million ounces of silver, and 2.65 million tons of manganese. Low-grade resources are approximately 20 million tons, containing 500,000 tons of zinc metal.

Metaline District, Washington

Extremely large low-grade zinc resources exist in Pend Oreille and Stevens Counties, northeastern Washington. Stratabound zinc ore bodies occur in the Josephine horizon and in the stratigraphically lower Yellowhead horizon of the Cambrian Metaline Limestone. Zinc-bearing material included in this report is restricted to the Josephine horizon in the Metaline area of Pend Oreille County. Zinc is the principal metal, with lead, silver, and a small amount of cadmium as byproducts. The Josephine horizon in the Metaline district is estimated to contain 13 million tons of zinc metal, 4 million tons of lead, 15 million ounces of silver, and 32,500 tons of cadmium.

Southeast Missouri Lead District

The largest domestic lead reserve containing significant byproduct zinc is in southeast Missouri. Stratabound replacement ore bodies occur in the dolomitic Cambrian Bonneterre Formation, peripheral to the structural dome of the St. Francois Mountains. Lead-zinc-bearing material not classed as ore reserves in 1971 is in explored and developed prospects and inactive mines in the Viburnum Trend and Fredericktown subdistricts. A total of 325 million tons of lead-zinc-bearing material, containing 5.5 million tons of zinc, 17.6 million tons of lead, and over 600,000 tons of copper is estimated to be present in the two subdistricts.

Changes in U.S. Zinc Reserves, 1951-71

Domestic zinc reserve studies were made by the Bureau of Mines in 1951, 1964, and 1971; reserve figures incorporated in the respective studies were current as of January 1, 1950, 1964, and 1971. The total U.S. zinc reserve, in tons of contained zinc metal in all ore reserve categories, increased from 21 million tons in 1951 to 24 million tons in 1964, and to 27 million tons in 1971. Table 9 compares 1964 and 1971 domestic reserves by State or mining district.

Significant reserve decreases between the 1964 and 1971 studies occurred in the Tri-State district, at Butte, Mont., and in the Southwestern States as a whole.

Mining has essentially ceased in the Tri-State district of Kansas, Oklahoma, and southwest Missouri. Many properties are completely worked out, and in others only low-grade zinc-bearing materials remain. Pumping has been abandoned in the district, and because of the interconnected nature of the deposits and mine workings, even the low-grade areas will be flooded. The cost of pumping and disposal of mine water is so great as to downgrade all ore reserves to resource category material.

TABLE 9. - Comparison of U.S. zinc reserves, 1964 and 1971

(Thousand short tons of zinc)

State	1964 reserve	1971 reserve	Difference	Remarks
Washington	874	719	-155	
Idaho	606	1,028	+422	
Montana	913	224	-689	
California	467	13	-454	
Nevada	555	-	-555	Reserve in 1964 mostly in indicated and inferred categories.
Arizona	1,174	442	-732	
New Mexico	808	188	-620	
Utah	447	831	+384	
Colorado	1,577	853	-724	
Missouri:				
Kansas, Oklahoma, southwest Missouri.	5,310	-	-5,310	Tri-State reserve downgraded to resources.
Southeast Missouri	-	9,915	+9,915	New reserves all in southeast Missouri lead district.
Wisconsin-Illinois	1,138	800	-338	
Illinois-Kentucky	434	434	-	
Tennessee	6,484	7,101	+617	Copper Ridge downgraded to resources.
New Jersey	850	3,691	+1,279	Data combined to protect confidentiality.
Pennsylvania	640			
New York	922			
Maine	-	294	+294	
Total	24,117	27,075	+2,958	-

No zinc is being mined at Butte, Mont., although large measured tonnages of complex, high-grade zinc-bearing material remain in the district. The high cost of underground mining, low metal prices, a scarcity of trained underground miners, and lack of smelting facilities are factors that lead to reclassification of Butte zinc reserves to the resource category.

Zinc reserves in the Southwestern States have decreased due to the depletion of ore bodies (Bisbee, Ariz., for example), the downgrading of reserves to resources because of low metal prices, increased mining costs, and in some instances a lack of currently operating smelter facilities within an economic transportation distance.

Significant zinc ore reserve increases between the 1964 and 1971 studies occurred in the Coeur d'Alene region Idaho, in southeast Missouri, in eastern Tennessee, and in parts of the Northeastern United States.

Increased ore reserves in the Coeur d'Alene are attributed to accelerated exploration and development of zinc-bearing base-precious metals ores, and to increased knowledge of the region as a whole.

The discovery and development of the Viburnum Trend in the southeast Missouri lead belt accounts for the largest single domestic zinc ore reserve increase. While the ores are mined primarily for the lead content, the extremely large tonnages present make the small percentage of byproduct zinc significant.

Increased exploration and mine development in eastern Tennessee, in both the straight zinc and pyrite zinc-copper deposits account for a modest regional reserve increase.

Zinc ore reserves in the Northeastern United States were increased primarily because of new mine developments at Balmat, New York, and in the Southern Volcanic Belt, Maine.

TECHNOLOGY

Through technology a known mineral occurrence is converted into a specific quantity of available ore (reserves). A high state of technologic development facilitates prospecting, exploration, mining, and production, arrests depletion, lowers costs, and assures a continuing supply. Inevitably costs of materials, power, capital equipment, and labor increase, and the grade of zinc deposits decreases with time. The burden of counteracting these supply-eroding influences rests almost totally on an ever-expanding technology gained through research.

Prospecting, Exploration, and Development

Prospecting is the search for ore occurrences, and exploration is the work involved in gaining knowledge of the size, shape, position, and value of an ore body. These two activities, although quite different in purpose, use the same tools. Many consider prospecting a phase of exploration and refer to the search for ore as exploration for new ore bodies; others use the terms interchangeably; such as, geochemical prospecting or geophysical exploration and geophysical prospecting.

Basic exploration as practiced by large exploration companies involves several stages. First, an area is selected by a study of the regional geology, using photogeology as a tool. Next, the area often is mapped by airborne magnetic and electromagnetic methods on a fairly close spacing. Some reconnaissance geochemical work may also be carried out. Results obtained are used to determine the extent and scope of three detailed ground surveys. This includes checking of geophysical anomalies using corresponding ground techniques, detailed geochemical work and geological mapping, and possibly shallow drilling, pitting, stripping, and trenching. The extent of the final drilling program is in turn conditioned by the quality of these results.

Data obtained by exploration are required for determining ore reserves, planning methods and equipment, projecting the scale of operations, and other technological and economic factors essential to establishment of a mining enterprise.

These objectives require that the ore body be penetrated by boreholes and/or underground workings at appropriately spaced intervals and that the exploratory work be carried far enough to permit sound planning of subsequent operations. For example, deposits usually are explored by a network of boreholes or underground workings on a 100- to 200-foot spacing over the entire area of the deposit, in advance of mining to determine the geology and type of equipment that is needed for mining. However, exploration of a vein deposit need only be carried far enough to demonstrate the existence of a workable ore body of sufficient extent and value to justify expenditures for development and equipment. A continuing program of exploration and development is relied upon to add reserves to replace mined-out ore.

Development is defined as the driving of openings to and in a proved ore body for the purpose of economic extraction of the ore minerals. Depending on the nature of the ore occurrence and on certain economic production factors, development may be a discrete activity or a component of prospecting, exploration, or stoping. In some mining districts it is possible and practical to discover, delineate, develop, and mine zinc ores in one coordinated activity.

Mining

Fragmenting of ore (usually by drilling and blasting), the removal of ore, and the support of openings in the ore mass to provide safe and economic extraction are common to all underground mining methods. Geologic and economic factors largely prescribe the mining method used. Skill of the available labor force, size of permissible capital investment, availability of equipment, timber, and stope fill also are important determinants. However, the overriding considerations are the physical characteristics of the ore and enclosing rocks, and the size, shape, and structural parameters of the deposit.

The principal mining methods employed in modern zinc mining are room and pillar, shrinkage, cut and fill, and square set. Each may be used with great variation or in combination with others. Within one mine several different methods may be used. Except for a few open pit mines in Canada, open pit and block caving methods have not been used extensively in zinc mining.

Room-and-pillar mining is a general term describing the excavation of a flat-lying or gently dipping ore body by excavating chambers and leaving pillars of ore or waste rock to support the roof. Zinc and lead-zinc stratiform bodies are most often mined by some variation of this method. Examples are to be found in the zinc mines of east Tennessee, the Missouri lead belt, the Balmat-Edwards zinc district in New York and the Wisconsin-Illinois zinc district.

In shrinkage stoping ore is mined in successive flat or inclined cuts or slices progressing upward from a haulage level. After each slice enough broken ore is drawn off through chutes or drawpoints to provide working space between the top of the pile and the new back or roof of the stope. The remaining broken ore serves as floor on which the miners prepare to cut a new slice. This method is used in tabular or vein deposits dipping at angles greater than 50°. It was formerly used in the Sterling mine in New Jersey and in many mines in the Western States.

The cycle of operations in mining consists of drilling, blasting, and removing broken rock. Drilling usually is done with compressed-air percussion drills or, more rarely, with diamond drills. Blasting is done with various types of dynamite or ammonium nitrate-fuel oil mixtures detonated by electric blasting caps or by ignition fuses and caps. Electric, compressed-air or diesel shoveling and loading machines are used for handling broken ore in most important underground operations. In fissure vein deposits, track haulage is by electric or compressed-air locomotives. Rubber-tired diesel truck haulage is popular in extensive flat-bedded replacement bodies. Hand shoveling and hand tramming ore are no longer economic in any but the smallest high-grade deposits; these make an insignificant contribution to zinc supply.

Mechanization has been the dominant advance in mining methods during the last two decades. In the flat-lying zinc and zinc replacement deposits, multiple drills mounted on crawler-tread or rubber-tired, self-propelled jumbos have replaced single uncoordinated drills. Broken ore is loaded with a variety of diesel or electric, high-capacity, specialized shovels or loaders, and haulage is done with trucks that hold many times the tonnage of the track cars they displaced. The trend continues toward rubber-tired, high-speed, maneuverable machines that may readily service stopes at great distances from the entry and convey the ore rapidly to the mill with a minimum of handling.

Milling

The winning of zinc from its ore begins with the milling of the ore to prepare a concentrate which can be treated to recover zinc and the associated byproduct metals.

The mineralogy of zinc-containing ores determines the technology and economics of the milling practice. Ores containing nearly pure sphalerite (67 percent zinc) yield concentrates containing in excess of 62 percent zinc. Most sphalerite contains at least trace quantities of iron and occasionally manganese in isomorphous solution. Grades of concentrates from ores composed of carbonate or zinc silicate minerals (oxidized ores) are limited to the percentages of zinc contained in these minerals (52 and 54 percent, respectively). Other important factors include the size and interlocking of the mineral grains, association with other metallic and nonmetallic minerals, and oxidation or coating with soluble salts on the mineral surfaces.

The initial step in the milling process is reduction in the size of broken ore fragments by crushing and grinding. Ball mills and rod mills are used for grinding the crushed ore slurried with water. Rod mills produce a more uniform grind with less overgrinding, but ball mills are needed where tough and resistant particles must be reduced to fine sizes.

Gravity methods were the principal concentration processes until after about 1917 when flotation rapidly became the most important milling practice.

High-intensity magnetic separators have been used in the past to make separate concentrates of a zinc-iron-manganese magnetic mineral (franklinite) and a less magnetic zinc silicate mineral (willemite) which occur in the large and unique zinc ore deposits in New Jersey.

A general scheme for the flotation of a mixed sulfide ore is (1) use of proper reagents for flotation of the lead-copper minerals and depression of the zinc and iron minerals, depression of the sphalerite is assisted by its tendency to differentially grind to larger sizes than the other sulfides; (2) activation and flotation of the sphalerite from the iron and gangue minerals; (3) separation by flotation of the lead-copper bulk concentrate; and (4) flotation of the pyrite if a recovery is desired.

Oxidized zinc minerals (carbonates, silicates) do not respond to the collectors that are available. However, sodium sulfide (provided by adding barium sulfide and sodium carbonate) sulfidizes the mineral surface and permits flotation to proceed as with a sulfide mineral.

Metallurgy

Several properties of zinc makes its extraction from concentrates somewhat more difficult and complicated than the relatively simple smelting of other base metals such as copper and lead. Perhaps as a consequence of the inherent metallurgical difficulties, zinc reduction is achieved by a greater variety of processes than for most other metals.

The conversion of zinc sulfide concentrates into metallic zinc is carried out in the United States by either a pyrometallurigical or a combination pyrometallurigical-electrolytic process. The three primary steps of the pyrometallurgical process are as follows:

1. Roasting of zinc sulfide concentrates to remove most of the sulfur and form an impure zinc oxide calcine.

2. Sintering the calcine to oxidize the remaining zinc sulfide, form a dense, permeable furnace feed, and eliminate impurities, most notably lead and cadmium.

3. Pyrometallurgical reduction of zinc oxide to metallic zinc.

In the combination pyrometallurgical-electrolytic process the roasted concentrates are dissolved in dilute sulfuric acid and the purified solution is electrolyzed to recover metallic zinc.

Roasting

Zinc plants utilize one or a combination of several types of roasters, which include Ropp roasters, multiple-hearth roasters, or the modern flash and fluid-bed roasters. During zinc sulfide roasting, 93 to 97 percent of the input sulfur is converted to SO_2. The gases from Ropp roasters contain 0.7 to 1.0 percent SO_2 and from the multiple-hearth roasters up to 6 percent SO_2. Flash and fluid-bed systems generate 10 to 15 percent SO_2 in exhaust gases. The Ropp roaster is the only type of roaster which does not generate an effluent amenable to SO_2 control. A gas stream free of particulate matter is required for converting the SO_2 to acid, therefore particles must be removed prior to the SO_2 conversion step.

Operating conditions for roasting zinc sulfide concentrates vary from plant to plant according to the composition of the raw material and the specific use of the roaster calcine. Higher roasting temperatures (1,800° F and over) eliminate more cadmium and increase the formation of ferrites. Excess oxidizing air results in lower temperatures and good sulfur elimination, but also lowers the SO_2 concentration in the roaster gas. Typical zinc roasting operations are shown in table 10.

TABLE 10. - Typical zinc roasting operations[1]

Type of roaster	Operating temperature, ° F	Feed capacity, tons/day	Dust in offgas, percent of feed	SO_2 in offgas, percent
Multihearth.............	1,200-1,350	50-120	5-15	4.5- 6.5
Do.[2]	1,600-1,650	250	5-15	4.5- 6.5
Ropp[3]	1,200	40- 50	5	0.7- 1.0
Fluid bed[4] (Dorr-Oliver).	1,640	140-225	70-80	7 - 8
Fluid bed[3] (Dorr-Oliver).	1,650	240-350	75-85	10 -12
Fluid bed (Lurgi)........	1,700	240	50	9 -10
Suspension..............	1,800	120-350	50	8 -12
Fluid column............	1,900	225	17-18	11 -12

[1] Dead roast except where noted otherwise.

[2] First stage is a partial roast in multihearth, second stage is a dry-feed dead roast in Dorr-Oliver fluid bed.

[3] Partial roast.

[4] Slurry feed.

Sintering

The fine-sized roaster calcines are suitable for the electrolytic process but a coarser feed is required for thermal reduction processes. Agglomeration of particles is accomplished with sintering machines. These machines have continuous conveyors made of grate-bar pallets, upon which the feed material is placed and processed. The conveyors range in size from 3.5 feet wide by 45 feet long up to 12 feet wide by 168 feet long. Downdraft machines are universally used in the zinc industry. The downdraft is produced by sectionalized wind boxes installed beneath the line of travel of the pallets.

Feed for the sintering machine is a mixture consisting of calcine or concentrates, recycled ground sinter, recovered dust in some plants, and the required amount of carbonaceous fuel of proper particle size and moisture content for pelletizing. After the mixture is pelletized, it is sized in the range of 20 mesh to one-half inch. The product is coarsely crushed and then goes to the zinc distillation step. Typical zinc sintering operations are shown in table 11.

TABLE 11. - Typical zinc sintering operations

Operation	1	2	3
New feed material	Calcine	Calcine	Concentrate
Total charge capacity, tons per day	240-300	400-450	550-600
Machine size, feet	3.5 X 45	6 X 97	12 X 168
Fuel added to feed, percent	6-7	10-11	0-2
Total sulfur in new feed, percent	8	2	31
Recycle, percent of new feed	35-75	40-70	80
Operating temperature, ° F	1,900	1,900	1,900
Dust in offgas, percent of feed	5	5-7	5-10
Offgas SO_2 content, percent	1.5-2.0	0	1.7-2.4

About 78 to 90 percent of the contained zinc in the new leach feed is taken into solution in the purified electrolyte. The total recovery of zinc from ores treated by the electrolytic process is 91 to 97 percent.

Reduction

There are two basic methods of recovering zinc from the concentrate or the roasted material--pyrometallurgical or electrolytic.

The electrolytic process entails dissolution of the roaster product in dilute sulfuric acid, purification of the resulting solution, and then electrolysis of the purified solution to plate out zinc on an insoluble cathode.

Pyrometallurgical processes for producing zinc are all based on the reduction of zinc oxide with carbon at elevated temperatures. The two simultaneous gas-solid reactions are

$$ZnO(s) + CO(g) = Zn(g) + CO_2(g),$$

$$CO_2(g) + C(s) = 2CO(g).$$

The rate of the zinc-reducing reaction is quite slow at temperatures below 1,800° F, and efficient commercial operations require a minimum temperature of 2,200° F. Since the reduced zinc is in a gaseous form at these temperatures, it must be cooled to a liquid for collection. Upon cooling the CO_2 or CO present could reoxidize the zinc to zinc oxide (blue powder). However, the CO reaction rate is quite slow under operating conditions and when the CO_2 content of the exit gases is kept low, the formation of zinc oxide is minimized.

Reduction of the sinter or calcine is performed in horizontal or vertical retorts, electrothermal open or submerged arc furnaces, or blast furnaces.

Horizontal Retort Process

Horizontal retorts are small ceramic cylinders that are mounted horizontally in racks that hold several rows of retorts mounted one over the other. They are fed with coal and sinter and produce liquid zinc metal. Horizontal retort plants are high-cost processes and gradually are being phased out as a commercial process. Air pollution control of the particulate matter, mostly zinc oxide dust, emitted by these plants is not economically feasible. Only three horizontal retort plants were operating in the United States in 1973.

The individual retorts are closed ceramic cylinders of about 9 inches inside diameter and 5 feet in length with a wall thickness of about 1 inch. The retorts are spaced in the retort furnace with provision for the admission of combustion air and gas. Furnaces contain from 600 to 900 retorts.

The vaporized zinc is collected in condensers, usually conical in shape. The condensers are about 2 feet long, 3/4 inch thick, match the retort diameter at the retort end, and taper to about 3 inches at the mouth end. High thermal shock conditions results in an average condenser life of only 5 days and every effort is made to keep manufacturing cost low.

Charge for the retorts is a mixture composed, in percent, as follows: Sintered or nodulized calcines, or in part zinc fume, 56 to 70; return blue powder and residues, 5 to 10; salt, about 2; and carbonaceous reductant, 23 to 32. Water equivalent to about 6 percent of the dry solids is added to the mix. The carbonaceous reductant can be anthracite coal, semianthracite coal, or coke breeze. Natural gas is the preferred fuel to fire the retort furnace although producer gas, oil, or powdered coal also can be used.

The furnace operation is cyclic and begins with charging. Sequential steps are (1) removal of the condensers, (2) collection and storage (for subsequent zinc recovery) of the zinc saturated loam and crust accumulated near the mouth of the retort during the previous cycle, (3) removal of the remaining residues, (4) replacement of unsound retorts, (5) emplacement of the mixed charge, and (6) connection of condensers to the retorts by use of a moistened fuel-clay mixture. A similar mixture is used as a plug in the mouth of the condenser to dam up the condensed zinc.

During the firing stage the temperatures in the furnace are quickly raised to bring the reaction temperature to about 2,200° F. Reduction of the zinc oxide by reaction with the carbon results in zinc vapor being forced out of the retort by the force of the expanding gases. The cool condenser liquefies the zinc and it collects in a pool in the condenser's mouth. Metal is drawn from the condenser into a ladle from 4 to 5 times per cycle by piercing the plug.

Direct furnace recoveries of zinc from the new retort feed are about 80 to 85 percent for the 24-hour cycle and 91 to 95 percent for the 48-hour cycle.

Re-treatment of residues, blue powder, and old condensers recovers additional zinc. Overall recovery of zinc in ore delivered to the roasters for horizontal retort treatment averages 90 percent.

Vertical Retort Process

This process, developed about 1930 by the New Jersey Zinc Co. uses a vertical, externally heated retort with feed, condensing, and discharge arrangements for continuous distillation.

The vertical, box-shaped retort has inside dimensions approximately 1 foot wide by 7 feet high and 35 feet long. It is constructed of tightly fitted silicon carbide blocks and the retort is enclosed in a suitable firebrick furnace. Producer or natural gas and air are admitted to the combustion chamber in controlled amounts to provide a fairly uniform temperature of 2,375° F along the retort wall. The exhaust gases are sent through a heat exchanger to preheat the combustion air.

The retort is charged with coked briquets consisting of a mixture containing approximately 55 percent bituminous coal, 10 percent anthracite, and 10 percent recirculated fines. Use of coked briquets insures free movement of the charge through the retort, permits heat transfer to the center of the retort, and provides sufficient porosity for the flow of combustion and distillation gases. The hot briquets are charged periodically to the top of the retort and reach reduction temperature as they move downward. At the bottom, the spent residues are withdrawn continuously through a water seal.

Zinc vapor leaving the top of the retort is condensed by passage through a spray of molten zinc thrown into the exhaust gas stream by a graphite impeller. About 95 percent of the zinc vapor leaving the retort is condensed to liquid zinc.

A wide variety of ores has been successfully treated by the vertical retort process. Feeds containing up to 10 percent iron and 1.5 percent lead present no great difficulty. Retorts are built with up to 8 tons per day of zinc output capacity.

Electrothermic Process

In this process zinc is distilled continuously in a vertical retort or furnace with heat developed internally by passage of an electric current through the feed mixture of zinc oxide sinter and coke. Modern installations have an inside diameter of 8 feet, a height of 50 feet, and a distance between the eight upper electrodes and the eight lower electrodes of 32 feet. A unit of this size achieves an average daily output of 50 tons of zinc. In order to prepare the feed for the electrothermic furnace the zinc concentrate is roasted or sintered under controlled conditions to remove most of the cadmium, lead, and certain other impurities and produce a porous, hard, properly sized sinter. The preheated mixture of sinter and coke in about equal volumes is fed into the top of the furnace and moves downward as the residues are withdrawn from the furnace bottom. The charge is heated to about 2,375° F by passage of electricity through the charge and the zinc oxide is reduced to zinc vapor and carbon monoxide which are drawn off through a vapor ring below the upper electrodes. The zinc vapor is condensed by passage through a pool of liquid zinc, and the accumulated addition is withdrawn by frequent tapping of the condenser. The exhaust carbon monoxide is scrubbed of final traces of zinc and then used as fuel in other plant operations.

Blast Furnace Process (Imperial Smelting Process)

The blast furnace process of producing zinc, also known as the Imperial vertical-type smelter process, was introduced commercially in 1950 by Imperial Smelting Corporation Ltd., Avonmouth, England. The process has never been used in the United States although a number of plants are operating in other countries. The usual blast furnace practice of burning carbonaceous matter in intimate association with the material to be reduced is followed and, as in other zinc distillation processes, the zinc is released as a vapor and which must be condensed.

The blast furnace is fed with a mixture of sinter and preheated coke intermittently through a double hopper system so as to exclude entry of air. Preheated air is blown in through tuyeres at the bottom of the furnace and sufficient heat is developed to cause the reduction of the zinc oxide and to fuse the gangue material. The exhaust gases, which enter a condenser at either side of the furnace, contain approximately 5 percent zinc vapor, 10 percent carbon dioxide, and 21 percent carbon monoxide.

The zinc vapor is condensed in a rectangular chamber containing a pool of molten lead. Mechanical rotors dip into the pool and throw up a dense spray of lead droplets, covering the whole area of the condenser. As the vapors from the furnace pass through this spray, they are chilled and the zinc is condensed and absorbed by the lead droplets. A flow of hot zinc-containing lead is withdrawn continuously from the pool and is cooled by passing through water-jacketed launders. As the temperature drops the solubility of zinc in lead decreases until the saturation point is reached. With further cooling, molten zinc appears as a separate liquid phase floating on the top of the lead. The zinc is removed, and the lead, now cooled and with a reduced zinc content, is returned to the condenser to repeat the cycle.

The gases leaving the condenser are scrubbed with water and the carbon monoxide is used to preheat the air and coke for combustion in the furnace. Any lead present in the charge collects at the bottom of the furnace together with the molten gangue material. The furnace is tapped periodically and the mixture of lead bullion and slag separated in a fore hearth. The lead collects any precious metals present and copper is also recoverable from the bullion.

An important advantage to the process is the ability to treat a mixed zinc-lead concentrate and recover both metals as well as any gold and silver present with no extra coke consumption and little extra labor. Zinc produced by the blast furnace is Prime Western grade, containing about 1.2 percent lead and 0.02 percent iron.

Electrolytic Reduction

The electrolytic recovery of zinc from the roasted ore involves the following steps: (1) Dissolving (leaching) the zinc-bearing materials, mainly roasted ore, in dilute sulfuric acid to form a zinc sulfate solution; (2) removal of impurities from the solution (purification); and (3) electrolysis of the zinc sulfate by passage of a current from an insoluble anode to an insoluble cathode upon which the zinc metal is deposited.

Leaching of the zinc oxide in dilute sulfuric acid is complicated by the simultaneous dissolution of the contained impurities and the attendant procedures to remove them without entailing large losses of the zinc. Leaching systems employed are broadly classed as (1) batch leaching, (2) continuous leaching, and (3) reverse leaching.

Purification of the electrolyte is a key factor in application of the electrolytic process. Many elements, alone or in combination, will disrupt the economic deposition of the zinc. Antimony, arsenic, copper, germanium, and tellurium are detrimental in the electrolysis of zinc. Cadmium and lead deposits with the zinc. Aluminum, magnesium, manganese, and potassium detrimentally affect conductance of the electrolyte. Iron, cobalt, and nickel lower cell efficiency because they cause redissolution of the zinc deposit. Impurities contained in the feed material, to a large extent, establish the flowsheet of the particular electrolytic plant and for certain ores even preclude electrolytic processing.

The electrolysis of the zinc solution is carried out in cells (tanks) usually constructed of wood or concrete and lined with lead. Each cell contains from 18 to 45 anodes with a cathode placed between each two anodes. The anodes are of lead sometimes alloyed with 0.5 to 1.0 percent silver and are either cast or rolled. Anodes with grid construction are sometimes used because of lower weight and improved electrolyte circulation. The cells are operated with an applied voltage of about 3.4 volts and a current density near 30 amperes per square foot. The zinc is deposited on rolled aluminum cathode starting sheets.

These cathodes are removed from the tanks at regular intervals of time and the deposited zinc stripped from each side. The stripped sheets are melted in a furnace and cast into slabs. Zinc produced by the electrolytic process is of High Grade and Special High Grade quality. A portion of the metal is usually treated in a furnace to produce the zinc dust used in purification of the leach solution.

The physical quality of the zinc deposition is improved by electrolyte addition agents such as glue in quantities of about one-half pound per ton of slab zinc produced. Strontium carbonate is sometimes added to inhibit lead deposition where the lead concentration is undesirably high. In low current density systems lead deposition is reduced by the addition of cobalt.

Residue Treatment

Residues from the retort processes or the electrolytic zinc process are treated to recover contained values by the slag fuming, the Waelz kiln, or the jarosite process. Only the slag fuming and Waelz processes are practiced in the United States.

The slag fuming process is used to recover zinc from new or old lead furnace slags with zinc contents of 8 or more percent. A fume containing 67 to 70 percent zinc and 7 to 10 percent lead is recovered. The fume may be used as feed material in a zinc reduction process or purified and marketed as zinc oxide.

General practice is to use a water-jacketed shaft furnace about 8 to 15 feet in section and 24 feet high. Molten slag is first charged into the furnace, then a proper mixture of air and pulverized coal is introduced through tuyeres near the bottom of the furnace. Part of the coal burns to achieve the desired slag temperature (2,100° to 2,200° F) and part acts as a reductant for the contained zinc and lead in the molten slag. Additional air admitted above the molten zone oxidizes the metal vapors and burns the carbon monoxide. The fume and exhaust gases are separated by bag filters after passage through a waste heat boiler. At the close of each operating cycle the slag tailing is tapped and drawn into pots or a water granulation system for disposal.

The Waelz process is used to beneficiate zinc-containing retort residues into an oxidic fume product suitable as feed for zinc reduction or for production of zinc oxide, zinc sulfate, or lithopone. Zinciferous material, in many cases with the zinc occurring as a tightly bonded compound of iron and silica, is mixed with carbonaceous fuel and fed into a slightly sloping, rotating kiln. A gas or oil flame at the kiln discharge end ignites the carbonaceous material; the contained zinc, lead, and germanium compounds are first reduced, then oxidized into a fume that is carried along in the gases exhausted at the feed end. The finely divided fume particles are collected in electrostatic precipitators or in bag-type filters.

In the jarosite process, a more recent development in zinc residue treatment, the zinc ferrite content of the residue is dissolved in hot sulfuric acid. The leach solution is treated with calcine so it is only slightly acidic with the result that the iron is precipitated as a jarosite compound by adding ammonia or salts of sodium or potasssium. The precipitated jarosites are easily filtered and washed free of the zinc-bearing solution which can be directly electrolyzed to recover the zinc or may be blended in with the main feed to the electrolytic cells.

Leach residues ordinarily contain significant quantities of zinc, lead, gold, silver, and copper as well as other minor impurity elements, and constitute an important feed material to lead blast furnace operations. If the value of the copper exceeds that of the lead, the material can be treated in a copper reverberatory or blast furnace. Partial recovery of the contained zinc is accomplished by fuming lead or copper slags, by treating the residue directly by the Waelz kiln process or by the jarosite process. The residues may also be roasted with sulfuric acid which converts much of the insoluble form for further leaching. Purification residues contain principally zinc, copper, and cadmium and are treated for recovery at copper smelters and cadmium plants. Electrolytic tank residues are treated by various methods dependent upon the principal composition.

Refining

Zinc produced by distillation processes is normally of the lower commercial grades and in some instances the contained impurities are greater than is acceptable for the lowest grade. Therefore, much of the distilled zinc is refined to reduce the quantities of the common impurities of lead, cadmium, and iron; also the lesser impurities such as copper, tin, and arsenic. Refining is accomplished by either liquation or redistillation.

Refining by liquation is used to remove lead and iron to a limited degree and is based on reduced mutual solubilities with zinc at progressively lower temperatures and separation into liquid layers according to specific gravities. The low-grade zinc is charged into a reverberatory furnace and melted. Floating oxides are skimmed off and the molten zinc, over a period of 16 to 24 hours, is cooled to just above the melting point. Under these quiescent conditions layers of lead, an iron-zinc alloy, and zinc separate out. Zinc is drawn off at the end of each cycle of operation. When the impurity layers become too large for efficient furnace operation they are withdrawn separately to reclaim the contained values. The liquated product containing 1.2 percent lead and 0.025 percent iron conforms to Prime Western grade zinc.

Refining by redistillation is accomplished by means of vertical fractionating columns which continuously separate the impurities contained in the feed zinc and produce zinc of 99.995+ purity.

The fractional distillation columns are made of tightly fitted rectifying stacks of monolithic silicon carbide rectangular trays. Melted impure zinc is charged into the lead column at a point just above the furnace. The molten metal flows through overflow ports on alternating ends of the trays to create a baffle path to the ascending zinc (and cadmium) vapors evolved in the heated trays in the furnace section. The vapors are cleansed of almost all lead and iron by movement through the descending molten metal and are then passed through a condenser. From 20 to 33 percent of the feed metal serves to wash the removed lead and iron into a liquating pot. The liquated zinc is cast either for marketing as Prime Western grade zinc or as return feed to the fractionating tower. The separated lead is sent to a refinery and the iron-zinc alloy is granulated for recirculation in the smelting process.

The condensed vapors from the lead column are the feed for the cadmium column. Virtually all of the cadmium and a small part of the zinc is distilled in passing through the furnace zone and these rising vapors are discharged into a cadmium canister as a cadmium-rich zinc dust. The purified zinc flows out the bottom of the column into a covered holding pot.

Casting

Casting of zinc is the final step in production of the metal. In the case of thermal reduction, the zinc is already in a molten state and ready for pouring into molds. In the case of electrolytic zinc, the stripped sheets must first be melted. The usual procedure is to melt the sheets in a reverberatory furnace. Washing to remove slimes or electrolyte and drying to prevent moisture explosions normally precede charging operations. Dross from the furnace operations, amounting to about 4 percent of the charged zinc, may be used to manufacture zinc dust used in the electrolytic process. Low-frequency induction furnaces are also used for melting.

SUPPLY AND DISTRIBUTION

Background

Zinc was known as an alloy material long before it was known as a metal. The oldest known piece of zinc is in the form of an idol found in the prehistoric Dacian Settlement at Doroseh, Transylvania. Analysis of the piece showed 87.5 percent zinc, 11.5 percent lead, and 1 percent iron. As early as 200 B.C. the Romans were well acquainted with brass. Zinc appears to have been known in India as early as 1000 to 1300 A.D. and was probably smelted commercially in the 14th century.

The first writing on the physical qualities of the metal "zinck" was by Paracelsus (1490-1541). During the 17th and 18th centuries, large quantities of zinc were imported from Asia and sold in the European market under various names with the term "spelter" finally being selected as the commercial designation of slab zinc. About 1730 the technology of smelting was brought from China to England, and in 1739 a patent was obtained for a distillation method and a smelter was erected at Bristol, England, with an annual capacity of 200 tons of spelter.

In the United States the first zinc was produced in 1835 at the Arsenal in Washington, D.C. The U.S. Government imported workers from Belgium and built a small spelter furnace utilizing zincite ore from New Jersey. The primary purpose of the furnace was to provide zinc for brass used in producing standard units of weight and measure.

The U.S. zinc industry began in 1860 upon successful operation of a plant at La Salle, Ill., for the treatment of Wisconsin ores and also at a plant at South Bethlehem, Pa., the same year. The processing technology of zinc improved rapidly with adoption of horizontal retorts; mechanically rabbled roasters; hydrometallurgical techniques to produce, by leaching, a zinc sulfate for lithopone and the American process for production of zinc oxide directly from ore. In 1895 natural gas was discovered in Kansas, which led to the building of a number of smelters in the Southwestern United States utilizing natural gas as a fuel.

The commercial introduction of the froth flotation process early in the 20th century, which made possible the efficient separation of lead and zinc minerals, was a most significant technological advance in the zinc industry. The problems of smelting lead-zinc sulfide ores and concentrates had previously prevented efficient recovery of the zinc at lead smelters because the zinc remained in the slag. The flotation process also made it possible to recover the zinc in mixed copper-lead-zinc ores.

Historical Sketch of Zinc-Industry, 1910-1973, by 5-Year Periods

1910 to 1914

From 1910 to 1914 mine production increased from 328,000 to 407,000 short tons and smelter output from 282,000 to 374,000 tons.. Galvanizing accounted for about 60 percent of slab zinc use, brass 20 percent, and sheet zinc about 13 percent. It was during this period that the concentration of zinc ores by flotation came into use at the mills of the Butte and Superior, Timber Butte Milling Co., and Butte Reduction Works, of Butte, Mont., and at the Federal Mining and Smelting Co.'s Morning mine, Mullan, Idaho, as well as elsewhere in the Coeur d'Alene area. The Bureau of Mines at this same time was testing the lead-zinc ores of the Joplin, Mo., area to determine their amenability to flotation. The first electrolytic zinc production in the United States was at Great Falls, Mont., October 1914; daily capacity was 110 tons. All other smelter production was based on horizontal retorts at 29 other plants. About 40 percent of the zinc production was from Joplin zinc concentrates. In 1910 the mechanical device for charging and discharging horizontal retorts was tested at American Zinc, Lead & Smelting Co.'s Caney, Kans., smelter. Tennessee became an important producer of zinc when the Mascot mill started June 1913.

1915 to 1919

During World War I the smelting facilities of France, Belgium, Germany, and Poland were unavailable to the Allies who turned to the United States for zinc supplies. Smelters were erected at an unprecedented rate, and by 1917 slab zinc production was 670,000 tons, 90 percent above the 1914 level and about 60 percent of world output. Domestic mines increased zinc output from 407,000 tons in 1914 to 713,000 tons in 1917. During the same period imports of zinc in ore increased from 25,000 tons to 148,000 tons. U.S. exports were 66,000 tons of slab zinc in 1914 and increased to 163,000 tons in 1917. The corresponding exports of rolled zinc were 12,000 tons increasing to 20,000 tons. Consumption in the United States during the war (1917-18) approximated 450,000 tons of slab zinc as compared to about 350,000 tons in 1912-14. About 44 percent was consumed in galvanizing (60 percent prewar), 38 percent in brass (20 percent), and 11 percent in rolled zinc (13 percent). Electrolytic zinc production increased from 252 tons in 1915 to 27,000 tons in 1919.

1920 to 1924

Following the war, the zinc market declined and exports of slab zinc decreased from an average of 120,000 tons per year to about 40,000 tons. Exports of rolled zinc declined from about 15,000 tons to about 3,000 tons. Metal prices declined from 8 cents per pound to an average of 6.2 cents for the 1920-24 period. Many mines were closed or forced to curtail output. Mine output in 1921 was cut back to 257,000 tons and smelter output to 218,000 tons. During this period production of electrolytic zinc increased from 52,000 to 77,000 tons per year, and Bunker Hill and Sullivan Mining and Concentrating Co. began construction of an electrolytic plant at Kellogg, Utah. The American Smelting and Refining Co. smelter at Amarillo, Tex., was put in operation in 1923. In this period of adjustment mine production varied from 257,000 in 1921 to 638,000 tons in 1924. Noteworthy was the fact that 61 percent of all mine production came from the Joplin, Mo., area, 13 percent from New Jersey, and 10 percent from Butte, Mont.

1925 to 1929

During this 5-year period U.S. mine production was at an extremely high level. It ranged from a high of 775,000 tons in 1926 to a low of 695,000 tons in 1928 and averaged 725,000 tons for the 5 years. Development of methods to selectively float previously unworkable complex ores was completed and the marketing of flotation-produced zinc concentrates more than doubled. High-grade concentrates improved the quality of smelter feed and stimulated new plant construction. Electrolytic zinc capacity was increased by construction of the Anaconda and Kellogg plants in 1928 and the Evans-Wallower Zinc Co.'s East St. Louis plant in 1929.

In 1928 a European zinc cartel was formed representing 95 percent of European smelter capacity. Several measures were attempted to curtail production in order to raise prices. However, the cartel failed to accomplish its objectives and the agreement was dissolved December 31, 1929.

1930 to 1934

Industrial activity declined greatly in the 5-year period and in 1932 zinc sold for as low as 2.3 cents a pound, averaging but 2.9 cents. Industry at first failed to cut production as demand declined and producers' stocks doubled in 1930. During the period U.S. mine production ranged from 595,000 tons in 1930 down to 285,000 tons in 1932, with an average production of 423,000 tons over the 5 years. This average was only 58 percent of the 1929 production. Consumption of slab zinc was about 360,000 tons for each of the last 4 years of the period, and about 40 percent less than in 1929. Declines were noted in all uses but rolled zinc for jar tops and that use increased due to the growth of home canning.

The Hudson Bay Mining & Smelting Co. (Ltd.) electrolytic zinc plant at Flin Flon, Manitoba, in Canada began producing slab zinc in 1930--producing at the rate of 25,000 tons per year.

The European cartel was revived in 1931, but was relatively unsuccessful in stabilizing prices at a profitable level. Its problem was made more difficult by depreciated currency in most countries, and demands for imposition of protective tariffs by other countries, As a result the cartel finally collapsed in December 1934.

1935 to 1939

This 5 years was one of recovery as mine output, smelter production, consumption, and price generally trended upward although failing to reach the high levels of 1928 and 1929. Inefficient smelters and mines remained closed; those that were operating effected economies through better technology and management. The St. Joseph Lead Co. began large scale production of zinc at its Josephtown, Pa., electrothermic smelter, and additional vertical retorts were installed by New Jersey Zinc Co. at Palmerton, Pa. Mechanical loading, detachable drill bits, and artificial pillars lowered costs at mines. At smelters recoveries had been increased by use of the electrolytic process, and greater revenue was obtained by selling premium-grade zinc. Byproduct sulfuric acid and cadmium brought additional revenue.

1940 to 1944

National defense pressures, first in assisting Great Britain and France and later in mounting the U.S. World War II offensive, caused mine and smelter output to increase rapidly in 1940 and 1941. During the 1940-44 period, mine production ranged between 665,000 tons and 768,000 tons with the minimum production in 1940 and the maximum in 1942. Production during the period averaged 730,000 tons--30 percent above the 1935-39 average. Smelter output of primary zinc averaged 840,000 tons--73 percent above the comparable figure for the 1935-39 period. Imports of concentrate, chiefly from Mexico, Canada, Australia, and Peru became more important in ore and slab form which had averaged only 33,000 tons per year in the 1935-39 period, but for the war period averaged over 400,000 tons (196,000 in 1940 to 595,000 in 1943). The U.S. smelters absorbed much of the foreign trade of European smelters which were in territory occupied by the Germans.

During the war, the zinc industry was rigidly controlled with ceiling prices, allocation of metal, and export-import controls. Consumption was geared to war requirements and the Government acquired large stocks of concentrate and metal. The 1940-44 consumption averaged about 800,000 tons of slab zinc per year (ranging between 719,000 and 889,000 tons annually) and was used primarily for galvanizing, 42 percent; brass, 29 percent; die-casting, 18 percent; and rolled zinc, 9 percent.

1945 to 1949

With the cessation of war, demand remained at high levels, but mine production declined from a 730,000-ton annual average for the prior period to 610,000 tons during 1945-1949. Smelter output declined by an average of 60,000 tons per year, and requirements exceeded domestic supply. This excess demand was met by increased imports of metal and liquidation of smelter stocks which declined from 256,000 tons at the end of 1945 to 21,000 tons at the end of 1948. As stocks declined and consumption firmed at about 800,000 tons per annum, prices were increased from an average of 8.2 cents in 1945 to a 13.6-cent average in 1948 and a high of 17.5 cents in that year. Consumption slackened to 712,000 tons in 1949 while smelter output was increased to 815,000 tons causing stocks to increase again and prices fell sharply to close 1949 at 9.75 cents per pound. Competition from foreign metal was again being felt on the U.S. market.

1950 to 1954

In 1950 demand was accelerated, by the outbreak of hostilities in Korea, to more than 900,000 tons and thereafter high demand was maintained by the joint requirements of the cold war and Government stockpiling. Mine production was increased somewhat in 1950-51, smelter production of primary and redistilled zinc reached near record levels and imports in 1953 and 1954 were in excess of the peak quantities imported during World War II. Inventory controls, price controls, and restrictions on use beginning in 1950 aided in meeting all essential requirements and at the same time permitted acquisition of strategic stocks by the Government. World price in 1951, however, exceeded the domestic price, and caused considerable movement of "non-contracted for" ores and metal to Europe. In 1952 the European market became saturated as new facilities came into production and excess production again moved to the U.S. markets. Prices declined from the 18-cent average of 1951 to a 10.9-cent average in 1953 and again some domestic mines were closed and other mines curtailed output. The domestic mines then petitioned the Tariff Commission for a hearing under the Escape Clause of the Trade Agreements Act, alleging damage by reason of trade concessions granted. The Tariff Commission found the complaint well grounded and recommended higher tariffs. However, the Government in lieu of increasing tariffs undertook additional stockpiling of domestically produced zinc beginning in June 1954. This action resulted in zinc prices of 11.5 cents, but was inadequate to keep marginal mines in production, particularly in view of world production greatly in excess of requirements.

1955 to 1959

Slab zinc consumption increased to a new high in 1955 of 1,120,000 tons, exceeding the previous high of 986,000 tons established in 1953. Mine production, however, continued to decline and by 1958 had reached 412,000 tons, the lowest output since the depression years. Smelter output attained record levels, but an increasing percentage of the output was based on annual imports of about 500,000 tons (content) of foreign concentrates. Total world production of slab zinc continued to be in excess of requirements and large imports of slab zinc also moved to the U.S. markets in response to consumer demand, barter arrangements, and Government contracts.

The domestic zinc and lead mining industry in 1957 petitioned the Tariff Commission for an escape clause investigation which would lead to reductions in the quantities of lead and zinc imported. On the basis of the findings, the President ordered the establishment of quarterly quotas beginning October 1, 1958. The quarterly quotas annually were to equal 80 percent of the average annual comparative imports in the 1953-57 base period.

Mine production began to decline in the latter part of 1957 and in 1958 reached the lowest point since 1933. Numerous zinc and zinc-lead mines closed and others reduced output in 1957 as nearly all the mines in the Tri-State district, many in the Western States and a few in the Eastern States became inactive. Mine and smelter output increased slightly in 1959 despite strikes in the latter half of the year. A strengthening of the zinc position was reflected in a further drawdown of producer's stocks as well as a price increase.

1960 to 1964

Domestic mine and smelter production increased each year from 1960 through 1964 as did consumption except for 1960 when consumption declined 8 percent below that of 1959. Import quotas continued in effect and combined imports of zinc in ore and concentrates and as metal combined decreased in all years except 1962. Imports of zinc in ore and concentrates were 100,000 tons lower in 1964 than in 1960; mine production was up 140,000 tons, smelter production advanced 160,000 tons, and both slab and total zinc consumed were at record levels.

Legislation authorizing a Government subsidy program to provide stabilization payments to small producers of lead and zinc ores and concentrates was enacted October 3, 1961, and maximum total annual amounts of payments were established by law for 1962 through 1965. Payments per pound of contained zinc were 55 percent of the difference between 14.5 cents and the average monthly base price for Prime Western zinc for the month in which the sale occurred.

In Canada mine production of zinc increased 44 percent to a record 730,000 tons in 1964 and that country outranked the United States for the first time as the world's largest producer.

1965 to 1969

In 1965 mine production increased to over 611,000 tons, the highest since 1952; records were attained for smelter output and slab zinc consumption; and imports of zinc in ores and concentrates and of zinc metal were the largest since 1962 and 1959, respectively. Mine production declined in the 3 following years but rebounded in 1969. Smelter production set records in 1966 and 1969 and slab zinc consumption was at a new high in 1966 at 1,410,000 tons.

U.S. import quotas for ores and concentrates were terminated by Presidential proclamation on October 22, 1965, and for metal November 21, 1965. The stabilization program for small producers was extended in 1965 under Public Law 89-238 to January 1, 1971. However, the price of zinc reached 14.5 cents per pound on May 1, 1969, the ceiling for payments on qualified production, and the program expired December 31, 1969. In the 8-year period of the program, payments totaling $2,589,597 were made to 91 producers in 11 States on sales of 35,830 tons of lead and 68,860 tons of zinc.

1970 to 1973

Almost all segments of the domestic zinc industry suffered setbacks in 1970 after the strong growth of the preceding 2 years. All elements of zinc supply and consumption declined following the general downward trend in industrial activity. The General Motors Corp. strike in the last 2 months of 1970 was a major factor in lowering demand. In 1971 mine and smelter closures, the cost-price squeeze, imposition of the surcharge on imports of concentrates, ceiling price controls, and devaluation of the dollar all combined to make a difficult year for the zinc industry. In 1972 consumption of slab zinc rose to a new high following the recovery of industrial activity in the United States. However, most of this demand was met by imports of zinc metal and purchases from the national stockpile. Mine production fell to 481,000 tons, the lowest annual output and the first year that production was below 500,000 tons since 1961. Smelter production in 1972 declined 150,000 tons and total imports of zinc in concentrates destined for domestic smelters was down 24 percent.

In early January 1971 the East St. Louis basing point for pricing Prime Western grade zinc was changed to a delivered basis which resulted in canceling the usual charge for freight and was equivalent to reducing the quotation by 0.5 cent per pound. On August 16, 1971, the President's economic stabilization program froze the price of zinc at 17 cents per pound and imposed a surtax on all imports of zinc; this surcharge was removed by Presidential proclamation effective December 20, 1971. The ceiling price was moved up to 18 cents and 18.5 cents per pound on individual application to the Price Commission. Sales of foreign zinc in the United States were not subject to control and the foreign metal was quoted 1 cent and 1.5 cents higher than the permissible domestic price. Phase III of the President's economic stabilization program effective January 11, 1973, removed the price ceiling from zinc. Domestic producers established quotations for Prime Western zinc at 19.0, 19.25, and 19.5 cents per pound by the end of January. Subsequently, an increase by five individual companies raised the price of Prime Western zinc to 20.25 cents per pound and one increased its quote to 21 cents effective April 18, 1973. These prices continued unchanged and were established as ceiling prices by the Cost of Living Council (CLC) on June 13, 1973. No increase had been granted any individual producer by CLC as of the end of October 1973.[5]

The price ranges of imported zinc in cents per pound effective October 1, 1973, were as follows:

Prime Western and High-Grade	27.30-31.00
Special High-Grade	27.80-34.00

European Producers' Price per metric ton effective September 24, 1973, was £250 (27.8 cents per pound for Prime Western equivalent).

London Metal Exchange (LME) price reached a record high of £510 per metric ton on October 15, 1973 (56.7 cents per pound Prime Western equivalent).

Dealer Special High-Grade zinc was quoted at 50.00 to 56.00 cents per pound on October 11, 1973.

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[5] The Cost of Living Council decontrolled the price of zinc on December 6, 1973.

Industry Pattern

The zinc industry is an international basic industry with worldwide influence in mining, smelting, and trade. In tonnage of metal, zinc ranks fourth following steel, aluminum, and copper. In 1972 some 48 nations, well distributed in all continental areas, produced zinc ore. Canada was the world's leading producer with more than double the output of the U.S.S.R. estimated to be in second position, followed by the United States. Ten other countries are known or believed to exceed production of 100,000 tons of zinc in ore annually: Australia, Peru, Mexico, Japan, Poland, Italy, North Korea, West Germany, China, and Yugoslavia. Ore concentrates are smelted in some 25 countries, several of which depend totally or in part on imported concentrates. In 1972 Japan was the leading country reporting metal production, the United States was next, and the U.S.S.R. was third. Other major producers with at least a 100,000-ton output annually were Canada, Australia, France, Belgium, United Kingdom, West Germany, and Italy.

The zinc industry is also closely associated with other nonferrous metals in mining, smelting, and marketing, both internationally and domestically. Some of the companies prominent in the U.S. industry have substantial investments or control of important zinc mines in Canada, Mexico, Bolivia, Argentina, Peru, Australia, and Territory of South-West Africa. Among these are American Metal Climax, Inc., American Smelting and Refining Co., and St. Joe Minerals Corp. Other important foreign zinc operations owned by U.S. corporations or in which they have large interests are Peruvian mines and smelter by Cerro Corp., Mexican mines by the Fresnillo Co., Canadian mines by Cyprus Mines Corp., and African mines by Newmont Mining Corp.

Zinc is recovered from ores showing wide variation in zinc content as well as variations in the content of other metals recovered as coproducts. The ores range from the zinc ores of the Eastern States through the low-zinc ores of new Missouri lead belt to the complex lead-zinc ores of the Western States. Essentially all ore is mined by subsurface methods and the ore beneficiated to a high-grade concentrate at the mine site. The zinc concentrate is shipped to smelters for recovery of byproduct metals, sulfuric acid production, and refining to commercial grade of zinc metal or zinc oxide.

Domestic mines vary widely in output of ore from a few tons to more than 10,000 tons per day. The mines are classified on the basis of the recoverable metal of major value in the ore; that is, zinc ores, zinc-lead ores, and all other ores from which some zinc is obtained. In 1972 zinc ores contributed 58 percent of the total mine output; zinc-lead ores, 21 percent; lead ores, 13 percent; and all other ores, about 8 percent. Seventeen States produced zinc, with Tennessee producing 21 percent of the domestic mine output, followed by Colorado, Missouri, New York, and Idaho. These five States contributed more than 68 percent of the domestic output.

Ores containing zinc are concentrated at mills and shipped to zinc plants for reduction to metal or manufacture of zinc oxide. At the end of 1972 domestic primary zinc plants were operated by six companies: American Smelting and Refining Co. at Amarillo and Corpus Christi, Tex.; Blackwell Zinc Co.

(subsidiary of American Metal Climax, Inc.) at Blackwell, Okla.; The Bunker Hill Co. (subsidiary of Gulf Resources & Chemical Corp.) at Kellogg, Idaho; National Zinc Co. at Bartlesville, Okla.; The New Jersey Zinc Co. (subsidiary of Gulf & Western Industries, Inc.) at Palmerton; and St. Joe Minerals Corp. at Josephtown, Pa. In addition to the above smelters treating concentrates of both domestic and foreign origin, plants for recovering zinc by processing slag from lead smelters are operated by American Smelting and Refining Co. at El Paso, Tex., and East Helena, Mont., and The Bunker Hill Co. at Kellogg, Idaho. Domestic primary capacity for refining slab zinc at the end of 1972 was 721,500 tons annually.

The primary zinc-producing industry is essentially controlled by a few large companies operating mines and refineries. Major U.S. operators of both mines and refineries are American Smelting and Refining Co., American Metal Climax, Inc., The Bunker Hill Co., The New Jersey Zinc Co., and St. Joe Minerals Corp. These five companies produce about 80 percent of the domestic slab zinc and more than 50 percent of the domestic mine output. In addition to the above companies, the United States Steel Corp., Missouri Lead Operating Co., Hecla Mining Co., Idarado Mining Co., Kennecott Copper Corp., Cyprus Mines Corp., Eagle-Picher Industries, Inc., Cominco American, and Ozark Lead Co. operated mines listed among the 25 leading zinc-producing mines in the United States.

Zinc oxide is produced directly from zinc concentrate and from zinc metal at six plants in the United States. American Smelting and Refining Co., Eagle-Picher Industries, Inc., The New Jersey Zinc Co., and St. Joe Minerals Corp. are the principal producers.

The recovery of zinc from old scrap, approximately one-half from zinc-base alloys and the rest from copper-base alloys, is a secondary source of supply, accounting for about 9 percent of the total zinc supply. However, zinc recovered from new scrap amounts to nearly 33 percent of the total primary zinc supply. Some 11 plants are considered secondary zinc distillers. New scrap originating in alloy manufacture is reused in alloys and zinc dust.

Consumption of slab zinc is distributed through 44 States with Illinois, Ohio, Pennsylvania, Michigan, and Indiana each using over 100,000 tons. The continuous galvanizing lines of the steel mills, hot-dip galvanizing pots of the job galvanizers, integrated die-cast shops of the automobile industry, and independent diecasters supplying the automotive and appliance industries make up the major consumers.

Mine Production

Mine production of zinc in the United States reportedly began in southwestern Missouri in 1872 with the first compiled data for zinc produced from domestic ore being for 1873. However, there are references to shipments of zincite ore to England as early as 1774 and references to an important producer of zinc ore in southeast Missouri, the Valle mines in Jefferson County, which were opened in 1824. The Franklin mine at Mine Hill in New Jersey, that has been worked since 1850, has also been mentioned.

Historical mine output by the principal producing States is presented graphically in figures 2-5 to emphasize the rise and decline of the major zinc areas in the United States.

The earliest compiled data show mine production in Missouri and New Jersey was first and second, respectively, from before 1910 through 1916 (figs. 2 and 3) with output in Colorado and Montana advancing in this period to peak output (fig. 4). Production in Oklahoma achieved first place in 1918 as output in Missouri and Colorado declined. Except for 2 years, 1931 and 1932, when production in New Jersey led, Oklahoma continued as the major producer until 1945, then output gradually declined to only token production in 1959. Production in Oklahoma again increased in the period 1962 through 1967 but then along with Kansas output dropped to zero in 1971 ending the Tri-State district's long history as a source of zinc. Mine output of zinc in southwest Missouri ended in 1957 but began again in southeast Missouri in 1966 as byproduct recovery from mines of the new southeast Missouri lead belt.

Idaho's mine production of zinc has been continuous since 1907 generally following the level of industrial activity, peaking in 1916, 1929, and again in 1944 with a production of over 91,000 tons. From 1945 through 1950 and again in 1954 Idaho was the largest producer and has continued to rank as one of the five largest producers to the present.

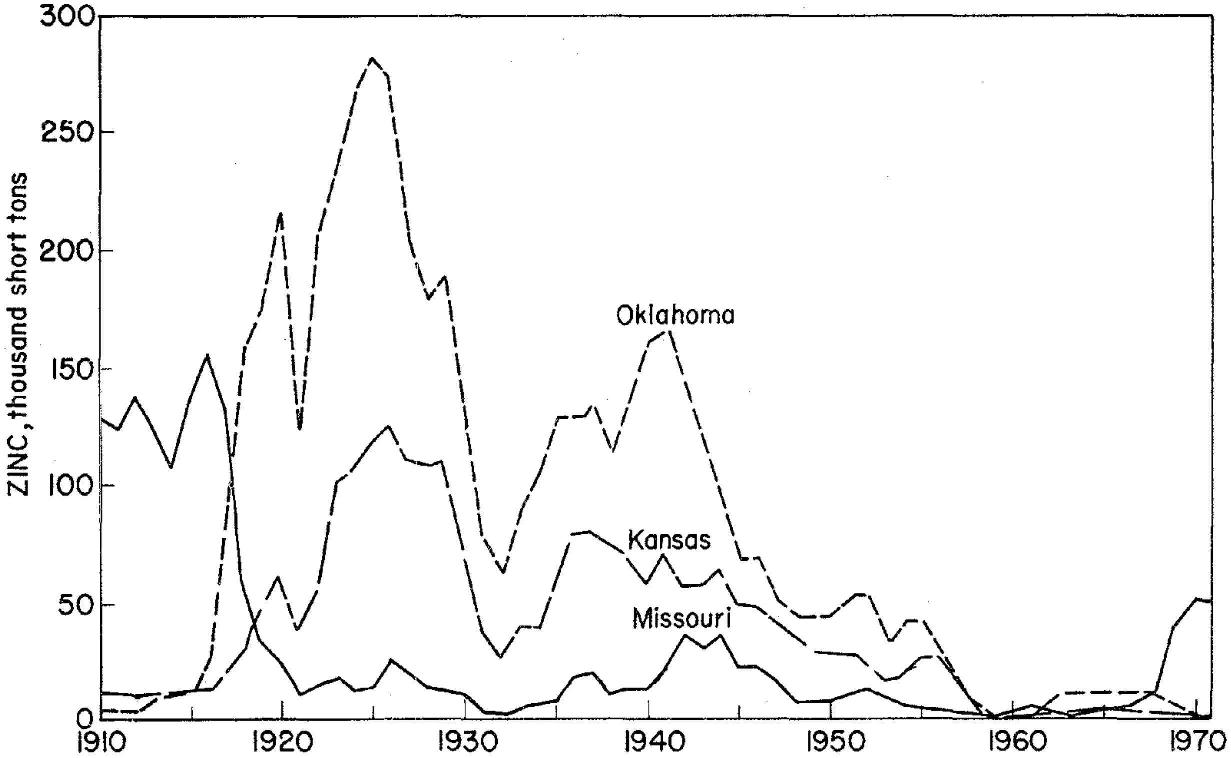

FIGURE 2. - Mine production of zinc, 1910-71: Oklahoma, Kansas, and Missouri.

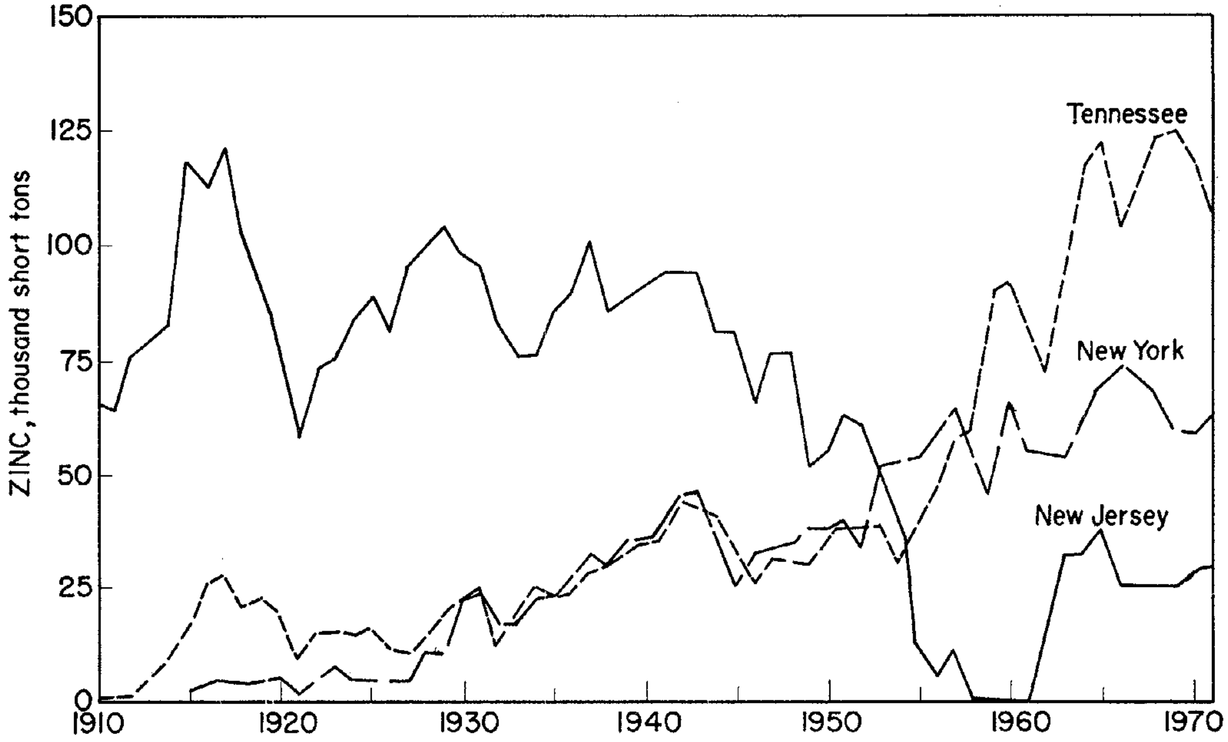

FIGURE 3. - Mine production of zinc, 1910-71: Tennessee, New York, and New Jersey.

Montana became a significant producer of zinc in 1910 and output reached almost 115,000 tons in 1916. Except for the lean years of 1921, 1931, 1932, and 1938, Montana maintained a high level of output and with the exception of 1954 was the leading producer from 1951 through 1956. Most zinc mined in Montana was produced by The Anaconda Company in the Butte district. After the strike in 1967 the zinc properties remained closed.

As a result, the former large Montana zinc deposits are not considered a reserve under present conditions.

Arizona was a fairly consistent producer of zinc from 1940 through 1965. Since then production has dropped to essentially that of only one mine (fig. 5).

Washington produced 10,000 to 32,000 tons of zinc annually from 1938 through 1970, then production fell to less than 6,000 tons in 1971, almost all from one mine.

Zinc was produced in Wisconsin from 1907 through 1971. However, 1971 mine production declined 48 percent from that of 1970 to 10,645 tons, then to 7,300 tons in 1972, the product of one company's mine.

From 1925 through 1970 Utah maintained an annual rate of mine production between 30,000 and 50,000 tons. Output in 1971 was 26 percent below the

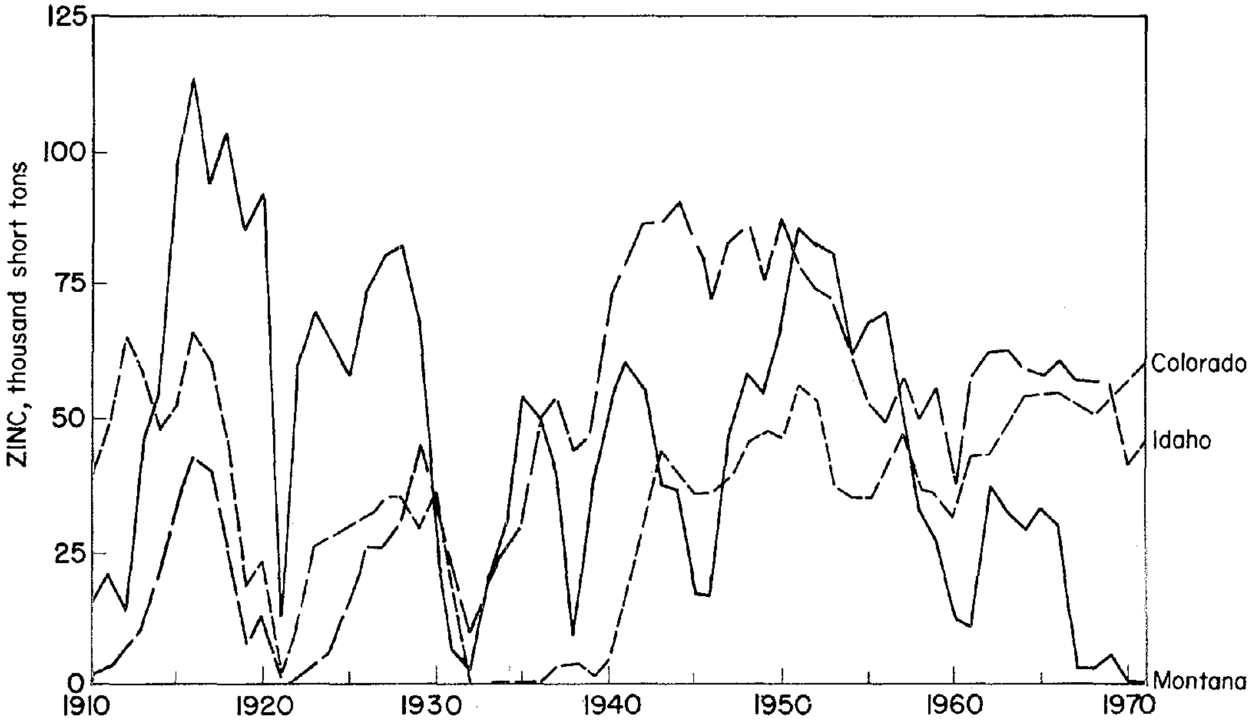

FIGURE 4. - Mine production of zinc, 1910-71: Colorado, Idaho, and Montana.

previous year with six properties reporting. Four mines ceased operations in 1971 and another closed December 31, 1972, leaving only one zinc-producing mine in Utah.

In California one principal producing mine, accounting for almost all 1971 production, was closed in February 1972. Mine production in Nevada declined from 3,000 tons in 1967 to 44 tons in 1971 and none was reported for 1972. The only zinc-producing mine in Maine reported mining 12,000 tons of zinc in 1970 and 5,800 tons in 1971. That mine was closed July 14, 1972, and a new mine, the Blue Hill, began production in October 1972. Total 1972 zinc production in Maine was 5,800 tons.

Zinc mine production began in Tennessee in 1907 and in New York in 1915. From 1930 to 1950 production from these two States was quite close and ranged between 13,000 and 45,000 tons. Beginning in 1955 production in Tennessee increased steadily and in 1958 it became the leading U.S. producer. Record production of approximately 125,000 tons was reached in 1969, then decreased to 104,000 tons in 1972 with the closing of the Mascot No. 2 mine in 1971 and the Coy and Flatgap mines in 1972. Exploration and development work is continuing at the Elmwood mine in Central Tennessee.

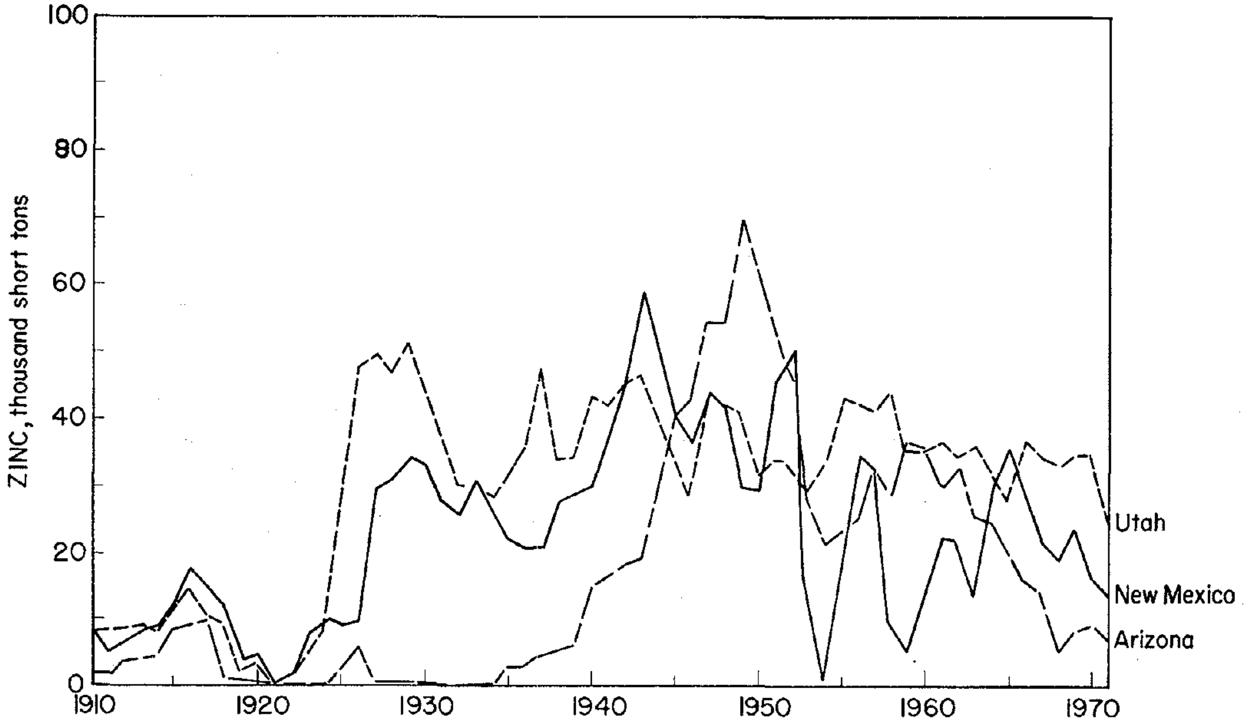

FIGURE 5. - Mine production of zinc, 1910-71: Utah, New Mexico, and Arizona.

Smelter Production

Historically the United States has been the largest producer of slab zinc in the world but has been dependent upon imports of foreign concentrates for a substantial portion of smelter feed since 1941. In fact imported zinc ores have been a part of the U.S. zinc supply since 1906 when 11 percent of the smelter production was from foreign ores; in 1916 and 1917 the average was 14 percent. Thereafter foreign concentrates were a minor item of supply until World War II when they accounted for 13 to 37 percent and averaged about 35 percent on through 1952. In 1953 imported ore provided 46 percent of the primary zinc produced and ranged from 40 percent to 58 percent through 1971. This proportion dropped from 54 percent in 1970 to 47 percent in 1971 and 37 percent in 1972. U.S. slab zinc production by methods of reduction is shown in table 12.

The U.S. slab zinc producing capacity is shown in table 13. At the end of 1970 the rated slab zinc producing capacity at primary plants was 1,161,500 tons, down from the alltime high of 1,290,500 tons in 1968. In addition to minor changes, the decline reflected the closing of Eagle-Picher Industries, Inc., horizontal retort smelter in Henryetta, Okla., which has an annual capacity of 45,000 tons of slab zinc, and the closing of The Anaconda Company electrolytic plant in Anaconda, Mont., rated 90,000 tons annually.

TABLE 12. - Mine production of recoverable zinc in the United States

(Short tons)

State	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
Arizona.....	60,480	52,999	47,143	27,530	21,461	22,684	25,580	33,905	28,532	37,325	35,811	29,585
California..	7,551	9,602	9,419	5,358	1,415	6,836	8,049	2,969	51	78	465	304
Colorado....	45,776	55,714	53,203	37,809	35,150	35,350	40,246	47,000	37,132	35,388	31,278	42,647
Idaho.......	87,890	78,121	74,317	72,153	61,528	53,314	49,561	57,831	49,725	55,699	36,801	58,295
Illinois....	26,982	21,776	18,816	14,556	14,427	21,700	24,039	22,185	24,940	26,815	29,550	26,795
Kansas......	27,176	28,904	25,482	15,515	19,110	27,611	28,665	15,859	4,421	1,017	2,117	2,446
Kentucky....	731	3,457	3,280	489	458	-	417	837	1,258	673	869	1,147
Maine.......	-	-	-	-	-	-	-	-	-	-	-	-
Missouri....	8,189	11,476	13,986	9,981	5,210	4,476	4,380	2,951	362	92	2,821	5,847
Montana.....	67,678	85,551	82,185	80,271	60,952	68,588	70,520	50,520	33,238	27,848	12,551	10,262
Nevada......	21,606	17,443	15,357	5,812	1,035	2,670	7,488	5,292	91	217	420	453
New Jersey..	55,029	62,917	59,190	45,700	37,416	11,643	4,667	12,530	607	-	-	112
New Mexico..	29,263	45,419	50,975	13,373	6	15,277	35,010	32,680	9,034	4,636	13,770	22,900
New York....	38,321	40,051	32,636	51,529	53,199	53,016	59,111	64,659	53,014	43,464	66,364	54,763
Oklahoma....	46,739	53,450	54,916	33,413	43,171	41,543	27,515	14,951	5,267	1,049	2,332	3,148
Pennsylvania	-	-	-	-	-	-	-	-	10,812	16,718	13,746	23,428
Tennessee...	35,326	38,639	38,020	38,465	30,326	40,216	46,023	58,063	59,130	89,932	91,394	81,734
Utah........	31,678	34,317	32,947	29,184	34,031	43,556	42,374	40,846	44,982	35,223	35,476	37,239
Virginia....	12,396	7,332	13,409	16,676	16,738	18,329	19,196	23,080	18,472	20,334	19,885	29,163
Washington..	14,807	18,189	20,102	32,786	22,304	29,536	25,609	24,000	18,797	17,111	21,317	20,217
Wisconsin...	5,722	15,754	20,588	16,830	15,534	18,326	23,890	21,575	12,140	11,635	18,410	13,865
Other.......	35	78	30	-	-	-	-	2	-	49	50	40
Total..	623,375	681,189	666,001	547,430	473,471	514,671	542,340	531,735	412,005	425,303	435,427	464,390

	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Arizona.....	32,888	25,419	24,690	21,757	15,985	14,330	5,441	9,039	9,618	7,761	10,111
California..	322	101	143	225	335	441	3,525	3,327	3,514	3,003	1,202
Colorado....	43,351	48,109	53,682	53,870	54,822	52,442	50,258	53,715	56,694	61,181	63,801
Idaho.......	62,865	63,267	59,298	58,034	60,997	56,528	57,248	55,900	41,052	45,078	38,647
Illinois....	27,413	20,337	13,800	18,314	15,192	20,416	18,182	13,765	16,797	12,706	11,378
Kansas......	3,943	3,508	4,665	6,508	4,769	4,765	3,012	1,900	1,186	-	-
Kentucky....	1,172	1,461	2,063	5,654	6,586	6,317	4,603	4,988	4,189	5,268	1,780
Maine.......	-	-	-	-	-	-	5,099	7,639	9,114	5,850	5,820
Missouri....	2,792	321	1,501	4,312	3,968	7,430	12,301	41,099	50,721	48,215	61,923
Montana.....	37,678	32,941	29,059	33,786	29,120	3,341	3,778	6,143	1,457	361	12
Nevada......	281	571	582	3,858	5,827	3,035	2,104	941	127	71	-
New Jersey..	15,309	32,738	32,926	38,297	25,237	26,041	25,668	25,076	28,683	29,977	38,096
New Mexico..	22,015	12,938	29,833	36,460	29,296	21,380	18,686	24,308	16,601	13,959	12,735
New York....	53,654	53,495	60,754	69,880	73,454	70,555	66,194	58,728	58,577	63,420	60,749
Oklahoma....	10,013	13,245	12,159	12,715	11,237	10,670	6,921	2,744	2,650	-	-
Pennsylvania	24,308	27,389	30,754	27,635	28,080	35,067	30,382	33,035	29,554	27,438	18,344
Tennessee...	71,548	95,847	115,943	122,387	103,117	113,065	124,039	124,532	118,260	119,295	101,722
Utah........	34,313	36,179	31,428	27,747	37,323	34,251	33,153	34,902	34,688	25,701	21,853
Virginia....	26,479	23,988	21,004	20,491	17,666	18,846	19,257	18,704	18,063	16,829	16,789
Washington..	21,644	22,270	24,296	22,230	24,772	21,540	13,884	9,738	11,956	5,782	6,483
Wisconsin...	13,292	15,114	26,278	26,993	24,775	28,953	25,711	22,901	20,634	10,645	6,873
Other.......	211	16	-	-	-	-	-	-	1	3	-
Total..	505,491	529,254	574,858	611,153	572,558	549,413	529,446	553,124	534,136	502,543	478,318

TABLE 13. - Slab zinc production in the United States, by methods of reduction, 1950-72

(Short tons)

Year	Method of reduction				Total
	Primary		Secondary redistilled		
	Electrolytic	Distilled	At primary smelters	At secondary smelters	
1950	342,085	501,382	28,411	38,559	910,437
1951	336,087	545,546	16,251	32,406	930,290
1952	351,106	553,373	18,861	36,250	959,590
1953	370,870	545,235	17,645	35,230	968,980
1954	311,237	491,188	31,658	36,355	870,438
1955	389,891	573,613	24,747	41,295	1,029,546
1956	410,417	573,193	30,221	41,906	1,055,737
1957	409,483	576,313	35,215	37,266	1,058,277
1958	326,449	454,797	24,297	22,308	827,851
1959	280,813	517,853	28,451	29,367	856,484
1960	319,777	479,739	40,009	28,722	868,247
1961	324,399	522,396	35,319	19,918	902,032
1962	354,138	525,257	41,732	17,148	938,275
1963	358,093	534,491	47,214	13,089	952,887
1964	389,383	564,701	57,546	14,050	1,025,680
1965	408,128	586,274	70,306	13,313	1,078,021
1966	433,576	591,490	71,560	11,703	1,108,329
1967	371,267	567,563	58,341	15,164	1,012,335
1968	398,265	622,626	67,101	12,764	1,100,756
1969	453,539	587,058	60,607	9,946	1,111,150
1970	393,280	484,531	65,776	11,380	954,967
1971	321,517	444,916	68,612	12,311	847,356
1972	259,816	373,364	63,034	10,684	706,898

Four slab zinc producing plants were closed in 1971: Two vertical retort smelters, the Matthiessen & Hegeler Zinc Co. plant at Meadowbrook, W. Va., and The New Jersey Zinc Co. plant at Depue, Ill., The American Zinc Co. electrolytic refinery at Sauget, Ill., and its horizontal retort plant at Dumas, Tex. These smelters had annual capacities totaling 255,000 tons. In addition, three other zinc processing plants ceased operations: ASARCO's slag fuming plant at Selby, Calif., the roasting plant of Eagle-Picher Industries, Inc., at Galena, Kans., and International Smelting and Refining Co.'s slag fuming plant at Tooele, Utah.

In August 1972 The Anaconda Company terminated operations at its Great Falls, Mont., plant which had a rated annual capacity of 162,000 tons of slab zinc. AMAX Lead & Zinc Co. has scheduled the closure of its Blackwell, Okla., horizontal retort plant at the end of 1973. The Sauget, Ill., electrolytic plant now owned by AMAX Lead & Zinc Co. will be fully reactivated by the end of 1974 to the original capacity of 84,000 tons. Projected capacities as of December 31 each year through 1974 also are shown in table 14.

TABLE 14. - Zinc smelter and electrolytic refinery capacities

(Thousand short tons)

Company	Plant location	1966	1967	1968	1969	1970	1971	1972	1973	1974
Electrolytic plants:										
ASARCO	Corpus Christi, Tex.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
American Zinc Co.	Sauget, Ill.	75.0	75.0	75.0	80.0	80.0	-	-	[1] 72.0	84.0
The Anaconda Co.	Anaconda, Mont.	90.0	90.0	90.0	57.7	-	-	-	-	-
Do.	Great Falls, Mont.	162.0	162.0	162.0	162.0	162.0	162.0	-	-	-
The Bunker Hill Co.	Kellogg, Idaho	92.0	98.0	110.0	110.0	110.0	109.0	109.0	109.0	109.0
Horizontal-retort plants:										
ASARCO	Amarillo, Tex.	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5
American Zinc Co.	Dumas, Tex.	57.0	57.0	57.0	57.0	57.0	-	-	-	-
AMAX Lead & Zinc Co.	Blackwell, Okla.	94.0	94.0	94.0	94.0	94.0	86.4	72.0	-	-
Eagle-Picher Industries, Inc.	Henryetta, Okla.	45.0	45.0	45.0	-	-	-	-	-	-
National Zinc Co.	Bartlesville, Okla.	47.1	45.3	52.0	61.0	53.0	53.0	53.0	53.0	53.0
Vertical-retort plants:										
Matthiessen & Hegeler Zinc Co.	Meadowbrook, W. Va.	48.0	48.0	48.0	48.0	48.0	-	-	-	-
New Jersey Zinc Co.	Depue, Ill.	56.0	56.0	70.0	70.0	70.0	-	-	-	-
Do.	Palmerton, Pa.	118.0	118.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
St. Joe Minerals Corp.	Monaca, Pa.	180.0	200.0	215.0	215.0	215.0	215.0	215.0	260.0	260.0
Total		1,216.6	1,240.8	1,290.5	1,227.2	1,161.5	897.9	721.5	766.5	778.5

[1] Now owned by AMAX Lead & Zinc. Co.

Secondary Zinc

Zinc recovered from processing scrap is divided into two categories, new and old. Drosses, skimmings, chemical residues, and scrap generated in the production of semifabricated and manufactured items fall into the new scrap category. Old scrap consisted of discarded, wornout, or obsolete items made from zinc or zinc-containing alloys.

New scrap returns to the recovery process in a relatively short time without reaching the end-product stage. Such scrap is part of the in-process cycle related to the initial consumption of zinc and is not considered a resource. Accordingly, all of the following text and tabulations exclude the new scrap category.

Old zinc-base scrap items include engravers' plates, old zinc, diecastings, and rod and die scrap. Engravers' plates are specially rolled zinc sheets used in the printing industry. Old zinc consists of a variety of products made from cast or rolled zinc, such as electronic device shields or flashings used for buildings. Zinc diecastings are zinc-base alloy products used for functional and decorative parts on automobiles, household appliances, and elsewhere. Zinc alloy rods and dies are used in metal forming operations, particularly in the aircraft industry.

Zinc-base scrap is used to make redistilled slab zinc, remelt zinc, zinc oxide, zinc dust, diecastings, and other products. The ultimate products made from scrap are essentially the same as those made from primary zinc.

Old copper-base scrap containing zinc as an alloying metal, principally brass, provides an important source of secondary zinc as the content of the remelted or reconstituted alloy.

The character and importance of old scrap zinc as a component of zinc supply is indicated by a tabulation of data for the period 1962-72 (table 15). These data show that zinc recovered from old scrap was equivalent to 5.2 to 5.9 percent of the zinc consumed in the form of slab zinc plus direct consumption of zinc in ores for production of compounds and for galvanizing. The reclaimed zinc by scrap source was 53 percent from zinc-base scrap, 43 percent from copper-base scrap, 3 percent from aluminum-base scrap, and the remainder from magnesium-base scrap.

Zinc-base scrap makes a relatively small contribution to supply since a large part of end products of zinc are dissipated and many of the nondissipative uses are in forms from which zinc cannot be recovered economically.

Recovery of zinc from old zinc-base scrap has represented a relatively constant part of consumption paralleling that of slab zinc and industrial activity. The only category of old zinc-base scrap with substantial potential for increasing zinc supply is zinc diecastings. Research studies by the Bureau of Mines and others have made important contributions to the technology of zinc recovery from diecastings. However, increased utilization resulting from this technology will depend upon improved scrap collection and favorable economic incentives.

TABLE 15. - Recovery of zinc from old scrap compared with consumption of zinc

(Short tons)

Item	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Recovered zinc:											
Zinc-base scrap.	33,588	32,572	33,375	43,603	45,990	40,862	41,408	40,284	41,255	44,876	42,998
Copper-base scrap..........	25,929	27,634	31,716	34,777	36,139	36,142	35,390	37,975	27,868	31,308	32,456
Aluminum-base scrap..........	2,192	2,302	2,832	3,524	4,000	3,165	2,900	3,288	2,959	3,587	3,854
Magnesium-base scrap..........	44	56	141	105	156	140	99	80	71	272	69
Total........	61,753	62,564	68,064	82,009	86,285	80,309	79,797	81,627	72,153	80,043	79,377
Zinc consumption:											
Slab zinc.......	1,031,821	1,105,113	1,207,268	1,354,092	1,423,666	1,250,673	1,350,656	1,385,380	1,186,951	1,254,059	1,418,349
Direct ore use..	101,582	104,705	105,948	122,892	126,696	114,301	124,109	126,712	124,781	119,254	118,305
Total........	1,133,403	1,209,818	1,313,216	1,476,984	1,550,362	1,364,974	1,474,765	1,512,092	1,311,732	1,373,313	1,536,654
Ratio, zinc from old scrap to zinc consumption, percent..........	5.45	5.17	5.18	5.55	5.57	5.88	5.41	5.40	5.50	5.83	5.17

In a broad sense, resources of zinc from old scrap are equal to the quantity of zinc used in consumer articles multiplied by a recovery factor which is based on past experience. This reserve of zinc is referred to as the "pool of zinc-in-use" (table 16). No statistics measure with precision the quantity of zinc-in-use or the percent that is reclaimable. However, estimates have been made on the basis of historic scrap consumption to derive annual increments to the pool. The sum of those increments indicates a total of almost 5 million tons of zinc can be expected to return as a contribution to zinc supply over the indefinite future.

TABLE 16. - Estimated increments to pool of zinc-in-use in the United States, 1939-72

(Thousand tons)

Year	Slab zinc consumption	Estimated recovery	Old scrap consumed	Increment to accumulated zinc reserve-in-use	Total zinc accumulated end of year
1939.......	626.0	161.0	45.1	115.9	115.9
1940.......	719.0	212.0	64.2	147.8	263.7
1941.......	827.4	224.0	81.2	142.8	406.5
1942.......	728.2	259.0	73.0	186.0	592.5
1943.......	816.8	327.0	84.2	242.8	835.3
1944.......	888.6	304.0	113.2	190.8	1,026.1
1945.......	852.3	238.0	91.3	146.7	1,172.8
1946.......	801.2	194.0	77.2	116.8	1,289.6
1947.......	786.4	168.0	75.0	93.0	1,382.6
1948.......	817.7	175.0	74.2	100.8	1,483.4
1949.......	711.8	145.0	51.7	93.3	1,576.7
1950.......	967.1	219.0	74.1	144.9	1,721.6
1951.......	934.0	224.0	68.2	155.8	1,877.4
1952.......	852.8	210.0	74.7	135.3	2,012.7
1953.......	985.9	255.0	64.2	190.8	2,203.5
1954.......	884.3	198.0	72.7	125.3	2,328.8
1955.......	1,119.8	280.0	83.5	196.5	2,525.3
1956.......	1,008.8	252.0	73.7	178.3	2,703.6
1957.......	935.6	234.0	76.8	157.2	2,860.8
1958.......	868.3	171.5	69.9	101.6	2,962.4
1959.......	956.2	196.2	73.8	122.4	3,084.8
1960.......	877.9	165.1	68.4	96.7	3,181.5
1961.......	931.2	187.8	59.4	128.4	3,309.9
1962.......	1,031.8	196.0	61.8	134.2	3,444.1
1963.......	1,105.1	210.0	62.6	147.4	3,591.5
1964.......	1,207.3	229.4	68.1	161.3	3,752.8
1965.......	1,354.1	257.3	82.0	175.3	3,928.1
1966.......	1,423.7	257.9	86.3	171.6	4,099.7
1967.......	1,250.7	237.6	80.3	157.3	4,257.0
1968.......	1,350.7	256.6	79.8	176.8	4,433.8
1969.......	1,385.4	249.4	81.6	167.8	4,601.6
1970.......	1,187.0	249.3	72.2	177.1	4,778.7
1971.......	1,254.1	263.4	80.0	183.4	4,962.1
1972.......	1,418.3	255.3	79.0	176.3	5,138.4

The recoverable zinc from total consumption has been based on the current technologic and economic situation. If the potential recovery of zinc from diecastings becomes an economic reality, the pool of zinc-in-use would be substantially increased.

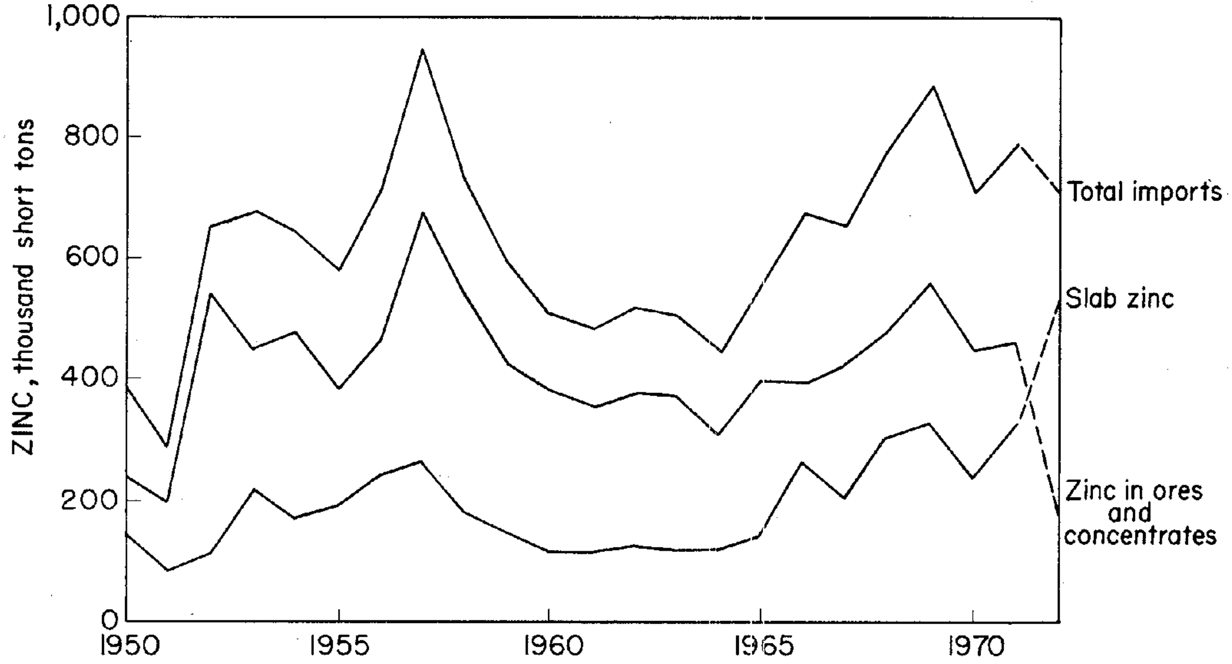

FIGURE 6. - U.S. imports for consumption, 1950-72.

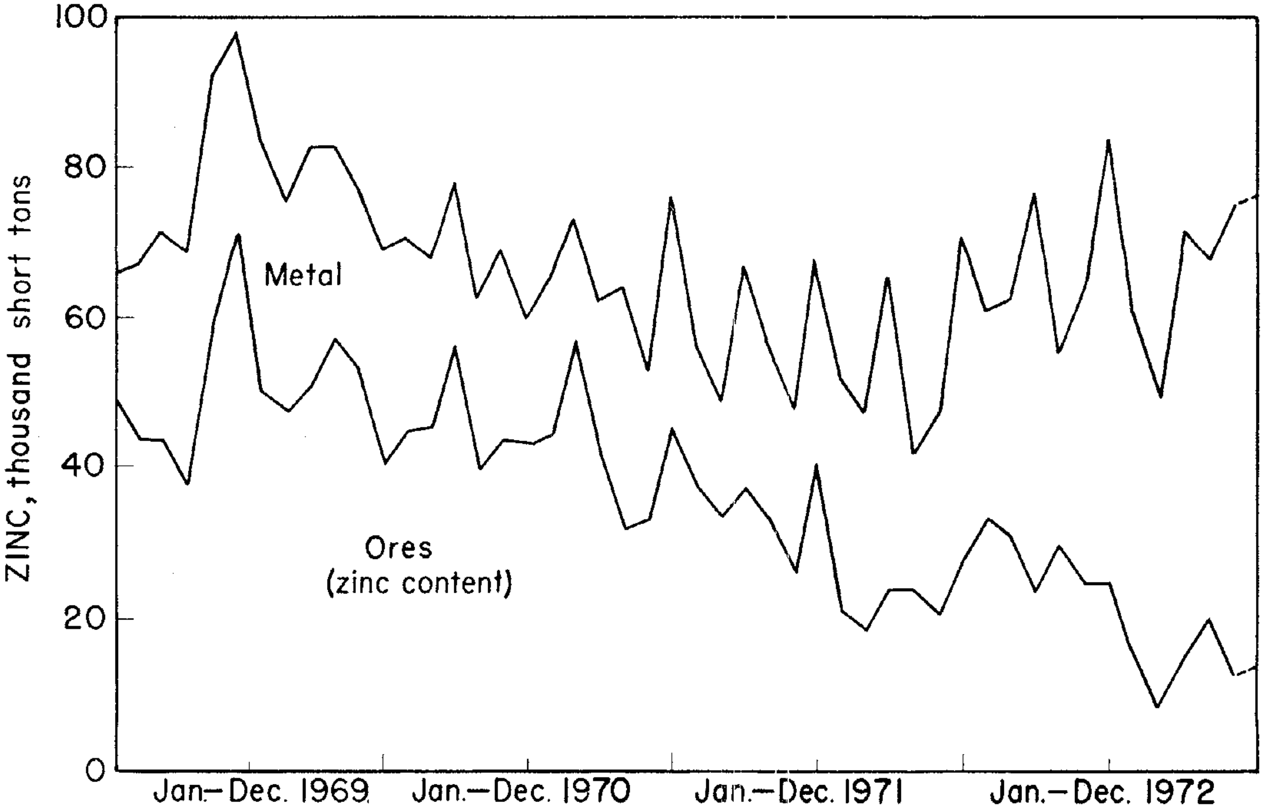

FIGURE 7. - U.S. general imports of zinc, 1969-72, by months.

Imports

The United States became a net importer of zinc in 1933. Substantial dependence on foreign concentrates began in 1940 when receipts (zinc content) rose to 180,320 tons from 36,100 tons in 1939 because of World War II demand. In the years following, imports of zinc concentrates became increasingly important as a raw material for domestic zinc smelters. Prior to 1940 Mexico and Peru had been the principal suppliers. From then on, Canada, in addition to Mexico and Peru, provided most of the U.S. imports of concentrates and metal with lesser amounts of concentrates available from 15 other countries and metal from 17 other countries (tables 17 and 18). Canada has been the major foreign source of zinc concentrates and metal since 1963 and will most likely continue this role in the forseeable future. However, with Canadian emphasis on new electrolytic zinc plants and expansion of existing ones for processing more of its mine production, the ratio of exports will change, favoring metal over concentrates. The same is true in Mexico where a new electrolytic plant with a capacity of 120,000 tons annually begins production in 1973 and in Peru with completion of a planned 80,000-ton electrolytic plant scheduled for operation in 1975.

For the period 1960 through 1971 total general imports (zinc content of ores and concentrates plus metal) were 57 percent of the total slab zinc consumption. Seventy percent of these imports was zinc in concentrates for feed to domestic smelters, the remainder was metal. In 1972, while the ratio of imports to consumption at 54 percent showed little change, the situation with respect to the concentrate to metal ratio in imports was reversed. Two-thirds of the imports was as metal and only one-third as concentrate, see figures 6 and 7. Canada showed the greatest change with 1972 imports of zinc in concentrates from Canada only 43 percent of those in 1970, whereas imports of metal were more than double those of 1970.

TABLE 17. - U.S. imports (general) of zinc ores (zinc content)[1] by countries

(Short tons)

Country	1950	1951	1952	1953	1954	1955	1956	1957
Algeria	-	-	-	2,804	-	-	-	-
Argentina	8	5,546	603	-	-	-	2	165
Australia	2,366	2,825	2,398	10,820	2,361	5,630	17,764	8,756
Bolivia	3,810	7,849	14,603	22,528	11,440	1,833	7,294	7,633
Canada	77,525	96,470	149,130	165,910	156,830	173,157	177,087	158,220
Chile	40	1,088	33	3,247	1,797	4,858	346	1,400
Germany, West	-	-	-	-	-	-	-	-
Guatemala	473	6,539	9,744	6,477	3,755	8,353	11,433	9,313
Honduras	104	154	316	637	792	1,433	2,288	2,589
Ireland	-	-	-	-	-	-	-	-
Italy	-	-	-	8,738	-	-	-	-
Mexico	155,283	143,769	200,647	169,124	175,692	186,461	193,007	192,519
Morocco	-	-	-	-	-	-	-	-
Netherlands	-	-	-	3,009	-	-	-	-
Peru	16,946	29,136	44,337	84,365	93,216	83,915	98,541	119,004
Philippines	42	86	1,664	2,104	444	465	828	777
South Africa, Republic of	3,794	2,655	4,917	13,356	4,183	5,050	13,400	21,048
Spain	17,738	4,392	16,647	8,617	-	-	-	-
Yugoslavia	-	1,756	2,512	10,820	4,871	-	-	-
Other	444	512	2,085	1,168	46	6,889	3,360	4,590
Total	278,573	302,777	449,636	513,724	455,427	478,044	525,350	526,014

Country	1958	1959	1960	1961	1962	1963	1964	1965
Algeria	-	-	-	-	-	-	-	4,408
Argentina	9	101	-	-	-	-	10,518	-
Australia	4,735	24,693	17,789	3,822	10,956	3,724	3,238	2,667
Bolivia	7,328	2,530	1,214	572	1,791	4,395	3,540	4,093
Canada	155,506	152,134	120,336	119,113	192,423	134,303	156,385	201,353
Chile	977	479	30	([2])	518	-	1,741	-
Germany, West	-	5,756	2	11	-	-	-	1,341
Guatemala	6,483	8	6,063	13,870	2,511	1,430	3	4
Honduras	1,435	1,427	4,714	6,851	7,048	8,234	7,709	6,786
Ireland	-	-	-	-	-	-	-	-
Italy	-	14,766	-	-	-	-	-	-
Mexico	158,609	182,409	190,621	186,174	165,005	138,185	103,879	117,354
Morocco	-	-	-	-	-	-	-	5,037
Netherlands	-	-	-	-	-	-	-	-
Peru	102,990	86,672	80,100	74,369	77,501	73,788	62,864	73,721
Philippines	92	48	4,774	3,203	24	9	7	9
South Africa, Republic of	21,700	7,957	12,300	7,551	9,589	8,614	6,086	11,267
Spain	-	16,479	18,913	-	-	-	-	-
Yugoslavia	-	-	-	-	-	-	-	-
Other	1,696	4,656	299	164	32	87	1,175	-
Total	461,560	500,115	457,155	415,700	467,398	372,769	357,145	428,040

Country	1966	1967	1968	1969	1970	1971	1972
Algeria	164	9,264	-	-	-	-	-
Argentina	-	-	-	-	-	-	-
Australia	4,334	4,836	2,267	2,940	2,324	2,857	5,871
Bolivia	5,788	9,576	6,011	2,069	2,904	-	-
Canada	272,950	289,387	310,586	367,529	317,992	209,084	135,534
Chile	-	-	74	421	1,056	-	-
Germany, West	9,685	6,248	5,942	-	-	-	1,162
Guatemala	318	-	-	525	4	138	723
Honduras	10,776	9,727	12,959	15,272	19,267	21,512	17,370
Ireland	-	-	-	-	-	3,975	5,978
Italy	-	-	-	-	-	-	-
Mexico	114,677	119,135	142,313	143,747	128,949	89,845	57,315
Morocco	7,407	6,516	15,715	5,988	-	-	-
Netherlands	3,198	-	3,313	-	-	-	-
Peru	78,254	69,357	39,899	57,087	48,037	15,025	15,256
Philippines	25	-	-	-	-	-	-
South Africa, Republic of	12,565	8,419	4,287	6,525	5,096	61	4,690
Spain	-	-	-	-	-	-	-
Yugoslavia	769	-	-	-	-	-	-
Other	410	1,627	-	17	130	24	[3]10,969
Total	521,320	534,092	543,366	602,120	525,759	342,521	254,868

[1] Zinc content less certain allowable deductions for processing losses, effective September 1963.

[2] Less than 1/2 unit.

[3] 10,960 tons from Nicaragua.

TABLE 18. - U.S. imports (general) of slab zinc, by countries

(Short tons)

Country	1950	1951	1952	1953	1954	1955	1956	1957
Australia	-	-	-	3,951	3,080	4,033	7,281	9,523
Belgium-Luxembourg	3,617	612	6,854	21,549	7,540	17,748	32,353	34,163
Canada	108,937	85,066	69,775	107,925	105,154	113,402	116,875	103,964
Finland	-	-	-	-	-	-	-	-
France	-	-	-	-	-	-	-	-
Germany, West	1,637	-	7,619	13,906	3,109	6,642	15,285	8,772
Italy	2,679	-	4,063	23,972	5,032	6,190	13,486	10,010
Japan	-	-	222	-	-	-	4,883	2,887
Mexico	26,293	760	18,686	33,878	9,306	19,480	17,153	23,536
Mozambique	-	-	-	-	112	-	-	-
Netherlands	2,005	254	3,976	4,338	1,461	1,079	5,965	2,504
Norway	7,939	882	110	6,323	717	504	-	-
Peru	1,205	26	1,600	8,406	8,963	9,767	6,590	22,947
Poland	-	-	-	-	-	-	-	-
Romania	-	-	-	-	-	-	-	-
South Africa, Republic of	-	-	-	-	-	-	-	-
Spain	-	-	-	-	-	-	-	-
United Kingdom	555	-	-	6,317	1,769	79	611	1,791
Yugoslavia	485	-	2,788	1,900	-	-	500	10,909
Zaire	-	-	-	882	13,895	15,228	17,782	33,007
Zambia	-	-	-	1,064	-	280	3,808	3,974
Other	622	443	12	165	-	1,264	2,406	1,020
Total	155,974	88,043	115,705	234,576	160,138	195,696	244,978	269,007
	1958	1959	1960	1961	1962	1963	1964	1965
Australia	2,240	9,365	450	1,029	1,750	583	385	1,120
Belgium-Luxembourg	21,707	7,666	5,724	12,854	23,232	21,904	5,557	8,889
Canada	93,475	88,414	74,168	71,628	72,825	73,817	75,712	88,554
Finland	-	-	-	-	-	-	-	-
France	-	-	-	-	-	-	-	-
Germany, West	2,673	55	2,680	779	1,162	6,103	265	230
Italy	6,166	7,459	3,517	1,820	992	907	-	2,129
Japan	2,039	-	-	-	-	-	-	12,995
Mexico	23,256	9,338	8,950	8,598	12,334	13,219	12,791	12,787
Mozambique	-	-	-	-	-	-	-	-
Netherlands	2,520	-	-	-	-	-	-	-
Norway	2,769	168	-	-	-	-	-	-
Peru	9,736	12,337	7,517	7,519	7,615	7,574	7,569	10,323
Poland	-	-	-	-	-	-	-	-
Romania	-	-	-	-	-	-	-	-
South Africa, Republic of	-	-	-	-	-	-	-	-
Spain	-	-	2,986	6,756	2,572	6,270	2,723	1,768
United Kingdom	672	841	333	([1])	-	1,183	682	-
Yugoslavia	5,781	3,643	4,520	3,198	3,310	1,185	441	887
Zaire	20,991	12,790	9,307	11,420	10,882	9,590	10,878	12,614
Zambia	1,064	4,667	615	1,400	4,643	1,982	62	-
Other	110	220	-	561	640	440	1,275	694
Total	195,199	156,963	120,767	127,562	141,957	144,757	118,340	152,990
	1966	1967	1968	1969	1970	1971	1972	
Australia	27,007	7,187	19,915	34,237	30,335	38,552	39,623	
Belgium-Luxembourg	27,469	16,100	16,500	13,296	14,371	9,365	39,616	
Canada	116,778	80,487	116,874	148,851	120,611	150,868	271,130	
Finland	-	-	-	-	1,313	31,702	8,583	
France	-	-	-	1,435	512	2,211	11,825	
Germany, West	6,062	939	-	-	3,198	3,661	31,358	
Italy	-	-	-	-	-	-	-	
Japan	19,805	41,621	45,735	52,502	32,525	8,705	30,072	
Mexico	22,702	18,673	19,034	12,092	7,358	10,130	8,394	
Mozambique	-	1,394	1,098	1,256	661	-	-	
Netherlands	-	-	-	-	7,725	13,283	14,001	
Norway	4,032	3,753	6,272	4,481	1,343	2,205	-	
Peru	30,805	33,568	53,729	30,204	31,923	23,873	30,625	
Poland	5,421	9,870	9,454	9,495	7,729	2,618	4,199	
Romania	-	-	-	-	-	1,221	5,526	
South Africa, Republic of	-	-	-	56	-	4,740	-	
Spain	926	2,094	2,877	-	-	5,071	1,102	
United Kingdom	258	1,145	3,261	1,041	1,054	800	1,553	
Yugoslavia	551	474	-	385	114	138	1,543	
Zaire	12,814	2,921	8,146	10,621	6,300	8,898	22,493	
Zambia	-	505	277	3,817	1,773	315	-	
Other	3,545	1,381	1,404	1,007	1,568	1,212	[2]969	
Total	278,175	222,112	304,576	324,776	270,413	319,568	522,612	

[1] Less than 1/2 unit.

[2] 909 tons from Ecuador.

Exports

The United States was a net exporter of zinc from 1900 through 1928 (except for 1921) and again in 1932. In the early years, 1900-14, exports of ore (zinc content) exceeded those of metal with most of the ore shipments consisting of high-grade willemite from New Jersey. The larger metal exports during 1914-20 reflected the stimulus of World War I on the zinc industry. Exports of metal increased significantly again during the World War II period and for the years of strong foreign demands, as in 1947 and 1960 (table 19).

TABLE 19. - U.S. exports of slab zinc and ores and concentrates

(Short tons)

Year	Metal	Ores and concentrates (zinc content)	Year	Metal	Ores and concentrates (zinc content)
1950...	12,917	1,140	1962...	36,102	136
1951...	36,510	3,090	1963...	33,853	17
1952...	57,714	3,370	1964...	26,515	39
1953...	17,969	2,953	1965...	5,939	NA
1954...	24,994	0	1966...	1,406	NA
1955...	18,069	0	1967...	16,809	NA
1956...	8,813	854	1968...	33,011	NA
1957...	10,785	7	1969...	9,298	NA
1958...	2,073	0	1970...	289	NA
1959...	11,629	1	1971...	13,347	NA
1960...	75,144	13	1972...	4,324	NA
1961...	50,055	1,670			

NA--Not available.

Exports of ore ranged from 0 to only 2,800 tons from 1914 to 1924. Then shipments of concentrates abroad from the Tri-State area (Kansas-Missouri-Oklahoma) expanded, increasing from 368 tons in 1924 to 69,000 tons in 1925, to 95,000 tons in 1926, down to 47,000 tons in 1927, then 4,500 tons in 1928. Thereafter, exports of zinc ore or concentrates ranged from 3,600 to 0 tons.

Ore and concentrate exports of zinc were so small from 1954 to 1964 that the Bureau of the Census discontinued separate reporting of exports of lead and zinc ores (lead and zinc content). Since 1964 Census has published the combined gross weight of lead and zinc concentrates exported under code number 283.0000. These quantities for 1971 and 1972 are 29,145 tons and 43,845 tons, respectively. The lead and zinc contents of these exports are not available.

Consumption

Zinc consumption is largely categorized in five semifabricating markets; namely, galvanizing, diecasting, brass products, rolled zinc, and zinc oxide. The pattern of use in the United States has changed significantly. Immediately before World War II galvanizing was the principal market, brass products were second, followed by diecastings and rolled zinc. Brass products were the major outlet for zinc during the World War II years 1942, 1943, and 1944 then galvanizing regained first place in 1945. Since 1963 zinc for diecasting alloys generally has been the largest market followed by galvanizing. During the past decade there has been a steady increase in demand for zinc oxide produced from slab zinc, with the result that since 1970 use of zinc for this application has exceeded the consumption of zinc for rolled zinc. A number of miscellaneous uses that are combined in an "Other" category include desilvering lead, light-metal alloys, precipitation of cadmium and copper in purifying zinc plant electrolytes, sacrificial anodes, and zinc dust from slab.

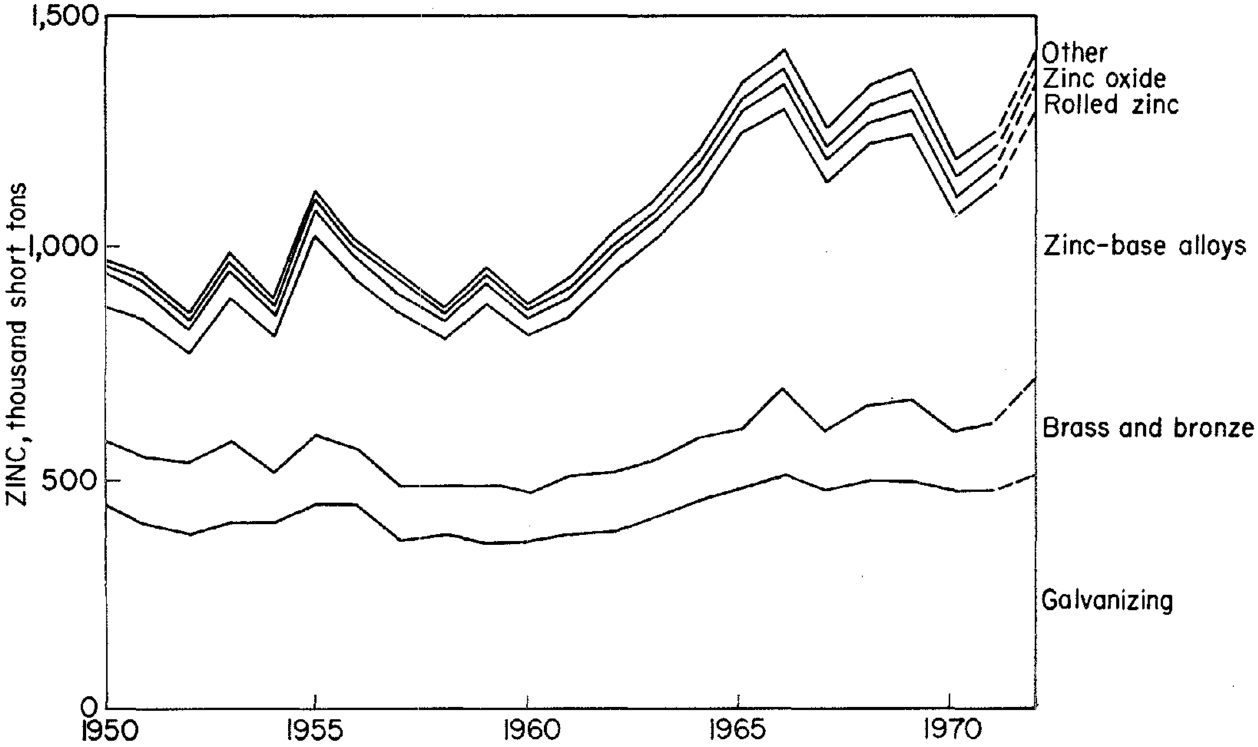

FIGURE 8. - Consumption by industry use.

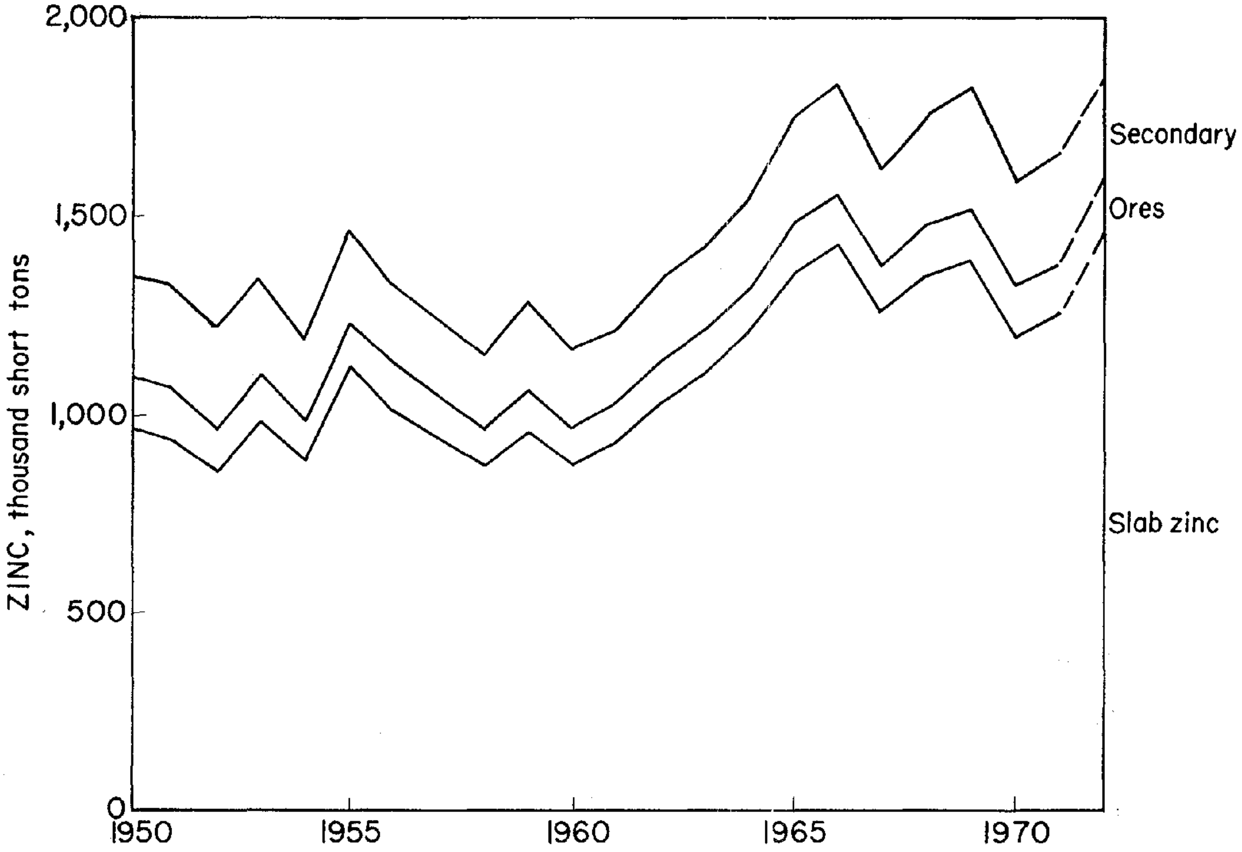

FIGURE 9. - U.S. consumption of primary and secondary slab zinc, and directly as ore.

Consumption of zinc in the United States by industry uses, and as slab, ores, and secondary are shown in tables 20 and 21, also graphically in figures 8 and 9; consumption by grade is shown in table 22.

TABLE 20. - Slab zinc consumption, by industry uses

Year	Galvanizing	Brass products	Zinc-base alloy	Rolled zinc	Zinc oxide	Other	Total
1950...........	441,686	139,373	289,527	68,444	18,187	9,917	967,134
1951...........	400,279	143,292	296,434	64,085	18,223	11,658	933,971
1952...........	377,688	155,608	236,689	51,318	17,205	14,275	852,783
1953...........	406,988	178,182	307,445	54,649	20,675	17,988	985,927
1954...........	403,463	108,268	290,846	47,486	18,701	15,535	884,299
1955...........	451,141	146,243	430,807	51,589	22,433	17,599	1,119,812
1956...........	439,146	124,004	360,507	47,359	19,160	18,614	1,008,790
1957...........	367,757	112,390	376,039	41,269	20,428	17,737	935,620
1958...........	381,229	101,375	316,830	40,616	13,331	14,946	868,327
1959...........	361,027	129,278	389,331	42,949	18,248	15,364	956,197
1960...........	371,589	99,023	338,373	38,696	15,593	14,610	877,884
1961...........	382,077	128,523	341,766	41,204	18,137	19,506	931,213
1962...........	388,570	129,805	423,608	42,233	18,517	29,088	1,031,821
1963...........	420,287	128,237	468,619	42,166	16,037	29,767	1,105,113
1964...........	456,336	135,095	524,582	44,181	19,991	27,083	1,207,268
1965...........	482,421	126,848	637,970	45,882	25,781	35,190	1,354,092
1966...........	509,436	185,552	606,036	52,612	28,438	41,592	1,423,666
1967...........	472,470	131,537	535,118	45,443	29,774	36,331	1,250,673
1968...........	498,774	161,906	562,946	48,943	34,937	43,150	1,350,656
1969...........	493,381	179,469	576,391	48,650	41,447	46,042	1,385,380
1970...........	474,249	127,747	463,636	41,065	43,829	36,425	1,186,951
1971...........	474,752	150,486	516,111	38,852	40,043	33,815	1,254,059
1972...........	518,204	192,147	579,761	45,216	51,992	31,029	1,418,349

TABLE 21. - Consumption of zinc in the United States

Year	Slab zinc	Ores	Secondary	Total
1950............	967,134	127,029	248,933	1,343,096
1951............	933,971	133,845	258,266	1,326,082
1952............	852,783	109,277	249,588	1,211,648
1953............	985,927	118,244	238,218	1,342,389
1954............	884,299	99,247	197,146	1,180,692
1955............	1,119,812	108,395	231,133	1,459,340
1956............	1,008,790	113,388	200,844	1,323,022
1957............	935,620	110,311	185,662	1,231,593
1958............	868,327	94,938	178,900	1,142,165
1959............	956,197	108,070	214,109	1,278,376
1960............	877,884	88,275	192,779	1,158,938
1961............	931,213	97,251	179,005	1,207,469
1962............	1,031,821	101,582	199,908	1,333,311
1963............	1,105,113	104,705	204,398	1,414,216
1964............	1,207,268	105,948	222,535	1,535,751
1965............	1,354,092	122,892	265,083	1,742,067
1966............	1,423,666	126,696	269,650	1,820,012
1967............	1,250,673	114,301	240,888	1,605,862
1968............	1,350,656	124,109	270,592	1,745,357
1969............	1,385,380	126,712	302,075	1,814,167
1970............	1,186,951	124,781	259,864	1,571,596
1971............	1,254,059	119,254	277,272	1,650,585
1972............	1,418,349	118,305	292,099	1,828,753

TABLE 22. - Slab zinc consumption by grade

Year	Special High-Grade	High-Grade	Intermediate	Brass Special	Prime Western select	Remelt	Total
1950.....	328,024	136,274	33,102	36,150	430,549	3,035	967,134
1951.....	352,532	128,155	21,831	41,833	385,115	4,505	933,971
1952.....	295,546	131,258	19,658	44,884	357,293	4,144	852,783
1953.....	375,276	137,616	21,507	55,184	392,634	3,710	985,927
1954.....	347,311	91,069	22,149	61,508	358,673	3,589	884,299
1955.....	494,466	105,640	25,118	73,581	418,010	2,997	1,119,812
1956.....	426,246	89,540	21,929	95,397	370,448	5,230	1,008,790
1957.....	427,883	83,726	16,941	76,328	323,937	6,805	935,620
1958.....	365,023	70,999	15,256	92,541	316,435	8,073	868,327
1959.....	446,796	86,163	12,731	84,277	321,021	5,209	956,197
1960.....	392,352	71,531	10,536	91,017	305,826	6,622	877,884
1961.....	409,913	92,040	9,269	100,617	311,846	7,528	931,213
1962.....	493,602	110,627	8,021	103,116	308,937	7,518	1,031,821
1963.....	544,668	117,454	7,326	109,692	319,073	6,900	1,105,113
1964.....	609,275	114,745	7,436	119,134	349,241	7,437	1,207,268
1965.....	730,715	116,807	7,839	126,654	364,290	7,787	1,354,092
1966.....	726,022	148,975	7,685	138,000	395,601	7,383	1,423,666
1967.....	643,495	101,205	8,048	123,744	368,527	5,654	1,250,673
1968.....	683,307	122,516	7,978	135,571	396,005	5,279	1,350,656
1969.....	690,979	137,830	7,581	128,152	415,190	5,648	1,385,380
1970.....	559,483	104,349	8,029	117,918	394,379	2,793	1,186,951
1971.....	620,206	114,970	17,496	111,093	389,499	795	1,254,059
1972.....	697,581	144,228	19,990	130,079	425,359	1,112	1,418,349

Galvanizing

There are two major types of galvanizing activities, galvanizing steel shapes prior to fabrication and galvanizing fabricated products. With the development of continuous lines for sheet and strip, galvanizing zinc specifications changed from the old Prime Western standards, particularly with respect to lead and aluminum contents. Lead content controls the "spangle" and a small amount of aluminum is considered essential to strengthen the zinc adherence to the steel surface. The continuous process produced much more uniform coatings tightly bonded to the basic steel which could withstand severe forming operations without cracking or flaking. New uses for galvanizing sheet and strip developed in the automotive industry and also for domestic appliances and office equipment. The continuous and semicontinuous galvanizing of sheet, strip, tube, and wire is done at steel plants. Fabricated products such as hollowware, water tanks and cisterns, window frames, structural steel, nuts and bolts, and many other iron and steel products are galvanized by both product manufacturers and independent jobbing galvanizers.

The most important market for galvanized sheets is in the building and construction industries because of low cost, good mechanical properties, excellent atmospheric corrosion resistance, and compatibility with concrete. It is estimated that about two-thirds of the U.S. production of galvanized sheet is used for building. The use of galvanized steel for underbody parts of many cars, for protection against severe corrosion problems, has grown substantially in recent years.

Zinc Alloy Diecasting

Diecasting is the fastest growing major zinc use in the world and since 1962, with the exception of 1 year, 1970, has been the largest use in the United States. Properties of zinc diecasting alloys are such that these alloys are suitable for many components having complex shapes that require good mechanical properties, close dimensional accuracy, fine surface detail, corrosion resistance, and good plating and enameling qualities. The alloys are readily adaptable to mass production techniques. The future of the zinc alloy diecasting industry depends on a number of factors including continued growth of the automobile industry, minimizing competition from aluminum and plastics, and an assured supply of Special High-Grade zinc.

Brass Products

It is estimated that about one-fifth of the world zinc consumption is used in making brass. Brasses are a series of copper-zinc alloys containing from 5 to 40 percent zinc. They combine good mechanical properties with the ability to be formed rapidly by various processes. The noncorrosive quality, attractive color, and formability account for the many applications of brasses in plumbing goods, builders hardware, appliances, jewelry, and other functional and decorative applications.

Zinc Oxide and Other Compounds

Zinc oxide is the most important zinc chemical and serves as a starting point for most zinc compounds. The rubber industry is the chief consumer of zinc oxide, followed by the paint and ceramic industries. Textiles, floor coverings, and lubricants consume minor quantities of oxide. Zinc sulfide and barium sulfate are coprecipitated to make lithopone, a pigment which is used in paints, floor coverings, and coated fabrics. Other chemical compounds manufactured from zinc oxide are used in specialized industrial applications. The use of zinc as a trace element in animal nutrition and in agriculture as a plant nutrient is an increasingly important application. Much of the agricultural area of the United States has proven to be deficient in zinc, hence zinc oxide and zinc sulfate are included in fertilizers and animal feeds. Shipments of zinc oxide by industry are included in table 23.

Rolled Zinc

Rolled zinc in the form of strips, sheet, wire, and rod has many and varied commercial applications. Strip zinc is formed into dry-cell battery cases, mason jar covers, and many other items which are subsequently chrome plated. Sheet zinc has an important application in photoengraving plate and also in construction as roofing and other architectural uses. Special High-Grade zinc in the form of plate and rods gives cathodic protection in marine and pipeline service.

TABLE 23. - Distribution of zinc oxide shipments by industries

(Short tons)

Year	Rubber	Paints	Ceramics	Chemicals	Agriculture	Photocopying	Coated fabrics and textiles	Floor coverings	Other	Total
1950	82,944	39,699	12,679	-	-	-	6,303	3,670	15,534	160,829
1951	71,507	32,934	10,324	-	-	-	7,265	3,114	22,572	147,716
1952	72,774	31,424	7,760	-	-	-	6,262	2,413	21,577	142,210
1953	78,439	31,920	8,862	-	-	-	8,718	2,234	18,454	148,627
1954	71,058	31,157	8,990	-	-	-	6,322	1,749	21,009	140,285
1955	86,677	33,932	10,617	-	-	-	11,263	2,281	23,771	168,541
1956	80,459	32,485	10,160	-	-	-	8,447	1,436	21,968	154,955
1957	81,745	32,605	8,459	-	-	-	3,623	1,249	23,586	151,267
1958	68,176	33,335	9,095	-	-	-	2,327	971	22,087	135,991
1959	79,505	33,708	10,486	-	-	-	2,125	1,207	27,203	154,234
1960	75,120	31,610	9,840	-	-	-	1,331	1,316	25,561	144,778
1961	71,534	30,405	10,058	-	-	-	1,185	1,174	30,852	145,208
1962	80,247	31,381	11,092	-	-	-	202	457	31,470	154,849
1963	82,776	34,382	9,381	-	-	-	W	W	35,732	162,271
1964	93,568	31,176	9,447	-	-	-	W	438	39,674	174,303
1965	103,057	30,249	10,009	11,365	977	W	W	363	30,550	186,570
1966	104,866	27,100	12,147	13,678	1,559	11,405	W	W	22,910	193,665
1967	94,388	24,547	9,850	17,509	5,048	14,039	W	W	16,105	181,486
1968	111,797	25,864	10,226	22,769	5,044	21,564	W	W	16,562	213,826
1969	115,988	25,170	9,469	22,775	4,007	27,566	D	D	14,748	219,723
1970	111,421	21,894	9,011	19,435	2,246	31,850	D	D	17,426	213,283
1971	124,472	24,990	8,125	18,901	1,615	34,504	D	D	14,896	227,503
1972	129,170	27,244	10,702	22,781	1,101	36,190	D	D	18,679	245,867

D--Category dropped, data not collected.
W--Withheld--included in other.

Other Uses

Zinc is used in zippers, instrument bezels, and power mowers. Metallic zinc in the form of slab or finely ground dust has important applications in the metallurgy of other metals. Desilverization of lead by the Parkes process requires a 1- to 2-percent zinc addition to the molten bullion to form intermetallic compounds of gold, silver, and copper which are skimmed and later separated. Recovery of cadmium, gold, silver, thallium, and other rare metals is accomplished with zinc dust as a precipitant in the final separation during the various complex chemical processes.

GOVERNMENTAL ACTIONS WHICH HAVE AFFECTED THE ZINC INDUSTRY

The U.S. zinc industry has been the subject of Governmental concern for many years. At various times and in many different ways the Federal

Government has taken actions designed to stabilize, assist, and in other ways assure a favorable climate for a viable industry from the standpoint of national security and domestic stability. While many forms of government-industry planning and assistance were employed in earlier years, examination of these relationsips during the more recent years seems to be appropriate in assessing their effect on the recent problems of the zinc industry in the United States. The year 1958 commends itself as a starting point for at least three reasons:

1. It marked termination of the most recent, precipitous post-World War II price drop, which severely affected the domestic zinc industry.

2. The United Nations fostered the formation of an International Lead-Zinc Study Group designed to improve world statistics and forecasting on supply and demand of these commodities and intergovernmental consultations on international trade.

3. Quotas on importation, both for ore and metal, were established by the United States in late 1958. These quota restrictions lasted until late 1965 and seem to coincide with a period of continual improvement in U.S. smelter production, mine production, and prices.

In retrospect the years between 1958 and 1965 would seem to have been one of the better periods from the standpoint of "health of the zinc industry." During this period, of course, inflationary forces were relatively milder than they were in prior and subsequent years.

Some of the other actions taken by Government have been helpful and some were ineffective or actually harmful. These may be categorized as follows:

1. Actions relating to stockpiling by the U.S. Government:

   a. Having authorized and established a national security stockpile of zinc immediately following World War II, acquisitions were authorized during the Korean War wherein counterpart funds were used to subsidize foreign mining developments, repayable in deliveries to the stockpile.

   b. A supplemental stockpile was further established in 1956 providing for acceptance of foreign origin zinc in exchange for certain agriculture commodities through barter. This program was terminated in 1959.

   c. The reduction of the total zinc stockpile goal to zero in 1963 resulted from an Office of Emergency Planning Mobilization Study.

   d. In late 1965 disposals were authorized from the stockpile.

   e. In 1969 OEP established 500,000 tons as a stockpile goal.

   f. In 1972 Congress authorized the GSA to dispose of the remaining surplus of slightly over 500,000 tons, which was largely committed to U.S. smelters for sale to the consuming industry over the next 10 years in propertion to their 1970 metal production. Table 24 shows status of the stockpile from 1945 through 1972.

2. Exploration assistance for zinc carried over from the Korean War through the Defense Minerals Exploration Administration, which in 1958 became the Office of Mineral Exploration. Such assistance was in the form of loans up to 50 percent of the approved costs of a domestic exploration project but not to exceed $250,000 in any one prospect. If a mine is eventually developed on one of these properties the Government loan is to be repaid over a period of years. Zinc was deleted from the program in June 1962.

3. In 1961 the Small Mines Stabilization Act became law providing for subsidy payments to those miners producing zinc in the amount of 3,000 tons or less in any 1 year, by paying 55 percent of the amount by which the market price was less than 14.5 cents per pound, East St. Louis. This law expired at the end of 1969.

4. A number of tariff and quota bills have been introduced in Congress in recent years but none has become law.

5. The Environmental Protection Act, effective in 1969, probably accelerated closure of obsolete plants. Other impacts of the Act are less obvious.

6. The Economic Stabilization Plan which became effective in 1971 reduced the profitability of the industry and made it difficult to compete for concentrates on the world market because the price of domestic zinc was controlled at 18 cents per pound. As the price of zinc increased in world markets, there was a concomitant increase in the price of concentrates. However, since the price of the metal produced in the United States was fixed, it was not economic to purchase foreign concentrates.

7. The establishment in 1960 of the International Lead-Zinc Study Group with regular meetings in the fall of each year has had a salutary effect on the world (and the United States) zinc industry for the following reasons:

a. Substantial improvement in the availability of individual country statistics on mine production, primary and secondary metal production, and on consumption. There also has been a standardization of units and definitions.

b. Canvass of member countries' zinc industry on operation rates, forward plans on mine and smelter production, and forecasting of probable demand for zinc for each of the ensuing years by the Statistical Subcommittee which is comprised of member governments and their industry advisors.

c. A rapport has developed between major zinc producing companies and countries in which operations are based, leading to an exchange of ideas and more realistic forecasts of the supply-demand balance and industry outlook.

d. Price stability during the 14-year period 1958-72 was marked, with periods of up to 2-1/2 years of stable prices being experienced. It appears that the individual decisions of foreign and domestic firms attempting to match production to anticipated demand based on collective estimates of forward supply-demand balance seem to have accounted for this relative price stability.

TABLE 24. - Zinc national stockpile inventories, receipts and releases

(Short tons)

Year	Inventory as of Dec. 31	Net purchases or releases (-)	Year	Inventory as of Dec. 31	Net purchases or releases (-)
1945.........	0	0	1959.........	1,583,564	35,329
1946.........	69,223	69,223	1960.........	1,578,719	-4,845
1947.........	93,381	24,158	1961.........	1,579,616	897
1948.........	490,595	397,214	1962.........	1,579,907	291
1949.........	594,657	104,062	1963.........	1,580,941	1,034
1950.........	644,146	49,489	1964.........	1,505,234	-75,707
1951.........	649,163	[1]5,017	1965.........	1,312,868	-192,366
1952.........	[2]661,714	12,551	1966.........	1,212,368	-100,500
1953.........	700,320	38,606	1967.........	1,198,122	-14,246
1954.........	824,463	124,143	1968.........	1,160,606	-37,516
1955.........	966,551	142,088	1969.........	1,142,185	-18,421
1956.........	1,147,710	181,159	1970.........	1,141,490	-695
1957.........	1,462,023	314,313	1971.........	1,137,937	-3,553
1958.........	1,548,235	86,212	1972.........	949,583	-188,354

[1] Authorized 15,000, released 90.

[2] Does not include Zn in DPA inventory (data are not available).

BIBLIOGRAPHY

1. American Bureau of Metals Statistics. Yearbook for 1972. New York. 1973, pp. 69-94.

2. American Institute of Mining, Metallurgical and Petroleum Engineers, Inc. AIME World Symposium on Mining and Metallurgy of Lead and Zinc, New York. V. 1, 1970, 1017 pp.; v. 2, 1090 pp.

3. American Society for Testing and Materials. Standard Specification for Zinc Metal (Slab Zinc). B6-70 in 1971 Annual Book of ASTM Standards: Part 6, Diecast Metals, Light Metals, and Alloys. Philadelphia, Pa., 1971, p. 104.

4. Arthur G. McKee & Company. Systems for Control of Emissions, Primary Nonferrous Smelting Industry. Final Report Under Contract PH 86-65-85, Public Health Service, HEW, v. 1, 2, 3, June 1969 (pages numbered by individual sections).

5. Boyle, James R., and Lloyd Williams. Mining Methods and Practices at the Young Mine, American Zinc Co. of Tennessee, Jefferson County, Tenn. BuMines IC 8269, 1965, 27 pp.

6. Brown, Harvey E. Zinc Oxide Rediscovered. The New Jersey Zinc Co. New York, 1957, 99 pp.

7. Cole, W. A. Mining and Milling Methods and Costs, Tri-State Zinc, Inc., Jo Daviess County, Ill. BuMines IC 7780, 1957, 19 pp.

8. Dobrin, Milton B. Geophysical Prospecting. McGraw-Hill Book Co., Inc., New York, 1960, 431 pp.

9. Eyre, R. E. Suspension Roasting of Zinc Concentrate at Trail, British Columbia. Can. Min. & Met. Bull., v. 54, No. 592, August 1961, pp. 589-594.

10. Fuller, M. L., and P. E. McGarry. X-Ray Controlled Reagent Feeding in Flotation. Eng. and Min. J., v. 163, April 1962, pp. 95-96.

11. Gaudin, A. M. Flotation. McGraw-Hill Book Co., Inc., New York, 1957, 573 pp.

12. Heindl, R. A. Zinc. Ch. in Mineral Facts and Problems. BuMines Bull. 650, 1970, pp. 805-824.

13. Horvick, Ernest W. Zinc and Zinc Alloys. Ch. in Metals Handbook. American Society for Metals, Novelty, Ohio, v. 1, 8th ed., 1961, pp. 1157-1172.

14. International Lead and Zinc Study Group. Factors Affecting Comsumption. United Nations, New York, November 1966, 83 pp.

15. Jackson, C. F., and J. H. Hedges. Metal-Mining Practice. BuMines Bull. 419, 1939, 512 pp.

16. Landucci, O., and F. T. Fuller. Oxygen-Enriched Air in Lead and Zinc Smelting. J. Metals, v. 13, No. 10, October 1961, pp. 759-763.

17. Mantell, C. L. Electrochemical Engineering. McGraw-Hill Book Co., Inc., New York, 1960, 680 pp.

18. Mathewson, C. H. Zinc, the Science and Technology of the Metal, Its Alloys and Compounds. Reinhold Publishing Corp., New York, 1959, 721 pp.

19. McKinstry, H. H. Mining Geology. Prentice-Hall, Inc., Engelwood, N.J., 1948, 680 pp.

20. McWilliams, John R. Mining Methods and Costs at the Holden Mine, Chelan Division, Howe Sound Co., Chelan County, Wash. BuMines IC 7870, 1958, 44 pp.

21. National Business Publications, Ltd. Canadian Mining Manual. Gardenvale, Quebec, 1960, 303 pp.; 1961, 276 pp.

22. Peele, Robert. Mining Engineer's Handbook. John Wiley & Sons, Inc., London, 1941, v. 1, 1340 pp.; v. 2, 1137 pp.

23. U.S. Bureau of Mines. Control of Sulfur Oxide Emissions in Copper, Lead, and Zinc Smelting. BuMines IC 8527, 1971, 62 pp.

24. _____. Zinc. Ch. in Minerals Yearbooks, 1932-72.

25. U.S. Department of the Interior. First Annual Report of the Secretary of the Interior Under the Mining and Minerals Policy Act of 1970 (P.L. 91-631). March 1972, pt. 1, 142 pp.; pt. 2, Appendices, 436 pp.

26. Wedow, Helmuth, Jr., Thor H. Killsgaard, Allen V. Heyl, and Robert B. Hall. Zinc. Ch. in United States Mineral Resources. U.S. Geol. Survey Prof. Paper 820, 1973, pp. 697-711.

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Changes in world mine and smelter supply sources of zinc have led to changes in zinc supply patterns in the United States during the past 3 years, 1970-1972. There has resulted a growing reliance on foreign sources of zinc metal to furnish an ever-increasing portion of expanding domestic requirements. This review of fundamentals and historical developments is intended to provide background in order to place the future of the U.S. zinc industry in perspective. The properties and uses of zinc are described. A new study on U.S. reserves is presented with description by geographical region and comparisons with older reserve data. The technologies of prospecting through refining are described with emphasis on the metallurgy involved in the various methods of smelting. Production, consumption, and imports are discussed and illustrated with graphs and tables to review the past and present pattern. Government actions affecting the industry are shown.

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