Economic Drivers of Mineral Supply

U.S. Geological Survey Open-File Report 02-335

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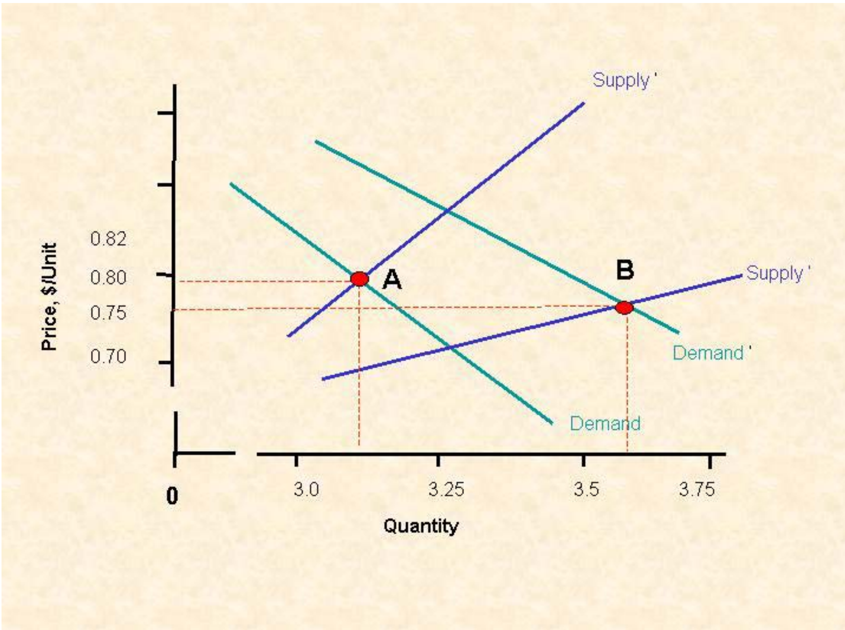
With an Introduction to the Series by Eric E. Rodenburg



Part of a multi-chapter study titled “The Meaning of Scarcity in the 21st Century”

U.S. Geological Survey

On the cover:

Supply – demand relation

Photograph of coins (Brøderbund Software, Inc., 1997)

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INTRODUCTION TO THE SERIES[1]

The possibility of future mineral scarcity is an important concern of environmental activists, those desiring to limit population growth, and those concerned with wealth distribution between industrialized and developing countries. Through the years, observers from Thomas Malthus (1798) to the 1972 Club of Rome report, (Meadows and others, 1972), for example, predicted exhaustion of resources at various dates, most of which have come and gone without the dire consequences of societal collapse they envisioned.

The static model from which these predictions came continues to inform many who choose to believe that mineral production cannot meet the material aspirations of a rapidly growing world population if consumption (one component of which is resource capitalization, which is often overlooked by these analysts) of some resources continues to increase. The perception of future scarcity, for example, motivated the Factor Ten Club, a group of resource economists, to issue the Carnoules Declaration in 1994 and 1995. The Declarations called for a swift 10-fold increase in material efficiency among industrialized countries to free materials for people in developing countries (Factor 10 Club, 1995).

The concerns of future scarcity may in part be caused by misinterpretation and (or) the misuse of published mineral reserve estimates for non-fuel mineral commodities. A reserve is that part of an in-place demonstrated resource that can be economically extracted or produced at the time of estimation (U.S. Bureau of Mines and U.S. Geological Survey, 1980). Some misinterpret the

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[1] Introduction to the series was written by Eric E. Rodenburg, Chief, Minerals and Materials Analysis Section, U.S. Geological Survey.

term “reserve” as an estimate of all-that-is-left.

Mineral supply starts with the physical existence of materials, and can be no greater than its occurrence in the Earth’s crust. The amount of material actually supplied to society (economic supply) is that which is called forth by demand (willingness-to-pay), as moderated by the cost of production, which is influenced by physical realities, technology, politics, and social concerns.

In fact, many of the minerals that the Earth’s population demands exist in nearly inexhaustible amounts. Additionally, there is an enormous stock of resources in materials in-use (machinery, buildings, and roads) and in unutilized waste (landfills). There is, however, a growing understanding that physical scarcity is not the only, or even the most, important issue. Industrial activities extract and transform resources into products people use. In many cases, these activities come with direct or accumulative environmental consequences that can pose serious threats to ecosystems and human health. Thus, the important issue of scarcity may be the capacity of Earth’s geologic, hydrologic, and atmospheric systems to assimilate the wastes (Meadows and others, 1972).

This series, “Scarcity in the 21st Century”, addresses resource constraints and opportunities, and the effects of their interactions on resource supply. Assessing potential supply requires a whole systems approach, both in physical terms by looking at the flows of materials through the economy, and in human terms by integrating the interactive domains of economics, environment, policy, technology, and societal values.

In 1929, D.F. Hewett, of the United States Geological Survey (USGS), reflecting on the effects of war on metal production, identified four factors he deemed most important in influencing metal production (Hewett, 1929).

1. Geology

> "First, there are the geological factors, which are concerned with the minerals present; their number and kind, which determine whether the problem of recovery is simple or complex; the degree of their concentration or dissemination; their border relations; the shape and extent of the recognizable masses."

2. Technology

> "Second, there are the technical factors of mining, treatment and refining. A review of these leaves a vivid impression of the labor involved in their improvement but they necessarily yield cumulative benefits."

3. Economics

> "The third group of factors that affects rates of production are economic, and among these factors cost and selling price are outstanding... Since 1800 the trend of prices for the common metals, measured not only by monetary units but by the cost in human effort, has been almost steadily downward…"

4. Politics

> "The fourth group of factors that affect metal-production curves are political or lie between politics and economics."

The four factors do not operate separately, but rather as parts of an integrated system, which also includes social constraints and drivers such as environmental issues and the structure of the mining industry.

"Scarcity in the 21st Century" is composed of six chapters to be published in a series of USGS Open File Reports and then compiled as a USGS Circular.

Chapter 1: "The Supply of Materials" examines the physical supply of minerals on the planet, in the ground and products-in-use, waste streams, and waste deposits (landfills). Current and future potential for recycling of products-in-use and landfill materials are examined.

Chapter 2: "Economic Drivers of Mineral Supply" explores price, investment, costs, and productivity, and their relevance to supply.

Chapter 3: "Technological Advancements – A Factor in Increasing Resource Use" investigates the impact of technological change on mineral extraction, processing, use and substitution.

Chapter 4: "Social Constraints and Encouragement to Mineral Supply" addresses social realities that affect mineral supply, nationally and globally, and the socio-cultural trends that promise to have an impact on future supplies.

Chapter 5: "Policy – A Factor Determining the Parameters of Minerals Supply and Demand" examines the effect of government policies that either promote or restrain mineral development, some of which include: access, title, regulation, rent, royalty, and tax fees, and direct and indirect subsidies. This chapter also discusses the affects of corporate policies on mineral supply.

Chapter 6: “Overview of Minerals Supply” presents an overall view of these parameters of supply to show their synergy in supply and ultimately production.

Each chapter contains ample reference to historical information about one or more commodities to illustrate the concepts.

ABSTRACT

The debate over the adequacy of future supplies of mineral resources continues in light of the growing use of mineral-based materials in the United States. According to the U.S. Geological Survey, the quantity of new materials utilized each year has dramatically increased from 161 million tons[2] in 1900 to 3.2 billion tons in 2000. Of all the materials used during the 20th century in the United States, more than half were used in the last 25 years.

With the Earth’s endowment of natural resources remaining constant, and increased demand for resources, economic theory states that as depletion approaches, prices rise. This study shows that many economic drivers (conditions that create an economic incentive for producers to act in a particular way) such as the impact of globalization, technological improvements, productivity increases, and efficient materials usage are at work simultaneously to impact minerals markets

[2] In this report, all tons are metric tons unless otherwise noted.

and supply. As a result of these economic drivers, the historical price trend of mineral prices[3] in constant dollars has declined as demand has risen. When price is measured by the cost in human effort, the price trend also has been almost steadily downward.

Although the United States economy continues its increasing mineral consumption trend, the supply of minerals has been able to keep pace. This study shows that in general supply has grown faster than demand, causing a declining trend in mineral prices.

INTRODUCTION TO THE STUDY

The objective of this study is to analyze the main economic drivers that prompt producers to either supply more or less mineral-based materials to the market. Economic drivers are those conditions that create an economic incentive for producers to act in a particular way.

Price is an example of an economic driver because, as prices rise, producers supply more mineral-based materials to the market. Price may be the most important economic driver since other economic drivers such as production costs and the impacts of globalization, influence price. This study builds upon research conducted previously (Sullivan, Sznopek, and Wagner, 2000) that analyzed the long-term trend of mineral prices in the United States.

An almost endless list of factors could be considered economic drivers because in one-way or

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[3] All historical mineral prices in this study are from U.S. Geological Survey Open-File Report 01-006 where they are referred to as unit value. For a complete explanation of unit value, please refer to the methodology section of OFR 01-006 at URL http://minerals.usgs.gov/minerals/pubs/of01-006/.

another these factors can impact the supply-demand curve. These factors include people's perceptions of the economy, current events, political activities, population and factors such as the weather. Governmental actions in the form of taxes, environmental regulations, and governmental spending also can greatly influence the decisions producers make regarding the amount of material to be supplied to the market. These factors are complex, take place simultaneously, and interact with one another. This study addresses the major economic factors that influence the amount of material supplied to the market. Other chapters in this series "Scarcity in the 21st Century" address additional factors.

Chapter 1: "The supply of materials" examines the physical endowment of minerals.

Chapter 3: "Technological advancements - A factor in increasing resource use" addresses the impact of technological change.

Chapter 4: "Mineral supply - Sociocultural drivers and constraints" addresses the social realities that affect mineral supply.

Chapter 5: "Policy – A factor determining the parameters of mineral supply and demand" examines the effect of government policies including regulation, rents/royalties, subsidies, and taxes.

Chapter 6: "Overview of minerals supply" brings together these parameters of supply to show their synergy in supply and ultimately production.

These chapters present additional information on factors which influence the amount of material supplied to the market.

This report shows the supply of minerals in the United States has been sufficient to meet the increasing consumption trend of the U.S. economy. The historical trend of mineral prices in constant dollars continues to decline due to the impact of efficient materials use, globalization, productivity increases, and technological improvements.

In this report, trends in material use and resources and reserves are discussed first. Then the basic principles of the supply-demand relation theory follow to support the subsequent discussion regarding economic drivers such as price, production, globalization, technology and productivity, production costs, capital costs, and strategies for efficient materials use. More detailed discussion of the theory of the supply-demand relation, price indices and prices, and production indices and production levels is presented in Appendices A, B, and C, respectively. Case studies describing the economic drivers for the commodities aluminum, copper, potash, and sulfur are presented in Appendices D, E, F, and G, respectively.

ECONOMIC DRIVERS OF MINERAL SUPPLY

Economic activity is one way human beings provide for their material requirements, including both basic necessities and additional items that make life more enjoyable. Mineral-based materials play a vital role in the economy of the United States and the world. The value of domestic production of mineral raw materials from mining was estimated at $40 billion in 2000, while the value of old scrap[4] reclaimed in this same year was estimated at $10 billion (U.S. Geological Survey, 2001a, p. 4). As shown in figure 1, these raw materials are processed domestically to produce aluminum, brick, cement, copper, fertilizers, steel, and other products. Shipments of processed nonfuel minerals in the United States in the year 2000 were valued at

[4] Old scrap is the term used for products that have reached the end of their economic life and are discarded and then enter back into the system as material available for recycling.

$429 billion. Both durable and nondurable goods manufacturers use these materials in their products.

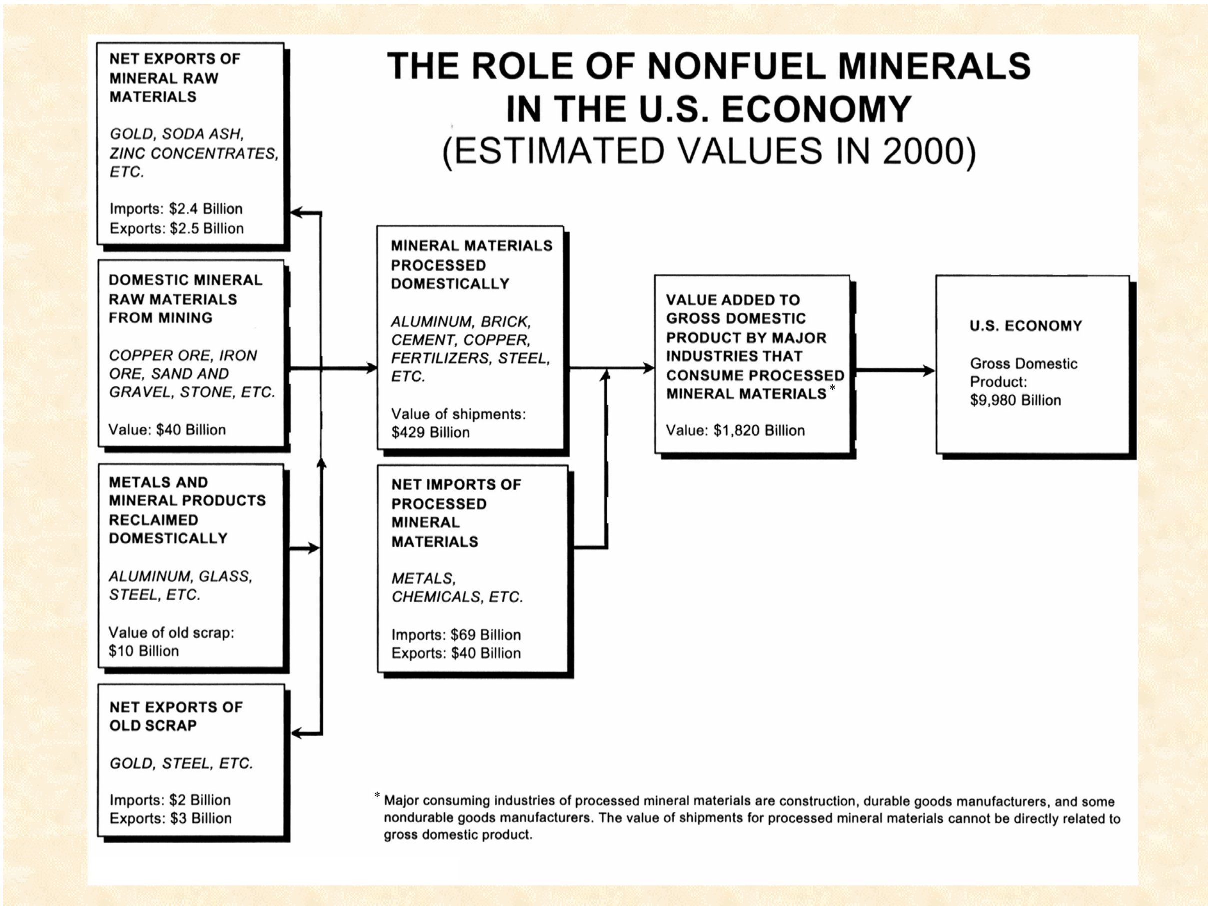


Figure 1. The role of nonfuel minerals in the U.S. economy for the year 2000 (U.S. Geological Survey, 2001a).

The value of nonfuel mineral production has risen dramatically in the United States over the last 50 years. In 1950, the value of U.S. nonfuel mineral production was approximately $3.2 billion (D'Amico, 1966) and by 2000 this value was $39.4 billion (Smith, 2002). However, when these values are converted into constant 2000 dollar terms, taking out the influences of inflation, the values for 1950 and 2000 are less dramatic. During this time period, the value nearly doubled from $22.7 billion in 1950 to $39.4 billion in 2000 as shown in figure 2. Also, the price of most mineral-based commodities has shown a long-term price decline in terms of constant dollars (p. 37-39, this chapter). However, the United States has dramatically increased its output in terms of quantity, thereby resulting in an increased total value of production (p. 39-42, this chapter).

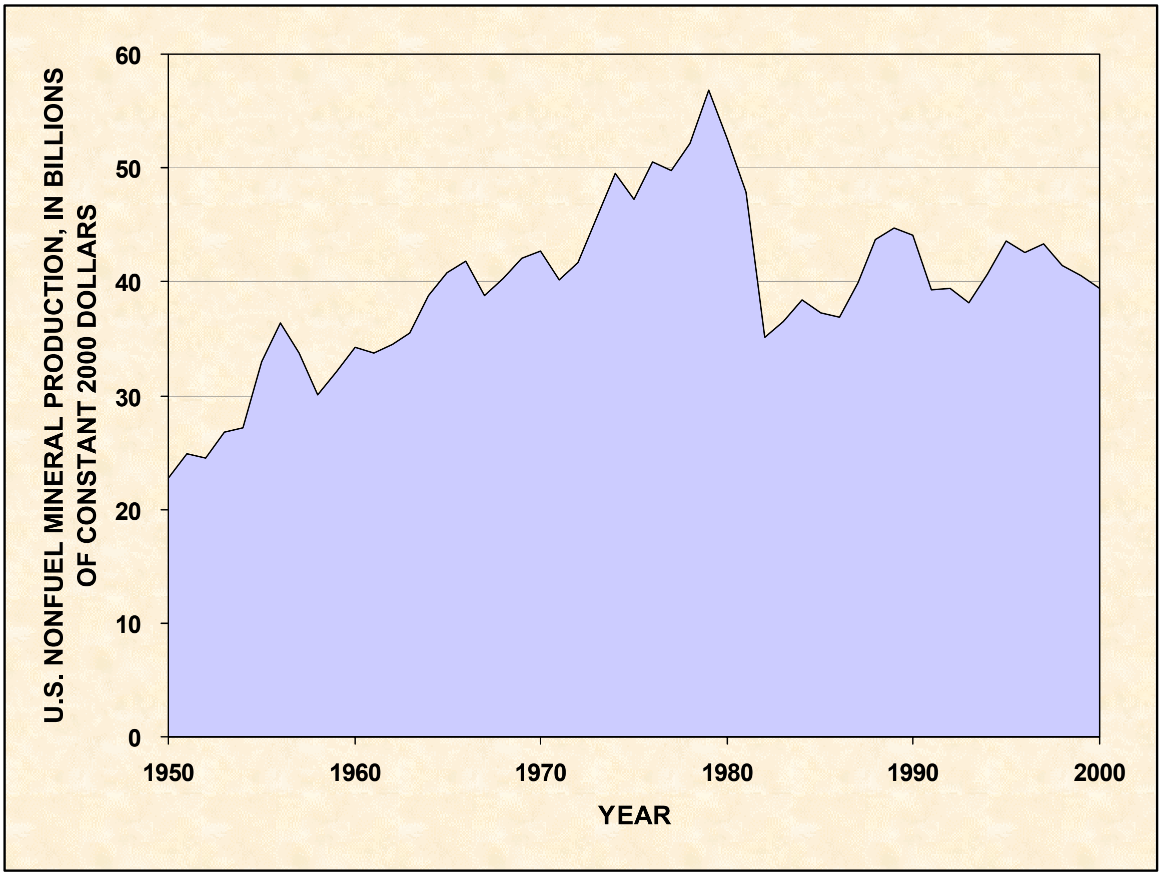


Figure 2. Value of nonfuel mineral production in the United States in constant 2000 dollars, 1950-2000 (data calculated from U.S. Bureau of Mines (1966a–80a, 1981b, 1982a–95a); U.S. Geological Survey (1997b–2002b): U.S. Department of Labor, Bureau of Statistics (2001§[5]); and U.S. Census Bureau (1975)).

[5] The § indicates that the source is an Internet site, the citation for which is located in the sub-section "Internet References Cited", within the section "References".

What Are Constant Dollars?

The dollar you use to buy something today looks like the dollar that you spent last year or the one you spent 20 years ago, but it is not the same. The loaf of bread that you can currently buy for a dollar may have cost 95 cents last year and 50 cents 20 years ago. Thus the dollar that you had 20 years ago would have purchased two loaves of bread at that time. The basket of groceries that you purchased last year for $57 currently costs you $60. What has happened to the dollar? Why does it purchase less today than it did in the past?

What happened is called inflation. Inflation is an increase in the general level of prices and an erosion of the purchasing power of the dollar. Both inflation (increasing prices) and deflation (decreasing prices) are possible. However moderate inflation has been the prevailing trend in our modern economy since World War II.

Constant dollars are dollars in which the effects of changes in the purchasing power of today's dollar (current dollars) over time have been removed. Analysts have developed price indexes to estimate constant dollars. Price indexes estimate the relative changes in average prices over time.

This analysis uses the Consumer Price Index (CPI) to estimate constant dollars. The CPI utilizes changes in the average prices of a market basket of goods to estimate changes in the value of a dollar. The market basket is designed to be a representative sample of goods purchased. The

What Are Constant Dollars?—*Continued*

CPI can be used to estimate how many of today's dollars it would have cost to purchase a loaf of bread or some other item in past years. Constant dollars are in comparable terms over time. Thus we can compare the real prices of a good at different time periods.

Historical trends of some of the factors that affect the amount of material supplied are important trends to be examined. The historical time series identifies long-term trends and can indicate possible future scenarios regarding the supply of minerals. Analyzing historical data is important, as it can reveal how past supply shortages have been overcome, or diverted. It can also show how the economic system can work to reduce the possibility of future resource scarcity.

Use

Before a mineral can attain any value, it needs to be located, extracted, and converted into usable products for which a demand exists, and delivered to consumers in the required quantities and qualities at the needed times and locations. Demand for minerals stimulates their supply. Demand is the relation between the various possible prices of a product and the amounts of it that consumers are willing and able to buy during some period of time, other economic factors remaining the same. It is important to note the "willing and able to buy" concept is different from a consumer's wants and needs. A consumer's desire or willingness to purchase a product has no impact on demand if the consumer does not have the purchasing power to buy the product. In many cases, consumption (or use) is a proxy for demand because products were actually purchased by the consumer.

Supply occurs to meet current and anticipated demand. In theory, if there is no demand for a material, the supply will be zero. When demand increases, prices tend to rise and/or producers supply more goods to the market to keep up with the rising demand. When demand increases faster than supply, temporary shortages exist[6]. When supply increases faster than demand, excess supply in the form of stockpiles can become an issue.

Historical minerals usage in the United States

Food, fuel, and materials are three broad categories of commodities used in the economy to support the requirements of society. The following section from Matos and Wagner, 1998, examines the historical usage of mineral-based materials since 1900. The mineral-based materials of metal and industrial mineral commodities like cement and sand and gravel are examined.

Since the beginning of the 20th century, the types of materials used in the United States have changed significantly. In 1900, on a per weight basis, 41 percent of the new[7] materials used domestically were renewable as shown in figure 3. Renewable resources are those that regenerate themselves, such as agricultural, forestry, fishery, and wildlife products. If the rate

[6] A detailed explanation of the supply-demand concept can be found in Appendix A.
[7] New materials in this report refers to newly produced materials, either by the extraction of resources or by recycling, flowing into the economy. It does not include, for example, an automobile purchased in a prior year that is still in use.

they are harvested becomes so great that it drives the resource to exhaustion or extinction, however, renewable resources can become nonrenewable. In contrast, nonrenewable resources typically form over long periods of geologic time. They include metals, industrial minerals, and organic materials (such as fossil-fuel-derived materials).

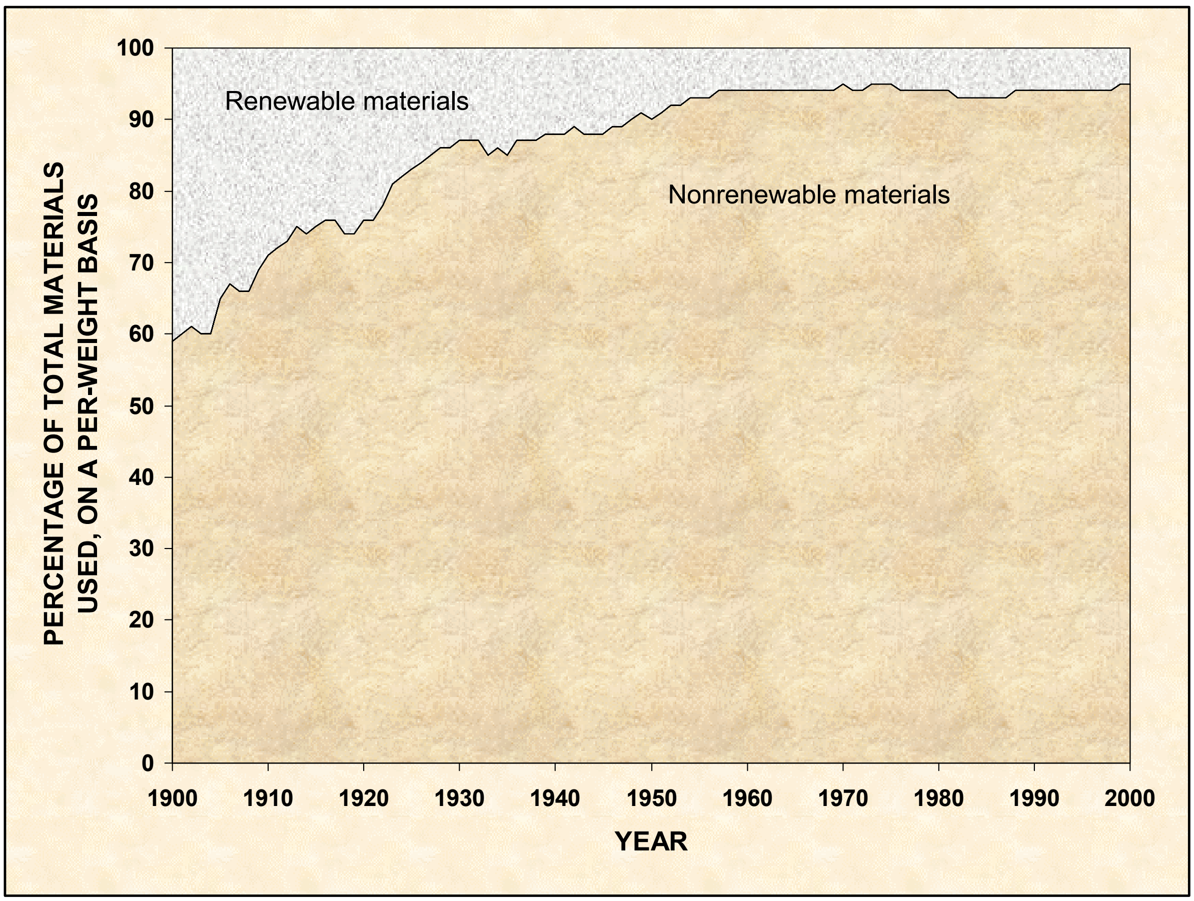


Figure 3. Renewable and nonrenewable materials used in the United States, 1900-2000 (Wagner, 2002).

The quantity of new materials entering the U.S. economy in 1900 was 161 million tons (Matos and Wagner, 1998). The changes in the quantity entering the U.S. economy each year mirrored major economic and military events, including the depression of the 1930s, World War I, World

War II, the post-World War II boom, the ‘oil crisis’ of the 1970s, and the recession of the 1980s as shown in figure 4. During this time frame, the U.S. economy moved rapidly from an agricultural to an industrial base. In the 1950s and 1960s, it started to shift toward a service economy. These trends changed the mix of materials used, as shown in figure 5, and were accompanied by more extensive automation, computerization, high-speed transport, miniaturization, and processing.

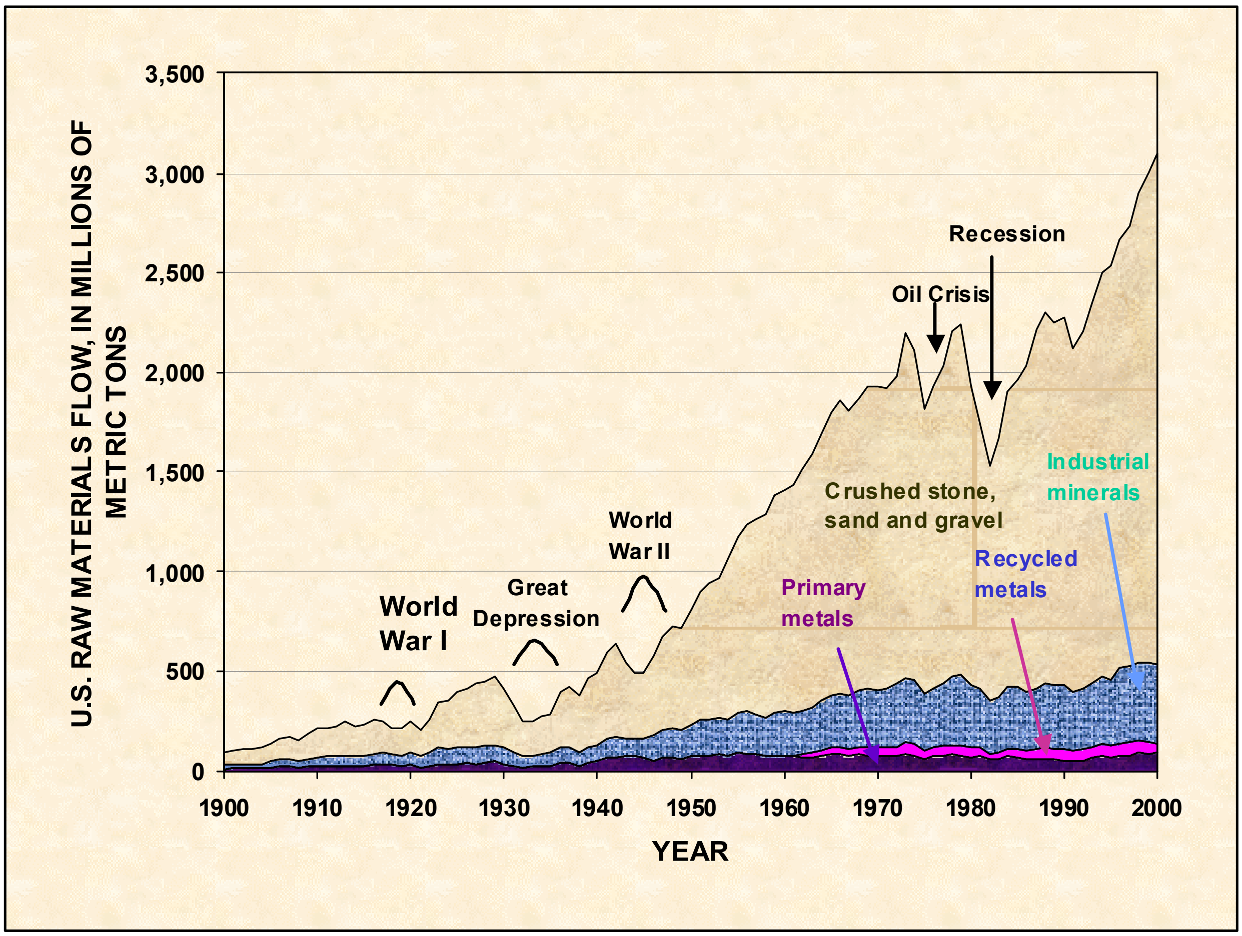


Figure 4. U.S. flow of raw materials by weight, 1900-2000 (Wagner, 2002).

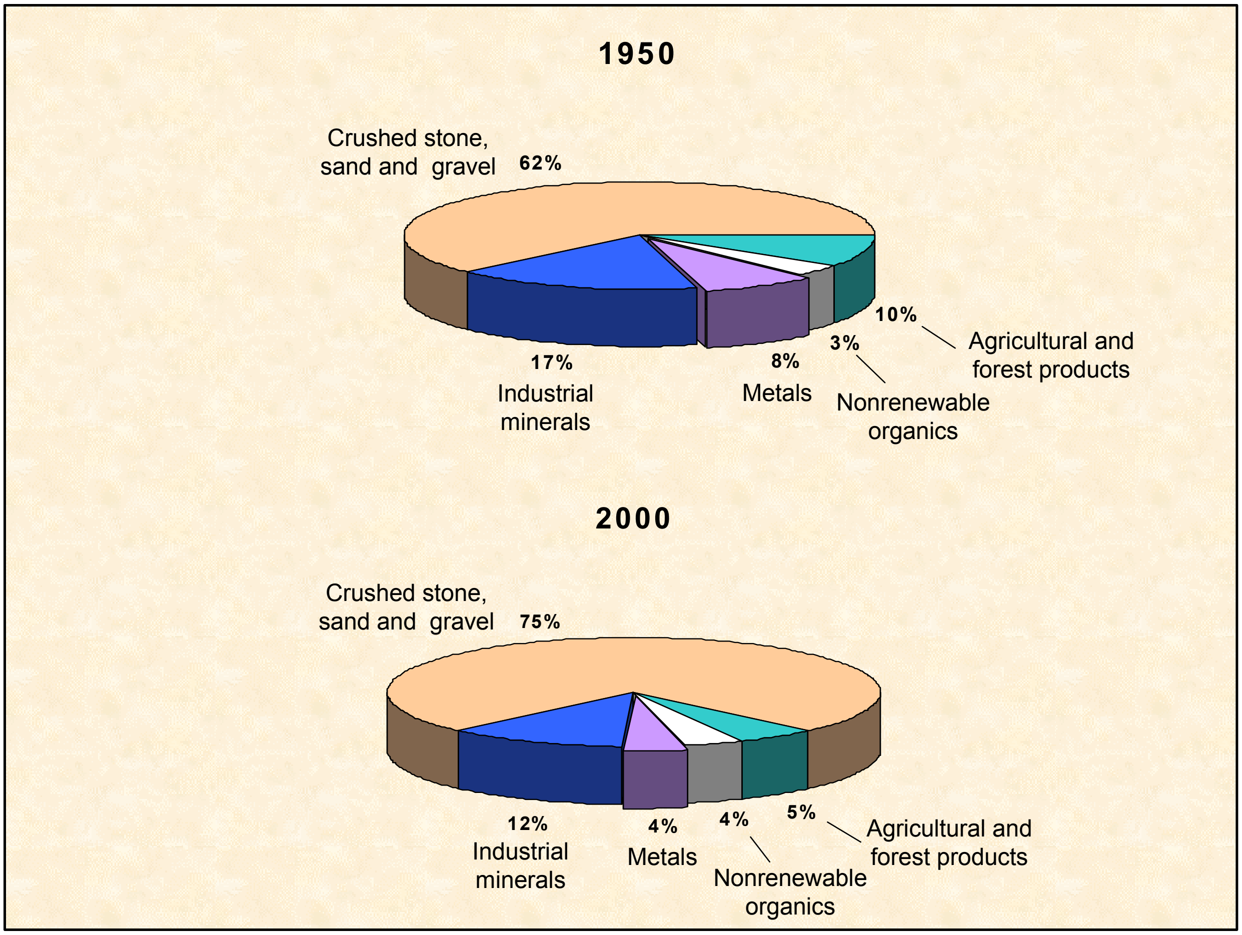


Figure 5. U.S. flow of raw materials by weight, 1950 and 2000 (Wagner, 2002).

By the end of the 20th century, only 5 percent of the 3,400 million tons of new materials entering the U.S. economy in 2000 were renewable whereas 41 percent of the 161 million tons were renewable in 1900. Of all the materials used during this century in the United States, more than half were used in the last 25 years. More details on the data and trends of materials usage in the United States are presented in Matos and Wagner (1998, p.109-113).

Crushed stone and construction sand and gravel make up as much as three quarters (by weight) of new resources used annually. Use of these materials greatly increased as a result of infrastructure growth (especially the interstate highway system) after World War II. In recent decades, construction materials have been used mainly in building new suburban complexes, widening and rebuilding roads damaged from weather and heavy traffic loads, and in construction of bridges, ramps, and buildings.

Other industrial mineral commodities account for the next largest share of materials use. These include cement for concrete; potash and phosphate for fertilizer; gypsum for drywall and plaster; fluorspar for acid; soda ash for glass and chemicals; and sulfur, abrasives, asbestos, and other minerals used for products and manufacturing processes.

On a percentage basis, the use of metals, by weight, declined slightly relative to other materials. Reasons for this include the desire for lighter-weight materials (such as aluminum), the introduction of high-strength, low-alloy steel in vehicles, and the availability of substitute materials such as plastics.

Improvements in recycling technologies, reduced recycling costs, and increased consumer preferences for environmentally friendly products have resulted in the growth of recycling of metals and industrial mineral commodities, such as concrete. The sudden emergence of recycled metals, shown in figure 4, in the 1960s reflects data disaggregation. Before the 1960s, recycled metals were included in total metals values. According to 2000 estimates, 62.1 percent of all aluminum beverage cans were recycled (Aluminum Association, Inc., 2001§). The 2000 recycling rates for steel-containing products were 84.1 percent for appliances, 95.0 percent for automobiles, and 58.4 percent for steel cans (Steel Recycling Institute, 2001§). As a result of this level of recycling of iron and steel, 55 percent of the requirement for iron and steel is met by recycled sources (Fenton, 2002, p. 63.14). This means that 74 million tons less material comprising iron and steel was produced from primary (virgin) sources.

Consumption and Use of Materials

—From Wagner, 2002, p. 5

"Consumption" or "use" of materials refers to use of the services that goods made from these materials provide. It means the destruction of the usefulness of the product, not necessarily the destruction of the materials of which the product is composed. For example, consumers purchase items such as automobiles, clothing, housing, and refrigerators. When a new automobile is purchased, both the materials of which the automobile is physically composed and the assembly of these materials into a working automobile is purchased, but more important, the services of transportation that the automobile provides is acquired. When the automobile reaches the end of its useful life and is no longer able to provide reliable transportation, the materials of which the automobile is composed are available to be transformed or recycled into other useable products. Although the use of materials is generally referred to as consumption; in many cases, the materials remain after the end of the useful life of the product to be reused or recycled into new products.

Consumption and Use of Materials—*Continued*

In 2000, 95 percent of all automobiles that had reached the end of their useful life were recycled (Steel Recycling Institute, 2001§, Photo source: Brøderbund Software, Inc., 1997).

Through use, however, some materials in products are dissipated. That is, the materials of which they are made are not available for recycling at the end of the product's useful life. An example of a dissipative use in an automobile is associated with the brake linings. Over time much of the brake lining wears away with the resulting small particles being dropped along the roadsides, not to be recovered again. The remnant of the worn down brake lining is available for recycling; however, the worn away portion is not.

A new automobile, for statistical purposes, is considered "consumed" in the year it is purchased

Consumption and Use of Materials—*Continued*

by a consumer and driven off the showroom floor, even though it may provide many years of service. This statistical accounting is used for other commodities as well. For example, large quantities of stone, sand and gravel, and cement were “consumed” in the construction of the Hoover Dam (built from 1931 to 1936). The Hoover Dam is still providing its intended services today. The same can be said of such American icons as the Statue of Liberty (erected 1885-86), the Empire State Building (constructed 1930-31), and the Golden Gate Bridge (constructed 1933-37). Infrastructure such as highways, buildings, and bridges may last 35, 50, or 100 years or more. In such cases, the use of materials today can be an investment for tomorrow if such structures continue to be used by society.

The Golden Gate Bridge, constructed in the 1930s, still serves the needs of society (Source: Microsoft® Clip Gallery Live, 2000§)

Resources and reserves

How is it possible to use nonrenewable resources without running out in the future? How is it that nonrenewable resources are still plentiful and in many cases even more available than in the past as shown by the falling trend in mineral material prices? Except for a few substances, notably crude oil and natural gas, which are discretely different from the rock masses that contain them, the quantities of mineral materials in even the upper few miles of the earth's crust approach near inexhaustible accounts by current projections. A single cubic mile of average crustal rock contains a billion tons of aluminum, over 500 million tons of iron, 1 million tons of zinc, and 600 thousand tons of copper (Brooks, 1973, p. 4).

In 1973, Brooks questioned why did the perception persist that mineral materials are in short supply with so much material in existence? Much of the confusion comes from different interpretations of the terms used to describe the amount of material available and the factors that cause mineral materials to move from one classification to another. Terms such as resources, reserve base, and reserves are frequently used among experts in this field when discussing the amount of mineral materials available for extraction. These terms can lead to confusion when interpreting the actual amount of material left in the ground to be extracted. As stated by Zwartendyk (1981), "Immense – and immensely misconstruable – figures for mineral resources fail to impart a clear picture of mineral-resource adequacy and long-term mineral supply. Such figures are almost routinely mistaken for amounts that will be available at acceptable prices when and where needed, as if the world were economically frictionless". Detailed discussions of resource, reserve base and reserves can be found in the sidebar "Resource, Reserve Base, and Reserve Definitions."

Resource, Reserve Base, and Reserve Definitions

Through the years, geologists, mining engineers, and others operating in the minerals field have used various terms to describe and classify mineral resources, which are defined herein include energy materials. Some of these terms have gained wide use and acceptance, although they are not always used with precisely the same meaning. The U.S. Geological Survey and the former U.S. Bureau of Mines developed a common classification and nomenclature system. The most recent work was published in 1980 as U.S. Geological Survey Circular 831 – "Principles of a Resource/Reserve Classification for Minerals" (U.S. Bureau of Mines and U.S. Geological Survey, 1980) and has been reprinted in the publication "Mineral Commodity Summaries" (U.S. Geological Survey, 2001a, p. 191).

Long-term public and commercial planning must be based on the probability of discovering new deposits, on developing economic extraction processes for currently unworkable deposits, and on knowing which resources are immediately available. Thus, resources must be continuously reassessed in the light of new geologic knowledge, or progress in science and technology, and of shifts in economic and political conditions. To best serve these planning needs, identified resources should be classified from two standpoints: (1) purely geologic or physical/chemical characteristics – such as grade, quality tonnage, thickness, and depth – of the material in place; and (2) profitability analyses based on costs of extracting and marketing the material in a given economy at a given time. The classification of mineral and energy resources is necessarily arbitrary, because definitional criteria do not always coincide with natural boundaries. The system can be used to report the status of mineral and energy-fuel resources for the Nation or for specific areas (U.S. Bureau of Mines and U.S. Geological Survey, 1980). A classification system, designed generally for all mineral materials, is shown graphically in figures 6 and 7. Detailed definitions for all components of these graphics can be found in U.S. Geological Survey Circular 831 – "Principles of a Resource/Reserve Classification for Minerals".

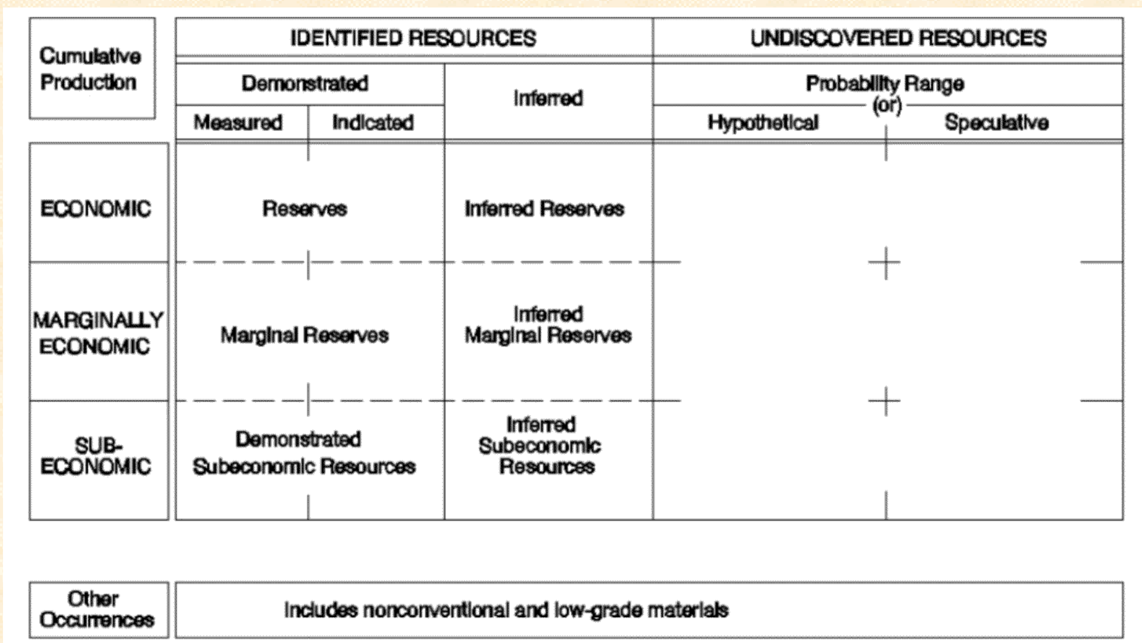


Figure 6. Major elements of mineral-resource classification, excluding reserve base and inferred reserve base (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Resource, Reserve Base, and Reserve Definitions—*Continued*

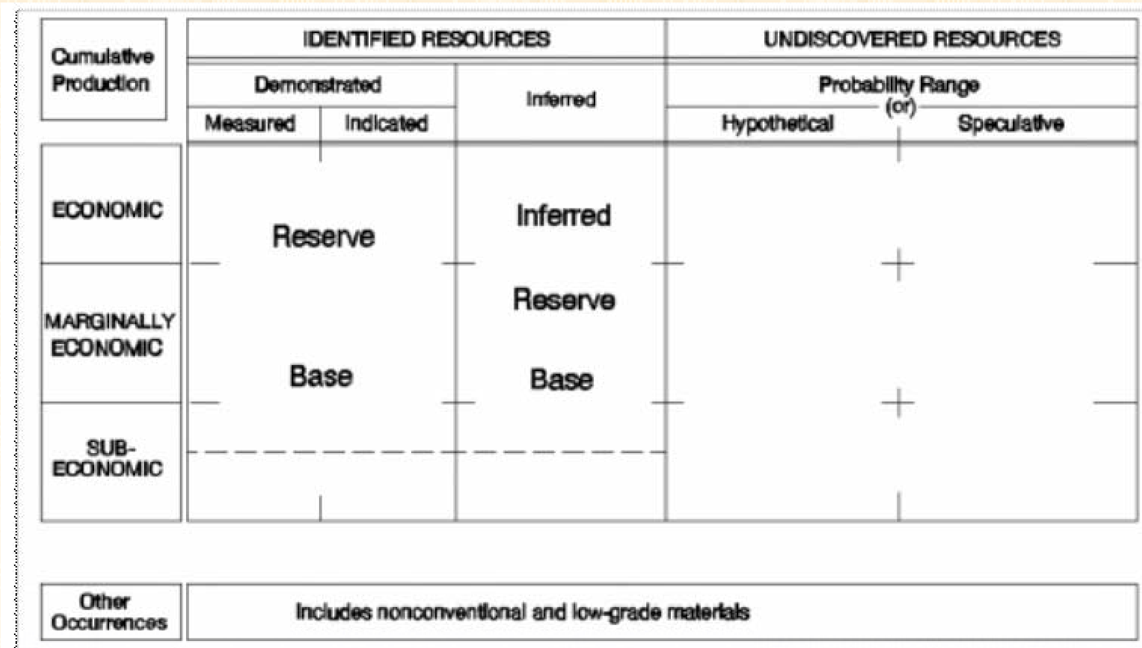


Figure 7. Reserve base and inferred reserve base classification categories (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Definitions

A dictionary definition of resource, "something in reserve or ready if needed," has been adapted for mineral and energy resources to comprise all materials, including those only surmised to exist, that have present or anticipated future value.

Resource. – A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the

Resource, Reserve Base, and Reserve Definitions—*Continued*

concentration is currently or potentially feasible (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Reserve Base. – That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology, and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources). The term "geologic reserve" has been applied by others generally to the reserve-base category, but it also may include the inferred-reserve-base category; it is not a part of this classification system (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Reserves. – That part of the reserve base that could be economically extracted or produced at the time of determination. The term "reserves" need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system (U.S. Bureau of Mines and U.S. Geological Survey, 1980). Table 1 is an example of the resource, reserve base, and reserve estimates for copper.

Resource, Reserve Base, and Reserve Definitions—*Continued*

Table 1. Copper resource, reserve base, and reserve estimates for the year 2001.

[Data from D.L. Edelstein, 2002, p. 55]

Estimated resources, reserve base, and reserves (Million of metric tons)	
Copper Resources	
United States	
Discovered	350
Undiscovered	290
Total	640
World	
Land based	1,600
Deep-sea nodules	700
Total	2,300
Copper Reserve Base	
United States	90
World	650
Copper Reserves	
United States	45
World	340

Many descriptions of the supply of mineral materials include only the material that could be mined at today's prices and today's technology – what is properly termed "reserves." This term does not include the amount of mineral materials that would be available over the long term with the development of new technology allowing more ore to be economically mined and with changing cost and price scenarios. This is the main reason why a common national or world level analysis of the 'number of years remaining' is not valid. As reported by Zwartendyk (1974), the "life index" of reserves is one such measure, also referred to as the "life expectancy" of reserves, "reserve life" or "reserves/production ratio." It is a misleading statistic that is widely used as a measure of "adequacy" of reserves of a mineral commodity on a national scale. In spite of its serious weaknesses as a statistic, it continues to gain undeserved and unjustified international respectability. In this analysis, the national or world reserve estimate for a commodity is divided by the current annual production (or consumption) level to yield the number of years remaining for production of that particular commodity at current prices. Because production costs and sales prices change frequently, virtually continuously in some cases, reserves also change frequently, even though the physical endowment of the earth's crust remains constant. As the economics change, mineral material that was once considered a resource can become a reserve. The amount of mineral material considered a reserve is influenced by numerous factors such as prices, the development of new technologies, costs to extract the mineral material, and discoveries of new deposits. Once the mineralized material in a deposit is considered a reserve (meaning it is economically available), it does not necessarily exist forever. Product prices can decline and/or costs can rise to levels at which the mineral deposit becomes uneconomic, whereby reserves of a mine cease to exit economically.

In addition, because delineating reserves requires investment in drilling, stated reserves of a mine may be approximately the same over many years. Typically, management will desire to have enough reserves to support production capacity for its planning horizon, for example, 5 to 10 years, and will not delineate more new reserves beyond that planning horizon. In a few States in America, there is a disincentive to develop additional new reserves as the calculation method for property taxes includes estimating future production and earnings. As a result, this method of valuation imposes a tax on the mineral reserves in place. This is a disincentive to exploration drilling and therefore efficient mine planning, because additions to reserves increase the mine life, creating greater future earnings and a greater tax liability (Gentry and O'Neil, 1984, p. 182).

Thus, as proven reserves are produced; more may be added by additional drilling. For that reason, it is useful to consider quoted reserves as the current working inventory (Harris, 1985).

An important question is not whether mineral materials exist, but at what rate different sources of supply will become available in the sense of being economically feasible to recover. Natural materials do not become resources until they are combined with human ingenuity. The record of this combination is impressive. Mineral resources have become more and more widely available despite (and partly because of) growing rates of consumption (Brooks, 1973, p. 8). Consider the case of copper. Even though world copper mine production has dramatically increased from the 1930s to present, from 1.61 million tons in 1930 to 13.2 million tons in 2000 (Porter and Edelstein, 2001), world copper reserves have more than kept up as shown in table 2. New developments in mining and ore processing equipment have greatly increased reserves by making possible the recovery of copper from ore that was not economically feasible using older technologies (Wilburn, Goonan, and Bleiwas, 2001). This demonstrates that reserves are dynamic concepts and should not be used as long-run indicators of the future availability of the material.

Table 2. World copper reserves.

[Data from D.L. Edelstein, U.S. Geological Survey, oral commun, 2001 and *U.S. Geological Survey, 2001b]

Estimated World Copper Reserves (Million tons contained metal)						
Year	1930	1950	1960	1970	1982	2000
Reserves	60	91	154	280	350	340*

Understanding the movement of deposits from the resource to reserve category requires an explanation of the theoretical relations between supply and demand and a discussion of factors that can make a deposit economic or noneconomic.

Supply-demand relation theory

In order to try to understand the complex set of economic drivers that influence producer's decisions, it is useful as a starting point, to consider the basic economic theory of supply and demand. Although it is based on several key, and in some cases theoretical assumptions, it nevertheless allows a number of important decision variables to be identified. If it is assumed that the market for minerals is perfectly competitive, free from government intervention, and staffed by rational profit-maximizers, then the scale of mineral production will be determined by the level of consumer demands and the cost of getting the mineral to them.

What, how, and for whom are the three basic questions related to the supply-demand relation that every economy must solve. The answers to these questions in a free enterprise economy are determined primarily by a system of markets and prices. They include:

1. What things will be produced is determined by the votes of consumers – by their everyday decisions to purchase an item and to not purchase a different item. Ultimately the money they spend provides the payroll that employees (also consumers) receive in wages. Thus, the circle is completed (closed).

2. How things are produced is determined by the competition between different producers. In theory, the method that has the lowest cost at any time will displace a more costly method.

3. For whom things are produced is determined by supply and demand in the markets for productive services: by interest rates, land rents, profits, and wage rates, all of which go to determine the income of those who participate in the market.

Therefore, each commodity and each service has a "price." Workers receive money for what they sell (their skills), and use this money to buy what they need or want. In this system, consumers reign and vote with their dollars to get services, or to purchase the things they want. The dollars of consumers compete against each other for services or commodities, and the people with the most votes theoretically end up with the most influence on what gets produced and where those goods go.

If more is wanted of any commodity, the suppliers will receive a large number of new orders. This increased demand will cause the price of the commodity to rise until more is produced. Similarly, if more of a commodity is produced than people will buy at the last quoted market price, the commodity's price will drop until the excess is absorbed. Since the commodity is now selling for a lower price, producers will be inclined to produce less. Eventually, the supply and demand situation will equalize, and that price where this occurs is called the equilibrium price.

There exists at any one time a relation between the market price and the quantity demanded of that commodity. This relation between price and quantity purchased is shown graphically by the "demand schedule" or "demand curve." The demand curve for each individual mineral at any point in time will be determined by the technological level and scale of economic activity in an economy, by the number of consumers, their tastes and affluence, and by the price of the commodity and substitute products. For nearly all goods, the demand curve will slope downwards as shown in figure 8. The higher the commodity's price, the smaller the quantity that consumers will be willing or able to purchase. If real income levels rise over time, the curve may shift outwards as consumers would be able to afford to take more of the mineral at all price levels. Alternatively, the development of a new low-priced substitute could cause consumers to switch their use, in which case the demand curve would shift markedly downwards.

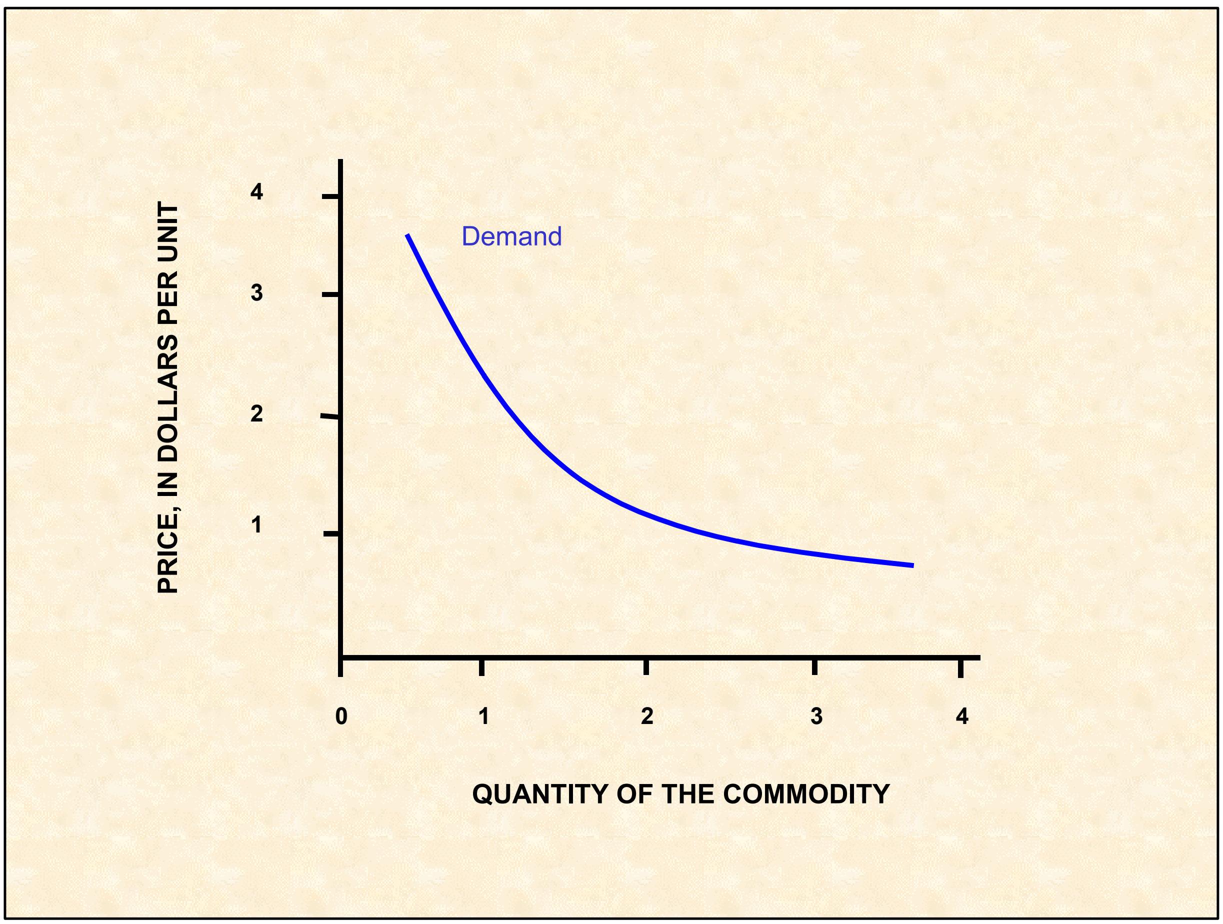


Figure 8. Demand curve.

The supply schedule (also known as the supply curve) is the relation between market price and the quantity of that good that producers are willing to supply. In a perfectly competitive situation, this would be determined by the costs of production, including normal profits and the market return on invested capital, and by the costs of transporting the material to the market. As prices rise, higher-cost producers can competitively supply materials to the market and it becomes possible to transport the resource from more and more remote production centers. This is especially true for bulk commodities where transportation costs can be substantial. In addition, at higher prices for commodities, where higher profit levels can be realized, mining companies typically take resources (capital, equipment, and workers) away from mining commodities which yield less returns and apply those resources toward discovering and mining those commodities where greater returns can be realized, increasing supply as shown by the sidebar: Prices and exploration for new mines. When prices for commodities rise, this brings greater quantities of the commodity to the market. Just as the demand curve can shift over time, shifts in the supply curve can also occur. If technological innovation reduced the cost of mining, processing, or transporting the material, then more could be supplied at all price levels. Conversely, increases in the market price of capital, freight rates, or energy costs could all act to shift the curve upwards, making less available at all price levels. As seen in figure 9, unlike the demand curve, the supply curve rises upward and to the right, from southwest to northeast.

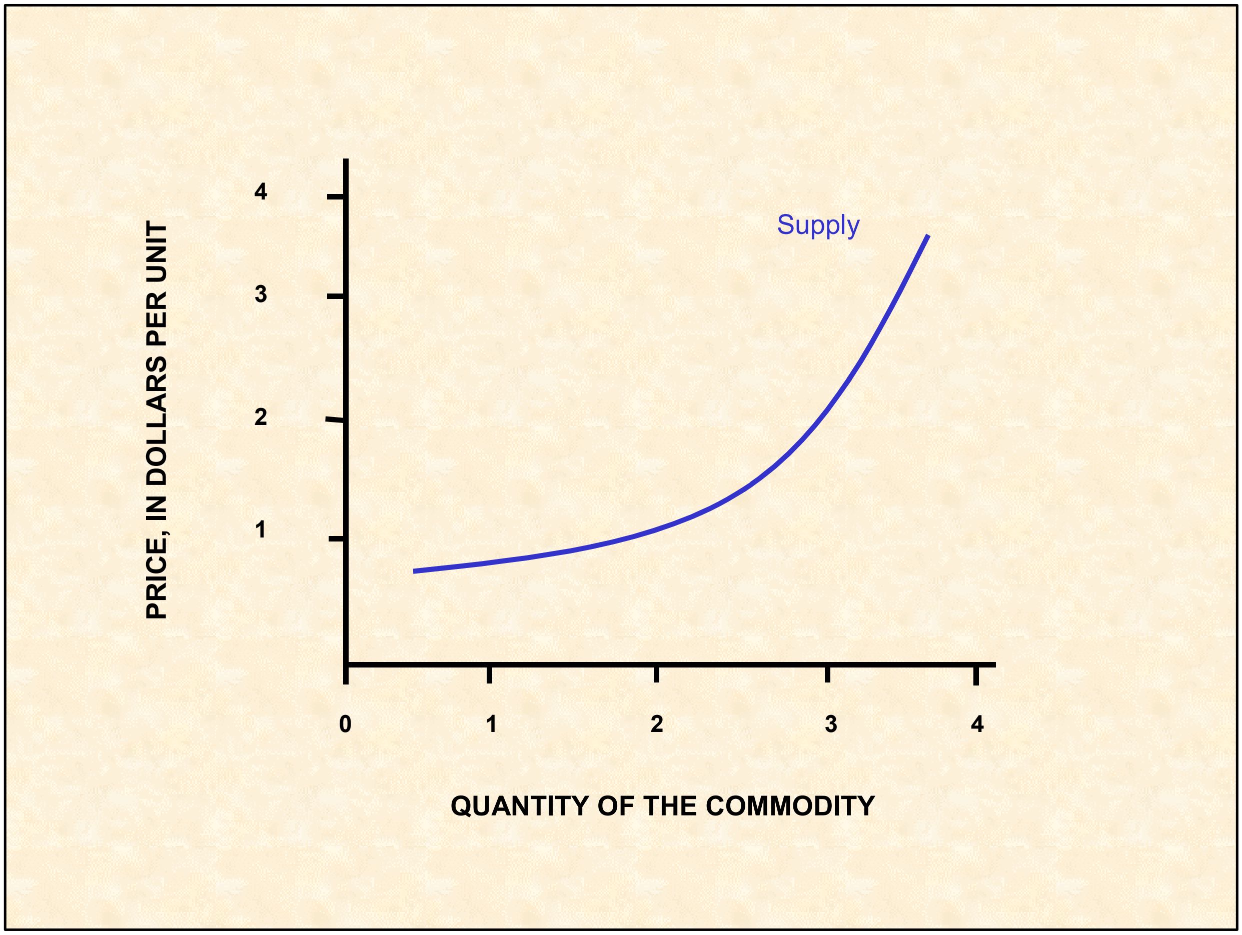


Figure 9. Supply curve.

Prices and Exploration for New Mines

—From Wilburn, 2001

Prices for some metals in the year 2000 remained near 1999 levels (gold, lead, and silver), and others inched upward from average 1999 prices (copper and zinc). Significant price increases for palladium (>64 percent) and nickel (44 percent), and a lower increase for platinum (>3 percent) resulted in some exploration companies reconsidering the mix of commodities being explored. It appears that during this period of generally low metal prices, the necessity for some exploration companies to contain costs has led them to shift their exploration focus away from areas where environmental costs may be significant or exploration more expensive, in spite of favorable policy climate or geology.

Figure 10 illustrates the distribution of reported mineral exploration budget estimates for 2000 by commodity grouping. According to the Metals Economics Group (2000) budget estimates, the principal targets for gold exploration in 2000 were in Latin America, Australia, and the United States. Gold remained the principal exploration target in 2000, although the exploration budget for gold in 2000 was 18 percent lower in nominal terms than that budgeted for gold in 1999 and much lower than the 1997 estimated budget for gold exploration. This decrease probably reflects the continued depressed gold price, which has declined steadily since 1996 and investor wariness for funding gold exploration activities while gold remained at a low price level.

Prices and Exploration for New Mines—*Continued*

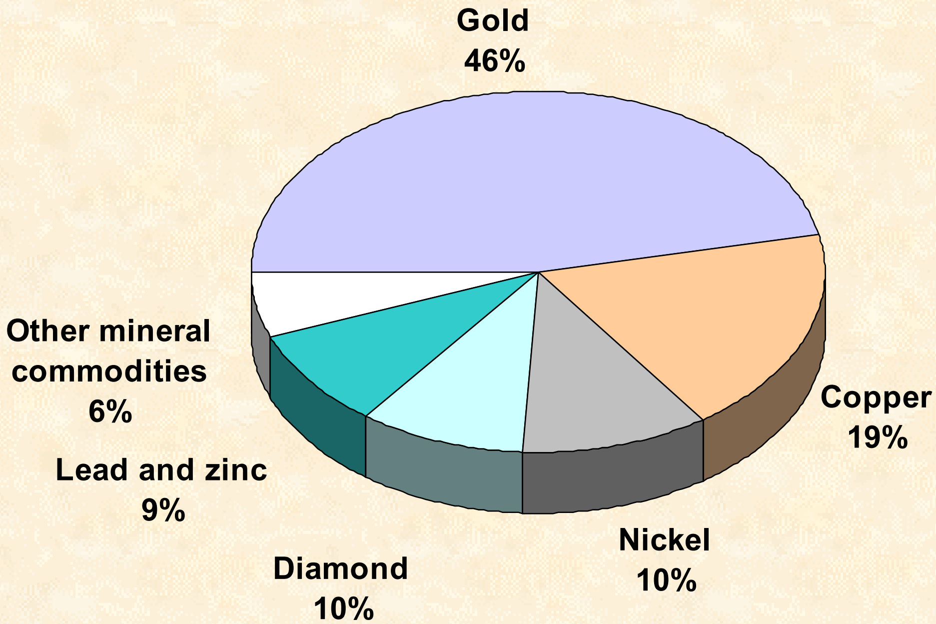


Figure 10. Distribution of mineral exploration budgets in the year 2000, by commodity grouping (data from Metals Economics Group, 2000).

The general decreasing exploratory budget trends may be attributed to changing exchange rates, continued low commodity prices, and tighter company budgets. The general decrease in mineral exploration budgets in the year 2000 continues a downward trend first noted in 1998, and marks a departure from the 1993-97 trend of increases reported by the Metals Economics Group, 2000.

In theory, the equilibrium price, that is, the only price that can be sustained, is that at which the amount willingly supplied and amount willingly demanded are equal. Competitive equilibrium according to theory must be at the intersection point of the supply and demand curves. When the two schedules are plotted on the same axis, their relationship shows surplus, equilibrium and shortage (figure 11). If more was supplied than was demanded at a given price level, the market price would fall and the highest-cost producers would be forced to cut or stop production.

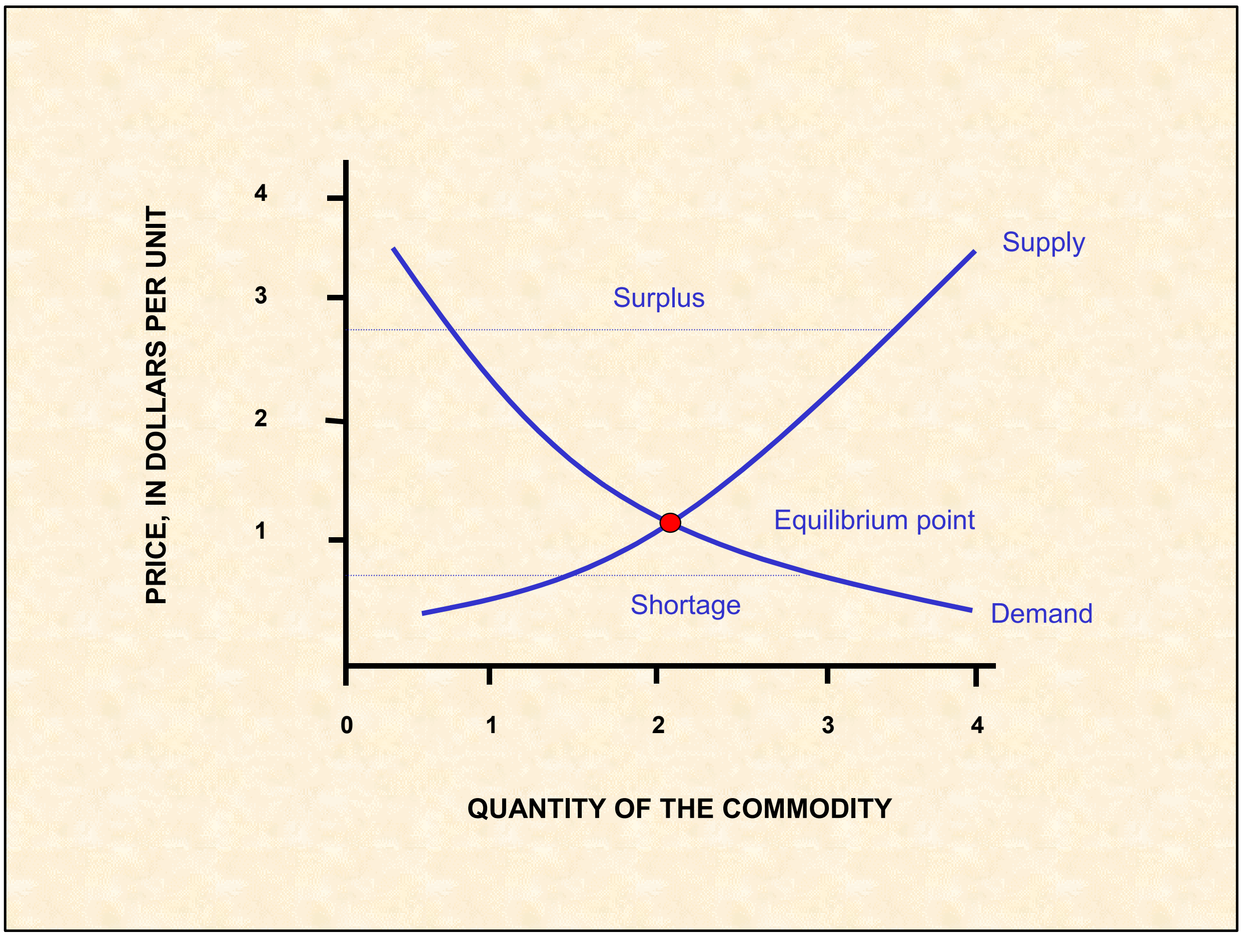


Figure 11. Supply-demand curve showing the equilibrium point.

As people’s desires and needs change, as technologies used to produce the goods improve, and as supplies of natural resources and other productive factors change, the marketplace commonly adjusts by registering changes in the prices and the quantities sold of commodities. The equilibrium market price and quantity traded of a good will not change as long as both the demand and supply curve for the item does not shift. However, a shift in one or both of these curves could lead to the establishment of a new equilibrium position.

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine

World War I generated the first appreciable uses of molybdenum, when it was substituted for tungsten in high-speed steels and used as an alloying element in certain steels for military armament (Blossom, 1985, p. 522). Prior to this time, molybdenum was a laboratory curiosity, a metallic element that had no use.

As World War I raged in Europe in 1914, British, French, German, and Russian armament manufacturers competed to buy all available molybdenum (Voynick, 1996, p. 14). Throughout 1914 to 1916, the annual average molybdenum concentrate price, in terms of dollars per kilogram of molybdenum content, remained at $2.24 as shown by figure 12. This higher price (from $0.45/kilogram in 1912) triggered commercial molybdenum mining in the United States. Development of the Climax deposit, the world’s largest, later proved the viability of high-tonnage extraction of relatively low-grade ore and established the United States as the leading producer of molybdenum (Blossom, 1985, p 522).

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

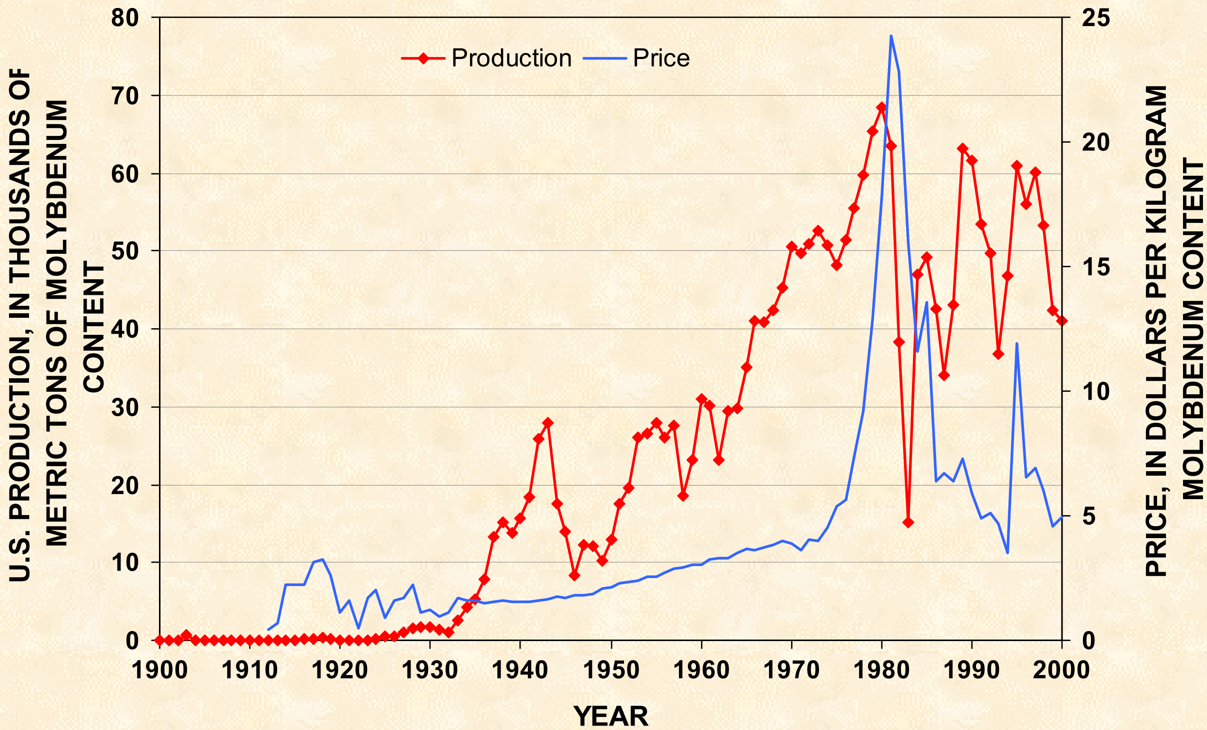


Figure 12. U.S. molybdenum concentrate production and price, 1900 – 2000 (data from Kelly and Magyar, 2001).

The end of World War I in 1918 signaled changes for the molybdenum market. Output terminated in 1920 in the United States and most other countries because nonmilitary consumption of molybdenum was insufficient to support continued production. However, industrial efforts to develop peacetime applications, primarily as an alloy in steels and cast irons, were successful, and by the mid-1920s, demand exceeded that of the war years (Blossom, 1985, p. 522). Operations resumed at the Climax deposit in 1924. By 1930, world output of

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

molybdenum totaled 4.2 million pounds, of which, the United States and the Climax Mine accounted for about 89 percent and 73 percent respectively (Blossom, 1985, p. 522). During the late 1930s, all primary foreign customers for molybdenite concentrate (France, Germany, Great Britain, Japan, and the Soviet Union) prepared for war and bought huge amounts of molybdenum (Voynick, 1996, p. 163). Exports of molybdenum, principally in the form of concentrates, provided an important outlet for the domestic molybdenum industry. Export data are not available prior to 1939 since molybdenum was not classified separately in export statistics; but according to Ridgway and Davis (1939, p. 618) it appears that 50-75 percent of the domestic production was exported.

In 1939, President Franklin D. Roosevelt asked for a voluntary 'moral embargo' of war-related materials to nations then using aircraft to bomb civilian populations (Voynick, 1996, p. 163). Those nations were Germany, Japan, and the Soviet Union (Voynick, 1996, p. 164). As shown in figure 13, export sales in 1939, the first year for which data are available, were 6,380 tons. In 1940 shipments to Belgium, Czechoslovakia, Germany, Hungary, and Norway ceased abruptly and those to Japan, Netherlands, Sweden and U.S.S.R. dwindled to small percentages of the 1939 exports (Ridgway and Davis, 1941, p. 611). Shipments to the United Kingdom were little more than half of the 1939 total, but exports to Canada, France, and Italy rose appreciably (Ridgway and Davis, 1941, p. 611).

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

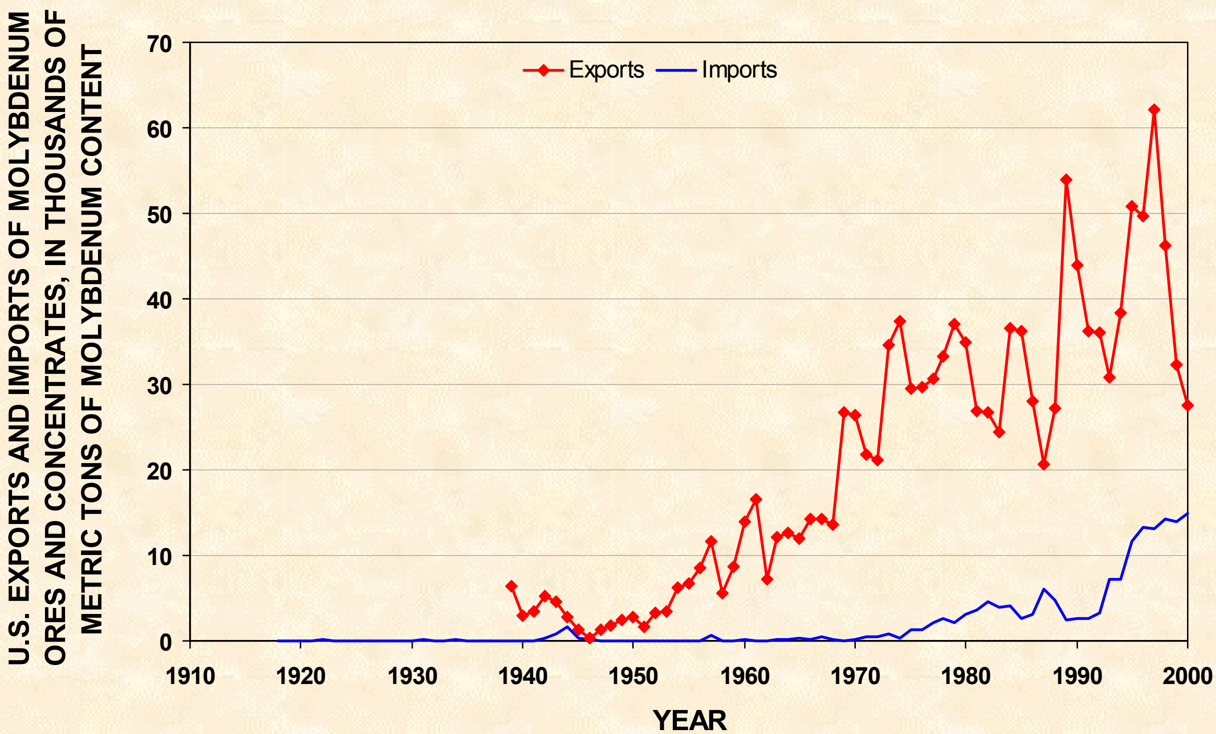


Figure 13. U.S. exports and imports of molybdenum ores and concentrates, 1918-2000 (data from Kelly and Magyar, 2001).

In 1941, as in 1940, shipments of molybdenum concentrates from the United States to foreign countries represented about 19 percent of domestic production, compared to 67 percent in 1939 (Betz and van Siclen, 1943, p. 627). As has been the case for a number of years, the Climax Molybdenum Co. was the world's leading producer of molybdenum, and in 1941 it supplied 69 percent of the domestic output (Betz and van Siclen, 1943, p. 627).

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

In December of 1941, under authority of the Executive War Powers Act, President Roosevelt placed American industry under the direction of the War Production Board; a quasi-military agency empowered to control military supply and distribution and to maximize industrial production (Voynick, 1996, p. 170). Global war made foreign supplies of such alloying metals as tungsten, chromium, nickel, manganese and vanadium scarce and unreliable, and the ready availability of tough molybdenum steels was obviously vital to victory (Voynick, 1996, p. 170). But molybdenum was unique from the standpoint of supply, for no other metal in the world was so utterly dependent upon a single mine source – the Climax Mine (Voynick, 1996, p. 170). In January 1942, the War Production Board served notice that it had assigned the Climax Mine the highest operating priority of any mine in the United States (Voynick, 1996, p. 170). By order of the War Production Board, the Climax Mine would immediately achieve and maintain maximum production (Voynick, 1996, p. 170). In an effort to assist in metals production in the United States, the War Production Board closed all primary gold mines in order to redirect men and mining materials to the production of iron, coal, and base and alloying metals. In addition, the War Department released 4,000 experienced miners from military service (Voynick, 1996, p. 173).

Even with American industry working around the clock, a full year passed before molybdenite ore mined and milled at Climax could be converted, alloyed into steels, manufactured into armament, and shipped to combat zones (Voynick, 1996, p. 191). When World War II finally

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

ended in August 1945, the Climax Mine produced 5,000 short tons per day as it headed for uncertainties of a deep postwar depression (Voynick, 1996, p. 192). Over the following years, Climax, which produced 75 percent of the world's molybdenum supply, remained the dominant influence on market price (Voynick, 1996, p. 193). Following the Korean War (1950-1953), the United States embarked upon an unprecedented, prolonged period of industrial growth and economic prosperity interrupted only briefly by the recession of 1958 (Voynick, 1996, p. 259). In just 10 years (1960-70), annual world mine production of ores and concentrates doubled as shown in figure 14. During the 1960s, researchers found new uses in moly-sulfide and moly-grease lubricants, special corrosion- and abrasion-resistant alloys, and high temperature alloys for rocket engine parts for the space program (Voynick, 1996, p. 260). Apparent consumption of molybdenum in the United States rose throughout the 1960s as shown in figure 15. Throughout the 1960s prices steadily rose and then rose more rapidly in the mid-1970s. By 1981, the annual average molybdenum concentrate price had increased to $22.28/kilogram molybdenum content (Kelly and Magyar, 2001) as shown in figure 12.

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

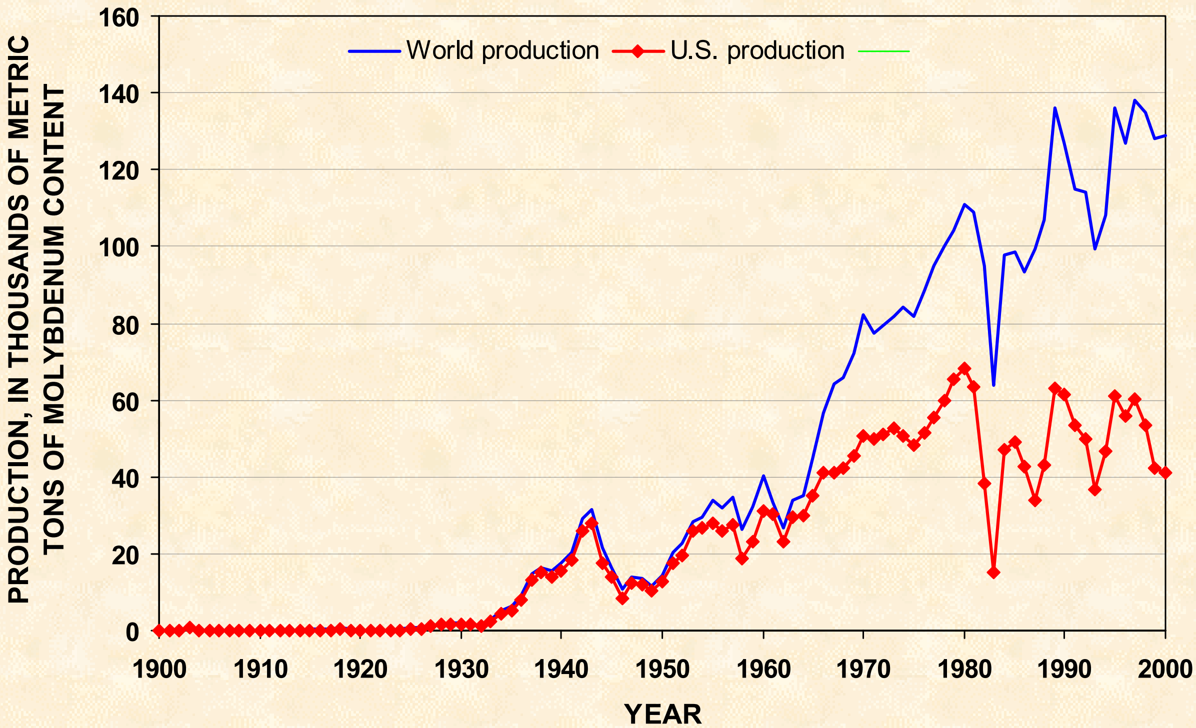


Figure 14. U.S. and world production of molybdenum concentrate, 1900-2000 (data from Kelly and Magyar, 2001).

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

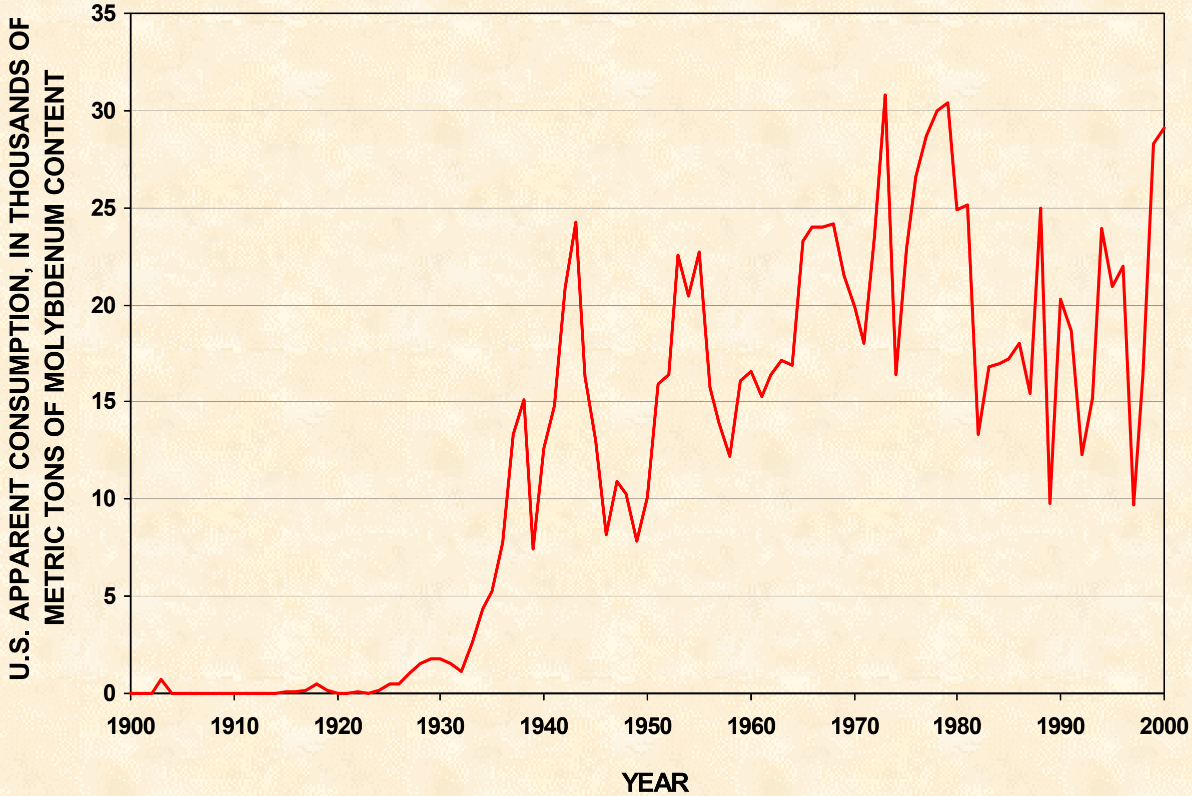


Figure 15. U.S. apparent consumption of molybdenum, 1900-2000 data from Kelly and Magyar, 2001).

During the 1970s, the molybdenum market changed more rapidly than at any time since the erratic years of World War I (Voynick, 1996, p. 311). Analysts had warned of a developing oversupply situation in the molybdenum market as early as 1978, but few, if any, gauged the full extent of market instability. The trouble began when the 1973-74 OPEC oil embargo spurred

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

demand for high-molybdenum oil-field steel, disrupting the projected market growth patterns. The market tightened further in 1975 when the Federal Government terminated its molybdenum stockpile disposal sales. Higher prices attracted the attention of competition, namely copper mining companies, which could recover by-product or co-product molybdenum (Voynick, 1996, p. 312). As prices offered no prospect of flattening, more molybdenum consumers turned to alternative alloying metals (Voynick, 1996, p. 315). American mining companies, burdened by lower-grade ores, escalating environmental restrictions, and high labor costs, was hard-pressed to compete with higher-grade ores and cheap labor of foreign mines (Voynick, 1996, p. 315).

The depth of the worsening recession became fully apparent in summer of 1981. The inflationary, soaring oil prices of 1980 began collapsing, killing the drilling boom along with demand for high-molybdenum oil-field steel. Automotive and general manufacturing slowed dramatically; U.S. steel companies, operating at half-capacity, laid off thousands of workers. The molybdenum mining industry suddenly faced the worst possible scenario: Burdened with record stockpiles (figure 16) and a huge overproduction capacity, the molybdenum market began falling apart (Voynick, 1996, p. 316). In one year, from 1982 to 1983, the average annual molybdenum concentrate price dropped from $22.80/kilogram to $15.97 per kilogram (Kelly and Magyar, 2001). At this point in time, the Climax Mine was shut down – layoffs began in January of 1982 as a result of the continued deterioration of the molybdenum market (Voynick, 1996, p. 319).

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

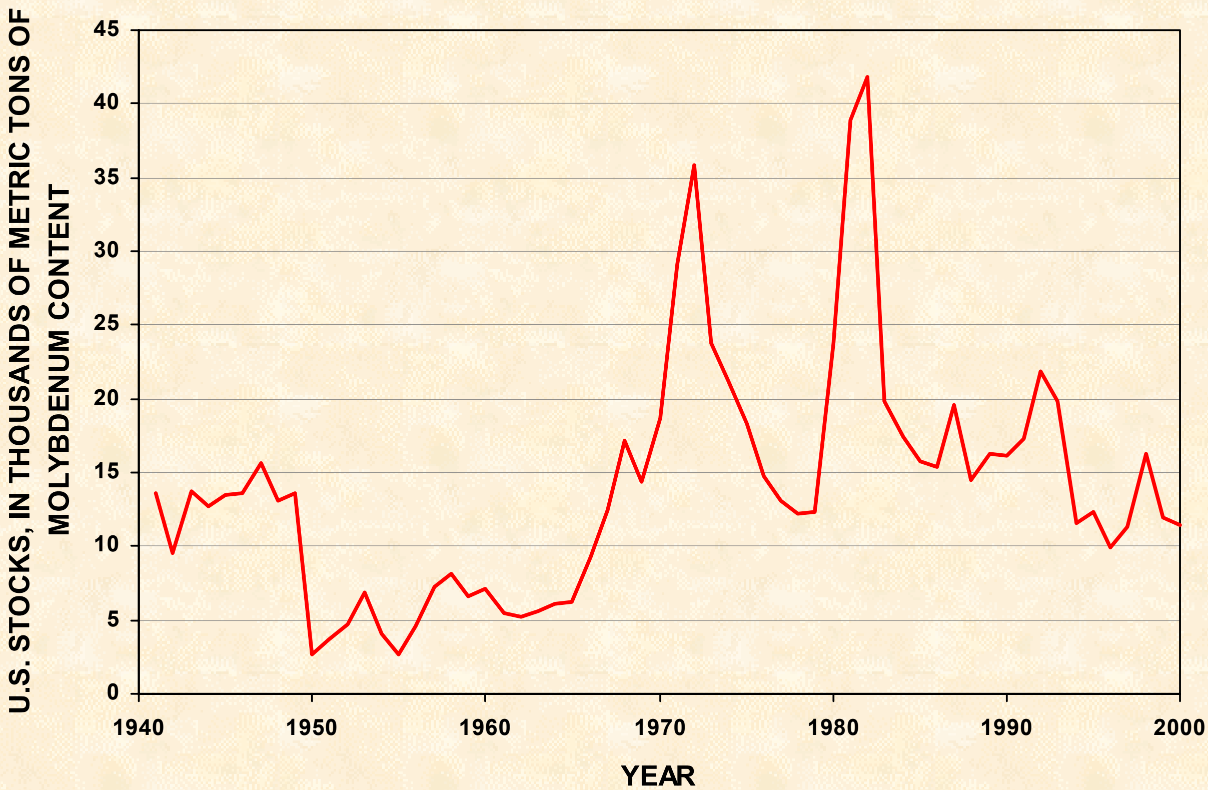


Figure 16. U.S. stocks of molybdenum, 1941-2000 (data from Kelly and Magyar, 2001).

In just 4 years, overall molybdenum apparent consumption in the United States declined 56 percent from 30,000 tons in 1978 to 13,300 tons in 1982 (Kelly and Magyar, 2001). The decline occurred mainly because steel makers had replaced molybdenum in standard alloys with vanadium and other alloying metals (Voynick, 1996, p. 328). Copper mines now supplied most of the market with co-product and by-product molybdenum. The Climax Mine had become a

The Molybdenum Story – Creation of Markets, Price Changes, and the Climax Mine—*Continued*

'swing producer' – they would produce only when warranted by market conditions (Voynick, 1996, p. 328).

The U.S. production of molybdenum reached a peak of 68,400 tons in 1980. The lowest U.S. production since 1980 was 15,200 tons in 1983. At the end of the 20th century, U.S. production was trending downward. Molybdenum was being used in many more applications, such as stainless steel, catalysts and lubricants, with reported consumption averaging over 20,000 tons per year in the last decade of the century (Blossom, 2002, p. 53.1).

Bartlett Mountain represents the history of the Climax Mine as well as its future (Voynick, 1996, p. 340). Even after mining 470 million short tons of ore, huge amounts of ore still remain in place (Voynick, 1996, p. 340). Although underground workings and reserves have been written off, open pit reserves are estimated at 137 million short tons with an average grade of 0.317 percent molybdenite (Voynick, 1996, p. 340). Contained within those ore reserves are 400 million pounds of elemental molybdenum worth in excess of a billion dollars (Voynick, 1996, p. 340).

Price

Mineral prices are an important driver of mineral supply. In economic theory, the market price is at the intersection of the supply and demand curves. It is at the equilibrium point where the quantity demanded equals the quantity supplied. Price changes may result from variations in supply or demand or both. Appendix A contains additional examples of how shifts in demand and supply can affect equilibrium price and quantity.

When a commodity's price increases, deposits may become economically viable and allow new deposits to be developed or previously shutdown operations to reopen. Such activities can supply more materials to the market. Alternatively, decreasing commodity prices can result in operations shutting down because they are no longer profitable as discussed in the sidebar: Prices and Closing Mines.

The demand for, and prices of, many metals are characteristically highly volatile. In economic theory a demand change would affect price levels, and this would immediately cause the quantity supplied to change in response. Therefore, shortage and surpluses (and the associated price fluctuations) should be short-lived features. However, there are four major imperfections within pure economic theory relative to the operation of the minerals sector that combine to inhibit a quick market response and act to compound the problems of the cyclical volatility of prices. It should not be assumed that those minerals markets with relatively stable price trends are less imperfect and conform more closely to the idealized, perfectly competitive market model; in fact rather the reverse is true (Rees, 1985, p. 127).

First, since it normally takes at least four years to bring new supply or mineral-based materials capacity on-stream, shortages can persist resulting in major price rises. Second, once capacity exists and fixed costs have been incurred, producers are reluctant to curb output as long as some contribution is being made to overhead. Third, price variations are magnified by the nature of demand for some minerals. The major end-uses for a number of metals are the construction industry and the production of machinery, commercial vehicles and other intermediate goods, all of which are more profoundly affected by recession than other sectors of the economy. The effects of recession will be magnified for the producers of intermediate goods; in their case the recession will not only be deeper, but also more prolonged, since consumer demand has to pick up before new orders for plant and machinery are made. The fourth important factor creating cyclical volatility is the nature of many of the open or auction markets for minerals. In most cases, these are strictly marginal, that is they deal with only a fraction of total production and sales (Rees, 1985, p. 127).

Prices and Closing Mines

Although there are additional factors such as environmental, and societal issues that affect the decision to cease a particular operation, both a commodity's selling price and the costs to provide that commodity are integral parts of the final determination. The following examples illustrate economic impacts upon the mining industry as commodity prices decreased and mining industries strived to lower their operating costs.

Phelps Dodge Corp., the largest U.S. copper producer, trimmed output by a third and eliminated 1,650 positions to cut costs and streamline operations in 1999. The announcement came against the backdrop of slumping copper prices, which suffered for the better part of two years due to decreased demand in the Far East. It also follows a similar announcement recently by Australian

Prices and Closing Mines—*Continued*

resource company Broken Hills Proprietary Co. (now BHP Billiton) to shutter its U.S. operations (Excuria, Inc., 1999§).

The Mesabi Iron Range is located in northern Minnesota. The mining industry in this region was originally built on the raw ore that lay just beneath the surface. From the 1890s through the World Wars, the Mesabi Iron Range was the leading producer of iron ore in the United States. But the mining that fueled the Industrial Revolution and the war effort left the area tapped of its raw iron reserves by the early 1950s. What saved the Mesabi Iron Range at this time was taconite, the very hard rock that encases soft-ore deposits and contains 20 to 30 percent iron. In the 1950s, a complicated process was developed to separate the iron from the rock. Taconite is blasted out of the ground and loaded onto large trucks and taken to a mill. There, the rock is processed into a powder (finer than flour) and then passed through a magnetic separator so that the iron can be removed. The iron is then wetted, mixed with clay and lime, and baked into marble-sized pellets that are about 80 percent iron. This resulted in a consistent product that steel makers preferred. This mechanized process, however, required continuous improvements to maintain a competitive economic edge and over time, these technological upgrades gradually reduced the number of workers. When taconite was first produced over 30 years ago, the largest mine in Minnesota produced 14 million tons of pellets a year with 4,200 workers. In 1999, 16 million tons were produced with only 1,500 workers. In recent years, Minnesotans are again faced with new mine closures as the modernization of the steel industry has led to more efficient furnaces and decreased use of taconite. The emergence of these processes, cheaper labor, and

Prices and Closing Mines—*Continued*

rich iron-ore deposits in other countries are drawing mining companies elsewhere as domestic steel producers have chosen to relocate their new facilities outside the United States (adapted from The Christian Science Monitor, 2000, p. 1). These two examples have a common theme. Economics are major drivers of the mining industry.

Recycling, a significant factor in the supply of many of the metals used in our society, provides environmental benefits in terms of energy savings, reduced volumes of waste, and reduced emissions associated with energy savings (Papp, 2002, p. 63.1). For commodities that are recycled, rising prices tend to bring additional scrap to the market place. In some cases, significantly higher prices can bring large amounts of material to the market, as is the case for silver in 1980, see the sidebar: Higher Silver Prices and Increased Recycling.

Higher Silver Prices and Increased Recycling

Following the dramatic rise in the price of gold as a result of rising inflation in the late 1970s, the average price of silver spiked to an all time historical high in 1980 of almost $43 per troy ounce (2000 dollars) as shown in figure 17. This final surge was attributed to speculation associated with the Hunt brothers' attempt to corner the silver market (Drake, 1981). After topping out in 1980, the price of silver then fell drastically, at one point, to under $5 per troy ounce in 1982.

Higher Silver Prices and Increased Recycling—*Continued*

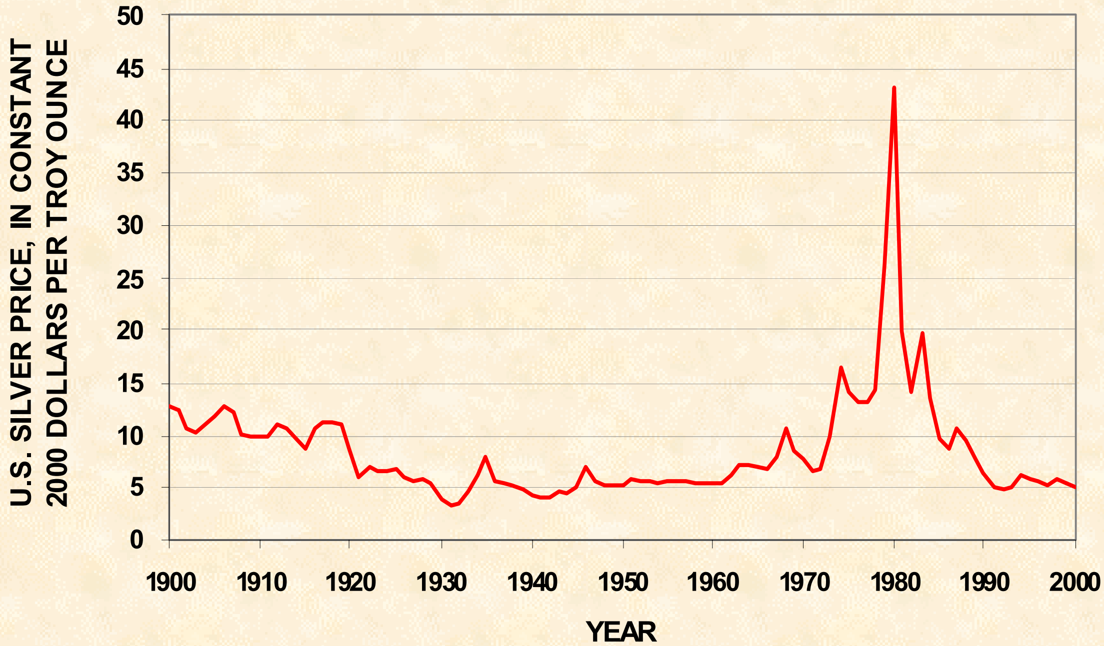


Figure 17. U.S. silver price in constant 2000 dollars per troy ounce (yearly average), 1900-2000 (data from Porter and Hilliard, 2001).

From 1979 to 1980, domestic silver production fell 18 percent, and domestic consumption of silver decreased 21 percent. These declines were attributed to strikes at production facilities and the high price of silver (Drake, 1981). The latter resulted primarily from the high degree of speculation related to the Hunt brothers' scheme. Although U.S. refinery output increased from 1979 to 1980, the input source to the refineries changed significantly. Refinery production from new scrap rose almost 79 percent and from old scrap rose 34 percent. Within the old scrap category, the coin sector increased by over 200 percent (Drake, 1981, p. 741). These major shifts in sources for silver were a result of the elevated price of silver. During 1980, as the price

Higher Silver Prices and Increased Recycling—*Continued*

of silver rose, people started selling jewelry, coins, and flatware. The higher the price of silver went, the more that entered the market from these sources as shown in figure 18.

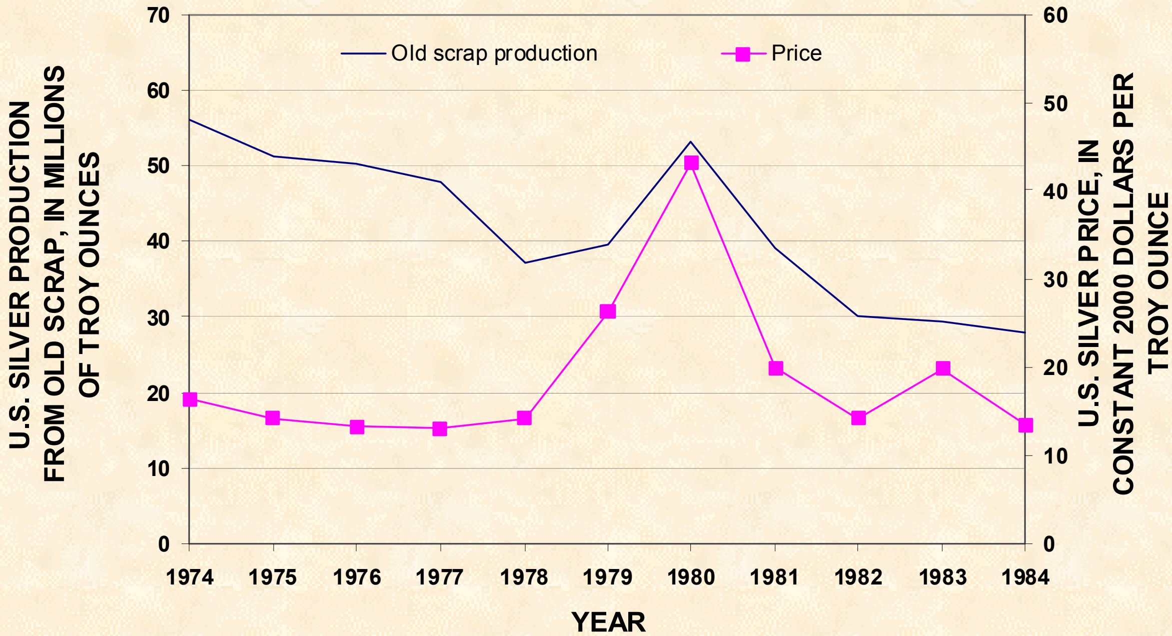


Figure 18. U.S. silver production from old scrap versus price, in constant 2000 dollars, 1974-84 (data from Porter and Hilliard, 2001).

In 1981, with the current price of silver returning to pre-speculation levels, refinery production from new scrap dropped almost 32 percent and from old scrap decreased about 26 percent. In the old scrap category, the coin sector declined by over 90 percent. More stable economic forces had again returned to the silver markets.

Historical prices

With price being such an important driver of mineral supply, how have prices of mineral raw materials fared over the long term? The U.S. Geological Survey developed price indexes for key U.S. mineral raw materials[8]. See Appendix B for the methodology and details of this price index. In spite of the fact that the use of mineral raw materials increased over the last century, the long-term constant dollar price of key U.S. mineral raw materials declined during the same period. New technologies that reduced production costs have allowed mineral production to continue even at these lower prices. These indexes were constructed in constant dollars that allow one year's prices to be compared with another without the influence of inflation.

The United States mine production composite price index (figure 19) was computed using data for the seven highest total value of production industrial mineral commodities (cement, clay, crushed stone, lime, phosphate rock, salt, and sand and gravel) and the five highest total value of production metal commodities (copper, gold, iron ore, lead, and zinc). During 2000, these commodities accounted for 88 percent of the value of industrial mineral mine production and 89 percent of the value of metal mine production in the United States as shown in table 3. Even though aluminum is produced and consumed in large quantities in the United States, it is not included in this index because the production of bauxite (the ore from which aluminum is derived) is not significant in the United States. However, a discussion of aluminum prices is included in the appendix because of the economic importance of aluminum production in the

[8] Includes the industrial mineral commodities: cement, clays, crushed stone, lime, phosphate, rock salt, sand and gravel, and the metals: copper, gold, iron ore, lead, and zinc.

United States. Figure 19 also shows the trend line of this data. The trend lines shown in the figures in this report were generated using the least squares method.

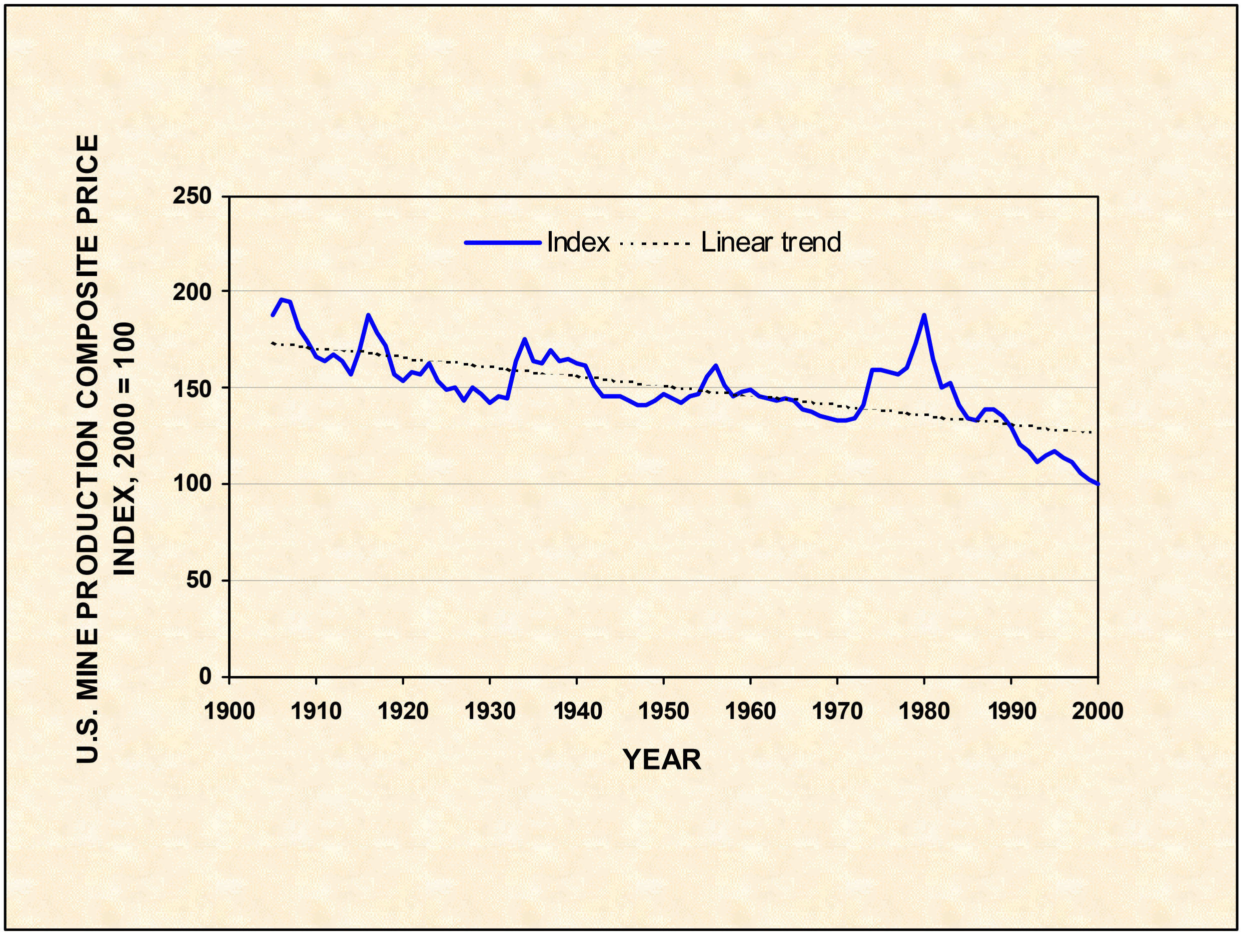


Figure 19. U.S mine production composite price index, in constant 2000 dollars, 1905-2000.

Table 3. Value of nonfuel mineral production in the United States in 2000

[Adapted from Smith, 2002]

Material	Million dollars	Percent
Industrial minerals		
Cement	6,891	23.6
Clays	1,529	5.2
Lime	1,180	4.0
Phosphate rock, marketable[1]	932	3.2
Salt	1,040	3.6
Sand and gravel	5,946	20.4
Stone, crushed	8,390	28.7
Other industrial minerals	3,292	11.3
Total	29,200	100.0
Metals		
Copper	2,810	27.5
Gold	3,180	31.2
Iron ore, usable[2]	1,560	15.3
Lead	439	4.3
Zinc	1,020	10.0
Other metals	1,191	11.7
Total	10,200	100.0

[1] The product of additional processing and condensing to the point of salability (S.M. Jasinski, U.S. Geological Survey, oral communication, 2002).
[2] Agglomerates, concentrates, direct-shipping ore, and byproduct ore for consumption (U.S. Geological Survey, 2001a, p. 83).

As table 3 shows, the value of industrial minerals production is more than double that of metals. Therefore, the composite price index is predominantly influenced by the prices of the key industrial minerals – crushed stone, cement, and sand and gravel. Overall, the trend of the inflation-adjusted prices shown in the composite price index (figure 19) dropped throughout the 20th century, declining from 185 in 1905 to 100 in the year 2000. This reduction occurred even though the use of mineral materials in the United States increased during this time frame to meet the needs of the economy. The decreasing long-term price trend is an indication that adequate sources of supply exist, competition within the industry is prevalent, and the costs of production have decreased. Detailed analyses of the composite price index in terms of industrial minerals, metals, and the individual commodities can be found in Appendix B.

Production

According to economic theory, production of mineral commodities occurs to satisfy demand. If demand for a commodity were nonexistent or decreased due to environmental regulations, prices would fall and production would decrease, (explained in sidebar: Mercury's Declining Production). If production exceeds the amount demanded, a surplus situation is developed and prices usually decrease to reach a new equilibrium point. In theory, production only occurs to meet demand. The fact that production of mineral commodities has been able to keep up with or exceed the demand for minerals is, in part, an indicator that based on the past, scarcity has not been an issue for mineral resources in general.

Mercury's Declining Production

In the year 2000, it was estimated that 1,050 tons (64 percent) of the world's mercury mine production was to be split evenly between Spain and Kyrgyzstan. The latter represents 86 percent of the former Soviet Union's production. Other countries that are major producers include Algeria and China. The trend in world mercury production continues to decline because of decreased consumption and lower prices.

Mercury's Declining Production—*Continued*

Mercury production from mining in the United States has been historically small compared to other countries. The last operating mercury mine in the United States (McDermitt Mine, Nevada) closed in 1990. Currently, the only domestic mercury recovered from mining is from byproduct production from gold and silver mines in several western states, mostly Nevada. Mercury occurs with gold and silver ores and is usually recovered to avoid contamination of the environment during gold processing.

Since 1991, recovery of secondary or recycled mercury has surpassed mercury production in the United States. Because of disposal issues, legal restrictions and potential liability, recovery of mercury from wastes, in some cases, is more cost effective than disposal. The last time data was reported, in 1997, mercury recovered by recycling (from discarded and obsolete products such as batteries, fluorescent lights, dental amalgams, control instruments, and electrolytic wastes) and U.S. consumption was roughly in balance at slightly under 400 tons. The amount of mercury recovered from recycling may increase as a result of increasing government regulation.

Historically, mercury had many uses and appeared in many products. Consumption declined as the toxic nature of this metal became better understood and substitutes were developed mostly as a result of legislation requiring its elimination from certain products. As an illustration, total domestic mercury consumption in 1970 was over 2,100 tons, but by 1997 it dropped to under 400 tons. Dissipative mercury uses, such as in paints, have also shown dramatic reductions in the last decade. Mercury use in paint was about 200 tons in 1985, but was phased out completely

Mercury's Declining Production—*Continued*

in the United States by 1992. In addition, mercury use has been essentially eliminated from household batteries. Since 1989, the largest U.S. consumption of mercury has been in the production of chlorine and caustic soda. This industry uses approximately one third of the total domestic consumption. Modern plants have greatly reduced or completely eliminated the need for mercury and the remaining mercury-cell plants are doing a better job of recycling within their own systems. In 1997, it was estimated that mercury consumed in this application declined over 50 percent since 1989. (Adapted from Sznopek and Goonan, 2000)

There are four main economic factors which influence where minerals will be produced:

- The existence of an ore body of the appropriate tonnage and grade.
- The location, size, and composition of markets for the mined product.
- The costs of production including the need for infrastructure.
- The costs of transporting the mined material to market.

As markets have changed in their relative importance, so too has the location of the least-cost mineral production sites. The growth over the last 50 years in the number of mineral producers throughout the world and the changes in their relative importance in part, at least, reflect the reduced concentration of mineral consumption. Iron ore mining provides a good illustration of this. In 1950, the United States dominated world iron ore production, producing 40 percent of the world total and consuming nearly 44 percent of the world total (Melcher, 1953, p. 615). But by 2000, the United States produced only approximately 6 percent of the world total and consumed only about 8 percent of total world production (Kirk, 2001, p. 82). Moreover, although the advanced nations still dominate world steel consumption, industrialization in many parts of the lesser-developed countries further broadened the range of potential ore markets. As a consequence, the United States has declined in relative importance as an ore producer and a wide range of new ore sources have found profitable market outlets. Countries such as Australia, Brazil, China, India, and Russia, which were either small or non-producers in the 1950s, are today major supply sources. Australian production is now 158 million tons per year compared with just over 2 million tons in 1950 (Kirk, 2001, p. 82, and Melcher, 1953, p. 643). Much of this increase in Australia is attributed to the rapid expansion of the Japanese market.

Favorable Political and Economic Factors Required in Recovering Mineral Deposits – Congo (Kinshasa)

Markets function within specific economic and political systems. Supply and demand theory explains how the market system works given certain assumptions. These assumptions include the ability of producers and consumers to make free, rational, and informed decisions. When economic and social order breaks down, even a country with a wealth of resources will not be able to benefit from its resource endowment. The Democratic Republic of the Congo [Congo (Kinshasa)] is one such example.

In 1985, the state-owned mining companies Generale des Carriers et des Mines du Zaire (Gecamines) and Societe de Development Industriel et Minier du Zaire produced about 7 percent

Favorable Political and Economic Factors Required in Recovering Mineral Deposits – Congo (Kinshasa)—*Continued*

of global copper mine production, 62 percent of global cobalt mine production, and about 1 percent of world zinc mine output. By 2000, Congo (Kinshasa) produced less than 0.5 percent of global copper mine production, approximately 20 percent of global cobalt mine production, and zinc production dropped by over 90 percent. These acute decreases in mineral output from Congo (Kinshasa) during this 15-year period were a result of a sequence of events that were unpredictable, but the impacts on their mining industry linger today.

During the early 1990s, the output of copper and cobalt declined precipitously as production was only 10 percent of capacity. The fall in output was attributable to the collapse of the Kamoto underground mine in 1990, the flooding of the Dikuluwe and Kova open pit mines in 1991, and the rioting that damaged Gecamines' production facilities in 1992. In addition, the redirection of sales revenue by the Government prevented Gecamines from spending money on maintenance and reinvestment. After 1995, the fall in copper and cobalt prices exacerbated Gecamines' difficulties and two civil wars (1996-97 and 1998-2002) discouraged foreign investors from providing the capital that Gecamines needed to maintain or upgrade its facilities. In early 2002, decaying national infrastructure and the lack of money for fuel, spare parts, and such process reagents as sulfuric acid further hobbled Gecamines' operations. The result of these problems was that potential foreign investment of more than $2 billion in the minerals sector remained on hold.

Favorable Political and Economic Factors Required in Recovering Mineral Deposits – Congo (Kinshasa)—Continued

The plight of Congo (Kinshasa) demonstrates that having rich mineral resources alone is no guarantee of the success of a country's mining sector. Congo (Kinshasa) is a country with substantial high-grade minerals deposits, but has been unable to utilize this advantage because of political and economic factors. In the future, Congo (Kinshasa) may be able to revive its minerals sector with the implementation of a recently signed peace agreement and if the introduction of a new mining code succeeds in encouraging the flow of capital back into its mining industries. (Adapted from Coakley and Yager, 2002)

Historical production

Production indexes for raw mineral materials over the last century have been calculated by the USGS. These indexes incorporate the same mineral commodities that were used to develop the price indexes.[9] Appendix C explains the methodology and details of the production index. The U.S. composite raw mineral production index is shown in figure 20. This index, similar to the price index, represents almost 90 percent of the value of domestic production of industrial minerals and metals. The peaks and troughs of the production index reflect major international conflicts and other economic events. There was a major downturn during the Great Depression of the 1930s when raw material demand dried up. A peak was reached during World War II when many types of materials were needed to construct military equipment. The index bottomed

[9] Includes the industrial mineral commodities: cement, clays, lime, phosphate rock, salt, sand and gravel, stone-crushed, and the metals: copper, gold, iron ore, lead, and zinc.

again at the end of the war due to a buildup of stocks that was followed by the post-war economic boom during the late 1940s and early 1950s as consumers' demand rose. This generally upward trend of the U.S. raw mineral production index continued until there was another major decline caused by the oil crisis of the early 1970s. Mineral production returned to earlier levels through the rest of the 1970s eventually turning down again in the recession of the 1980s. After this lull in 1982, mineral production rose to new heights with the economic prosperity at the end of the 20th century. Production indexes for industrial minerals, metals, and individual commodities comprising these categories can be found in Appendix C.

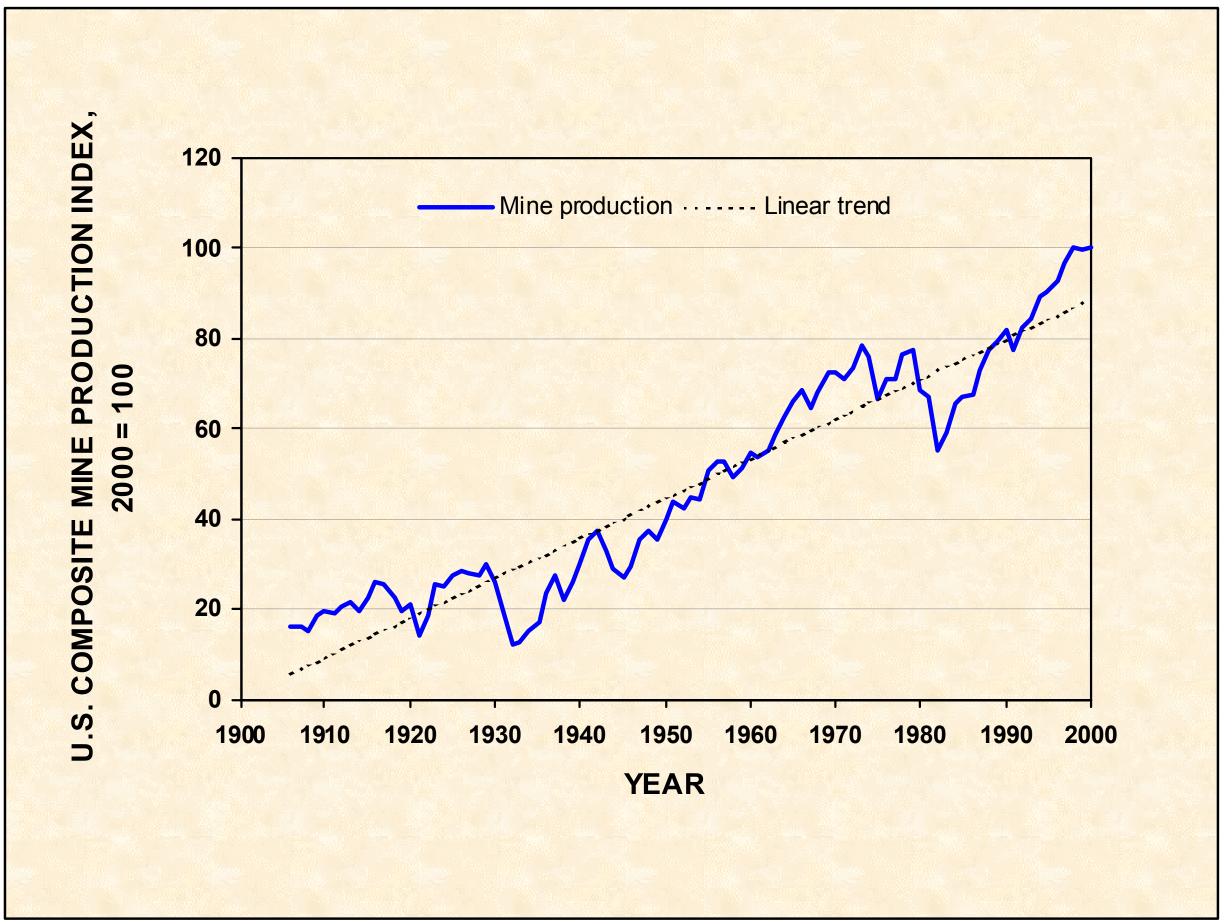


Figure 20. U.S. composite mine production index, 1906-2000.

The U.S. composite raw mineral production index has an increasing long-term trend, exhibiting nearly a 3 percent average annual growth rate over its 94-year span. In contrast, during its 95 year history the composite price index exhibited an annual average decline of slightly more than one half of a percent. How can the production index increase over this time period while the price index, a major driver of mineral supply decline? Such factors as the development of giant mining trucks, faster and more efficient conveyor systems, and other technologic advancements, as well as the discovery of additional large-scale economic deposits led to reduced costs of production. These lower costs of production, plus an increased global supply contributed to decreased prices.

Globalization

Throughout the 20th century, the speed of communication has increased and the transportation of materials has become more cost effective. Production technology has constantly improved, and accessibility to worldwide labor sources and markets has grown as a result of international free trade agreements such as the North American Free Trade Agreement. These are some of the factors that have contributed to the globalization of mineral supply.

Globalization refers to a market system that extends beyond national borders and creates international competition for all materials. Globalization results in part from technological advances that have made it easier and quicker to complete international transactions for trade flows. It means greater access to technology, cheaper imports, and larger export markets and offers greater opportunities for trade in more and larger markets around the world.

Historical imports and exports in the United States

As the United States' economy continues to grow, imports have expanded, reflecting increasing U.S. consumption. Figure 21 shows total U.S. imports and exports of all goods. Since the early 1980s, the gap between imports and exports continues to widen as the United States economy becomes more dependent on and integrated within global markets.

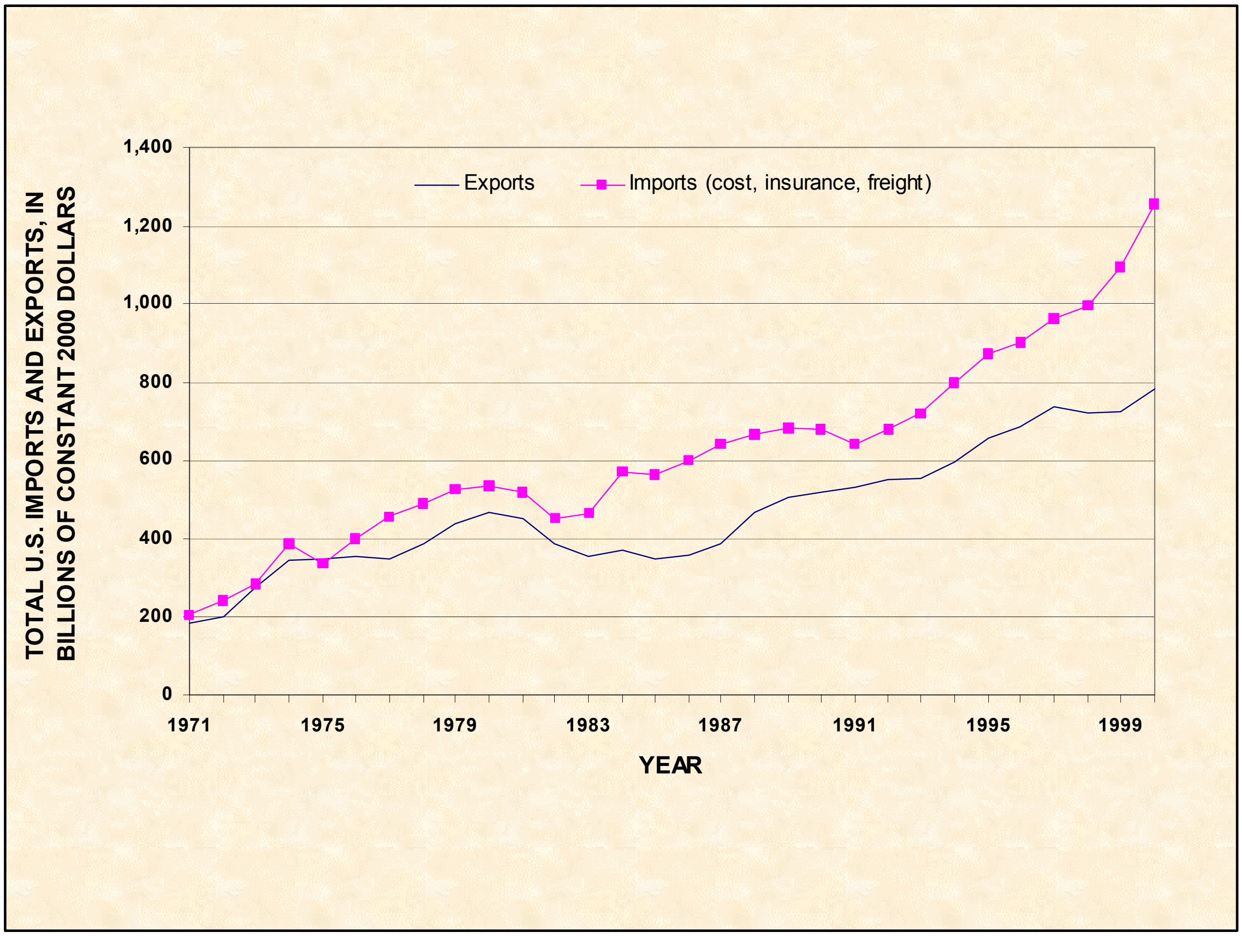


Figure 21. Total U.S. imports and exports in constant 2000 dollars, 1971-2000 (data from International Monetary Fund, 2001).

Imports to the United States of mineral-based materials originate from all over the world. Figure 22 demonstrates the global nature of mineral-based material imports into the United States. This figure is the result of several factors of which location of mineral-based materials and extraction costs are the major factors.

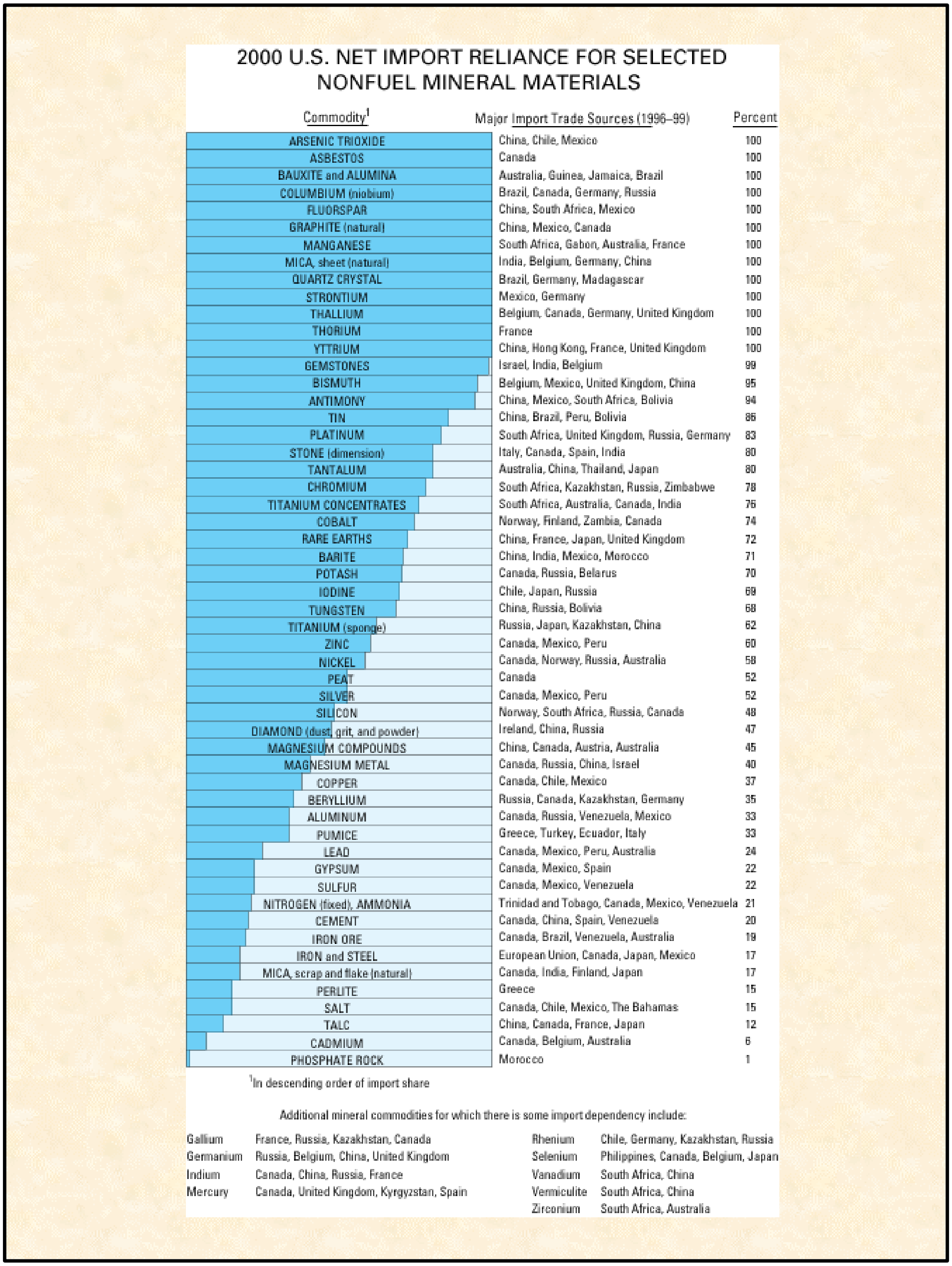


Figure 22. 2000 U.S. net import reliance for selected nonfuel mineral materials (U.S. Geological Survey, 2000a).

First, mineral-based materials production must take place where the mineral deposits exist. Processing sites may be close to, or far away from, the main use of production areas. In some cases, it can be economically advantageous to locate processing away from the production or use site. For example, vast quantities of metallurgical grade bauxite are mined and converted to alumina in Australia. The alumina is then shipped to the Pacific Northwest of the United States for processing into aluminum because of the energy-intensive nature of this process and the region's abundance of low-cost hydroelectric.

Second, costs of production play a significant role in shaping figure 21, total U.S. imports and exports. Some countries are able to produce their commodities at a lower cost than other countries – either through natural endowment of better quality deposits or lower production costs by factors such as lower energy, labor, and taxes. The development of lower cost sources displaces production in higher cost areas. If these high cost areas are the major consumers, international trade increases. Given these circumstances, mineral-based materials are heavily traded internationally.

In the year 2000, total U.S. imports (cif)[10] were valued at $1,257 billion and exports were $781 billion (International Monetary Fund, 2001). U.S. imports and exports of metal ores and concentrates, as well as raw industrial minerals totaled $5 billion in 2000 (U.S. Geological Survey, 2001a, p. 6). Imports of raw and processed mineral materials rose to an estimated $71 billion in the year 2000, with increases primarily from purchases of aluminum, copper, and steel.

[10] The value of imported goods that includes cost, insurance, and freight. It is the base usually adopted for the purpose of levying customs duty and sales taxation on imports because it normally corresponds with the landed price.

Exports of raw and processed mineral materials during the year reached an estimated value of $43 billion (U.S. Geological Survey, 2001a, p. 6). Imports of mineral raw materials (natural resources prior to processing) were fairly constant over the 10-year period from 1980 to 1990, figure 23. The sharp drop of imports in the early 1990s was probably due in part to the launch of the Gulf War. In the last several years, imports of mineral raw materials have risen as more mining operations moved offshore. This shift is partly due to economic advantages of mining in other countries and a variety of other factors encompassing increasing globalization.

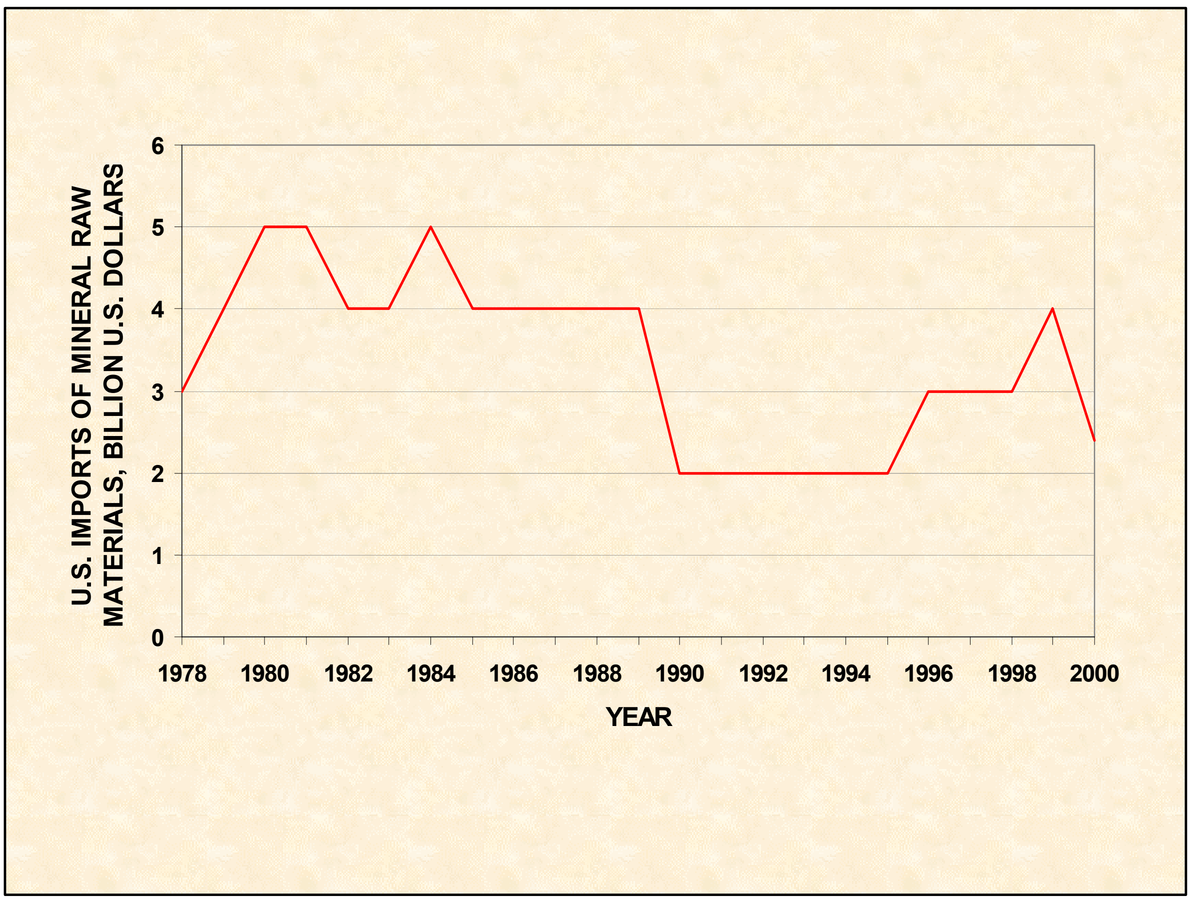


Figure 23. U.S. imports of mineral raw materials, 1978-2000 (data from U.S. Bureau of Mines, 1979b-95b; U.S. Geological Survey and U.S. Bureau of Mines, 1996; and U.S. Geological Survey, 1997a-2001a).

U.S. imports of mineral raw materials as a percent of total U.S. imports are shown in figure 24. As shown by this figure, U.S. imports of mineral raw materials have remained below 2 percent of total imports since 1978 and were less than 0.5 percent in 2000.

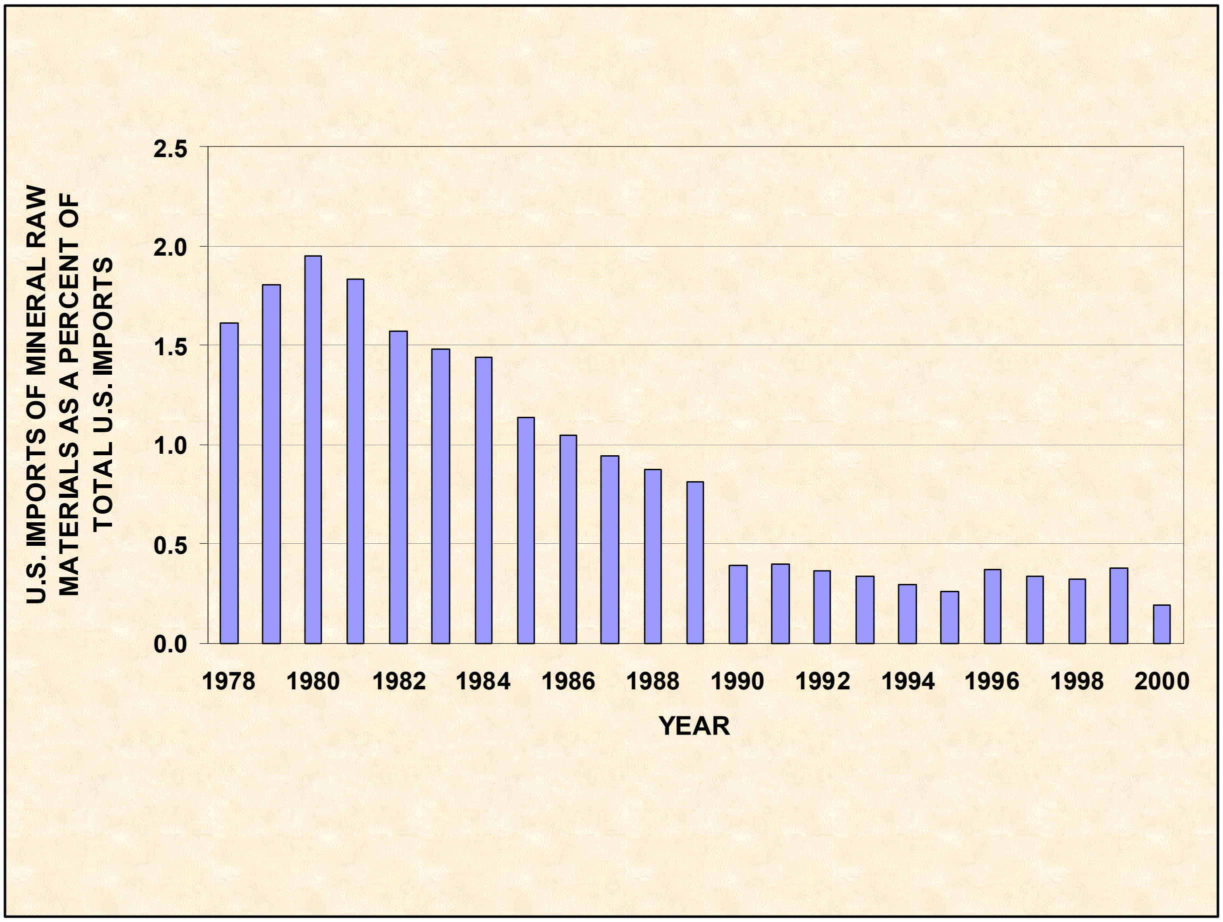


Figure 24. U.S. imports of mineral raw materials as percent of total U.S. imports (value based), 1978-2000 (data from International Monetary Fund, 2001; U.S. Bureau of Mines, 1979b-95b; U.S. Geological Survey and U.S. Bureau of Mines, 1996; and U.S. Geological Survey, 1997a-2001a).

The declining trend illustrated in figure 24 is an indication that fewer raw materials are being imported into the United States even though total domestic imports continue to increase (figure

22). This suggests that the composition of U.S. imports is becoming weighted more towards finished goods (foreign nations exporting more value-added products) and less towards mineral-based raw materials.

Although the U.S. economy generally continues its increasing consumption trend (figure 25), the international supply of minerals has been able to keep pace. Interestingly, the historical trend of mineral prices in constant dollars (figure 25) continues to decline due to the impact of globalization and technological improvements.

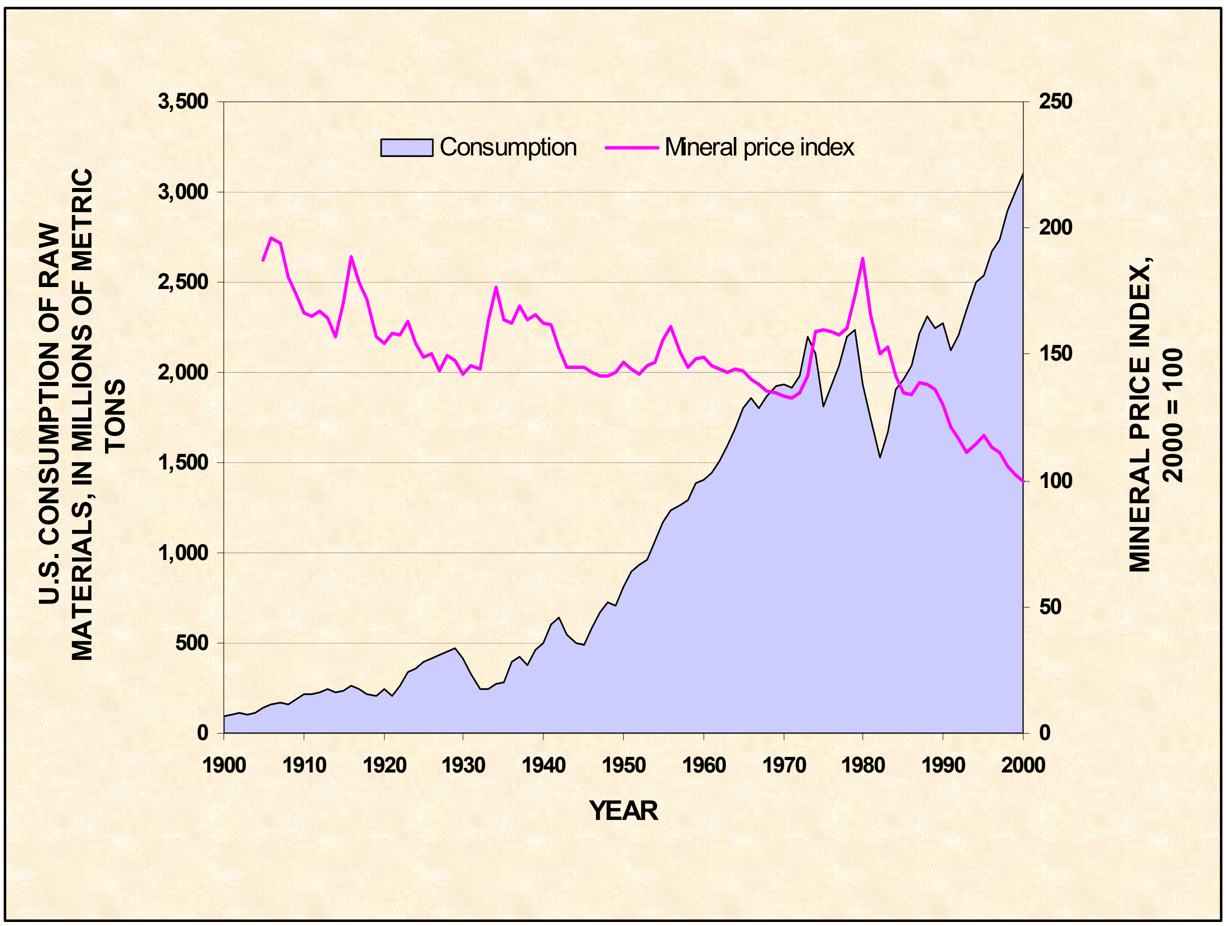


Figure 25. U.S. mineral price index, in constant 2000 dollars, versus U.S. consumption of raw materials, 1900-2000 (consumption data from Wagner, 2002).

Globalization of the Aluminum Industry

Although aluminum was isolated and identified in the early 1800s, a commercial process to economically recover it was not discovered until the beginning of the 20th century (U.S. Bureau of Mines, 1985c). The primary source for aluminum is the metallurgical grade of bauxite ore, which is spread unequally all over the globe. This bauxite ore is treated to obtain aluminum oxide (alumina), which is further processed to produce aluminum metal.

Aluminum was not widely utilized until WWII when its was incorporated into military aircraft. Since then, many other uses followed that took advantage of aluminum's properties of high strength and lightweight. Automobile components, beverage cans, and foils are just a few of these applications. Another important advantage of aluminum is that it can be efficiently recycled requiring far less energy than from the extraction of aluminum from bauxite ore (Aluminum Association, Inc., 2000§).

Initially, some of the less developed metallurgical-grade bauxite-producing countries operated their mining operations with no additional processing facilities. If possible, they moved into higher value processing by producing alumina or aluminum metal. This expansion was primarily determined by two factors: extensive bauxite deposits and abundant availability of low-cost energy.

The extraction of aluminum metal from alumina is extremely energy intensive; therefore, countries that have access to continuous, cheap energy sources (oil, hydroelectric, or natural gas)

Globalization of the Aluminum Industry—*Continued*

became prime candidates for aluminum processing. Normally, these conditions did not coincide; so processing facilities were located away from the mines. As international demand for aluminum and associated products increased, the development of mining and processing operations spread worldwide. Paralleling this action, international trade in bauxite, alumina, and aluminum became routine (U.S. Bureau of Mines, 1985c).

U.S. aluminum trade data and apparent consumption[11] are presented in figure 26. Imports and exports quantities were approximately equal until the early 1990s when they diverged with imports rising sharply. This trend will probably continue as the domestic aluminum industry depends more on imports due to higher energy prices and stricter environmental regulations. The substantial growth of apparent consumption of aluminum in figure 26 reflects the widespread application of this metal in global industries such as building and construction, containers and packaging, and transportation.

[11] Apparent consumption is defined as: Apparent consumption = production + imports - exports ± (stock change).

Globalization of the Aluminum Industry—*Continued*

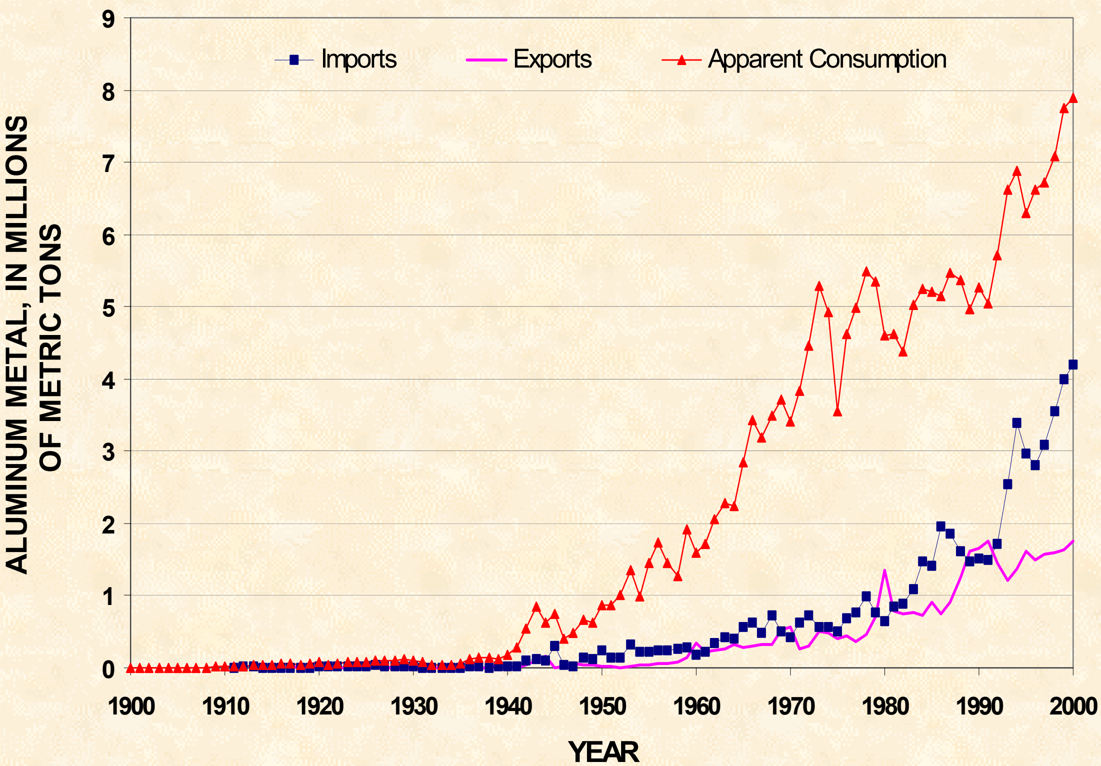


Figure 26. U.S. aluminum trade data and apparent consumption, 1900-2000 (data from Buckingham and Plunkert, 2001)

Technology and productivity

Technology and productivity can greatly influence the amount of mineral materials that is supplied to the market. Technological changes through new machinery, improved processes and the use of computer control systems all may contribute to increasing productivity trends. Productivity does not depend on what technologies exist; it depends on what technology is used.

Improvements in productivity can ultimately lead to economic growth that in turn creates higher living standards.

The mining industry has seen dramatic improvements in productivity due to advances in technology. Some technological examples are remote control mining and drilling equipment that will permit faster extraction and access to previously inaccessible deposits (Thomson, 1999). This new technology allows additional deposits to be mined, thereby increasing the supply of materials. Other examples include huge trucks, high volume crushers, high-speed conveyor belts, and automated control systems that can significantly reduce the costs of producing minerals. These lower costs result in more deposits being able to be economically mined, in turn increasing supply.

Productivity is driven by technology and depends to a large extent on production hardware and software. More information on how technology has changed the mining industry is presented in Chapter 3 in this series titled “Technological Advancements – A Factor in Increasing Resource Use” (Wilburn, Goonan, and Bleiwas, 2001).

Labor productivity (LP), which gauges the amount of gross domestic product (GDP) created per hour of work, is often taken as a measure of how efficient labor is in the economy. The more GDP each worker can produce, the better off the economy. The concept of increased productivity relates to a worker’s ability to produce the same output with fewer labor hours, thereby supplying more materials at a lower per unit cost.

Several decades following World War II were often characterized as a "Golden Age" for industrialized economies (Appelbaum and Schettkat, 1995). During this time frame, unemployment was low, real incomes increased, and productivity grew. When the era of computers began in the 1950s, they were used primarily in academic and industrial research to perform calculations that were impractical or impossible to do manually (Jonscher, 1994). Technological progress, which implies that a unit of labor can eventually produce more output, makes a unit of labor more valuable. Given time, this concept theoretically translates into higher wages and higher standards of living for all.

The United States had the poorest labor productivity record of the seven big industrial economies during the 1980s, with an average growth of only 1 percent a year, less than half that in Europe or Japan (The Economist, 1991). Productivity usually goes down in the early stages of a recession, as most firms are reluctant to lay workers off. As the economy turned upwards at the end of the 1982, productivity gains were evidence of the impact of American companies' response to stronger global competition. By trimming jobs as soon as there is an indication of a slow down, employers attempt to increase productivity. In the last decade, productivity has been the main driver of economic growth. Productivity growth (manufacturing sector) averaged 4.2 percent per year from 1993 to the end of 1999 (Council of Economic Advisers, 2000). Productivity increases for all sectors of the United States economy is presented in the Economic Report of the President, 2002 (Council of Economic Advisers, 2002).

Productivity measures provide important insights into technological changes and the effects of economic shifts. Important business decisions are made not only on market conditions, but also on the impacts of the various input components that make up the productivity indexes. Although labor productivity measurements have been traditionally based on output per hour, another measurement of productivity published by the Bureau of Labor Statistics (BLS) uses a more complex approach called multifactor productivity (MFP). Multifactor productivity (MFP) compares changes in output to changes in a composite of inputs used in production – capital, labor, and intermediate purchases. Capital includes equipment, inventories, land, and structures. Intermediate purchases are composed of materials, fuels, electricity, and purchased services.[12] This expansive input list allows MFP indexes to mirror advances in technology and production efficiency. Some of the uses for indexes are: economic indicators of technical progress and unit factor costs; basis for research on the sources of productivity advance; identification of policy options that can affect the pace of productivity change; aid in understanding trends in output per hour of all persons; and to provide a more comprehensive productivity measure that incorporates capital in addition to labor inputs (U.S. Department of Labor, Bureau of Labor Statistics, 2000§).

Historical productivity

Historical labor productivities based upon output per employee hour for two separate sectors of the mining industries (aluminum and nonmetallic minerals) are shown in figure 27. Each index reflects the continuous upward productivity trends in the mining industries as technological improvements came into being. The sidebar: Technology and productivity in the copper industry contains specific data and more details related to the productivity of the copper industry.

[12] For a thorough explanation, refer to the U.S. Department of Labor, Bureau of Labor Statistics, 1997.

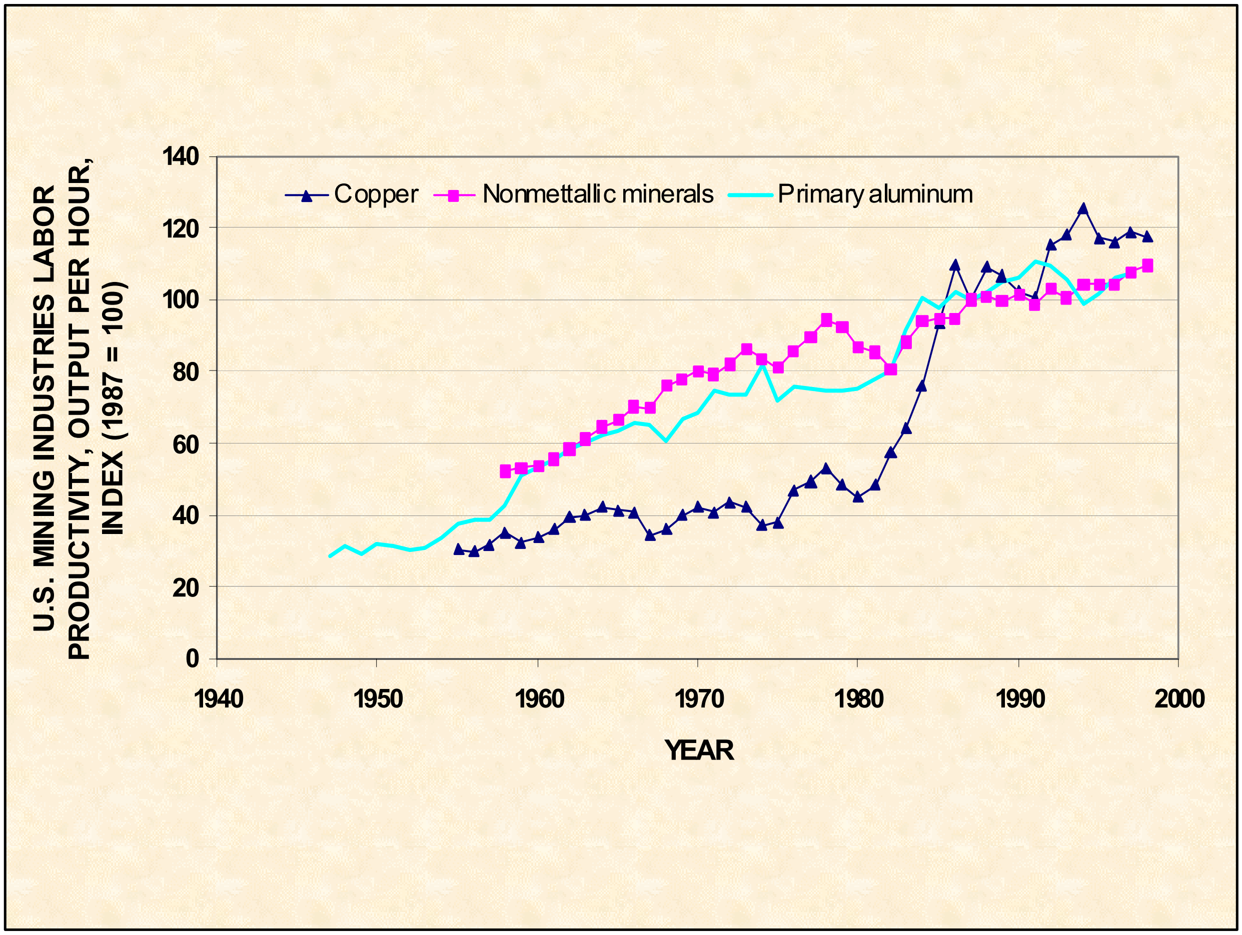


Figure 27. Mining industries labor productivity indexes, 1947-97 (data from U.S. Department of Labor, Bureau of Labor Statistics, 1999).

In figure 28, panel A and B, both LP and MFP indexes are plotted for the group that includes manufacturers of stone, clay, glass, and concrete products. The raw materials for these products are taken principally from the earth in the form of stone, clay, and sand. The productivity trends of the materials comprising the group provide another perspective on industries in the manufacturing process that are downstream from mineral-based raw materials industries.

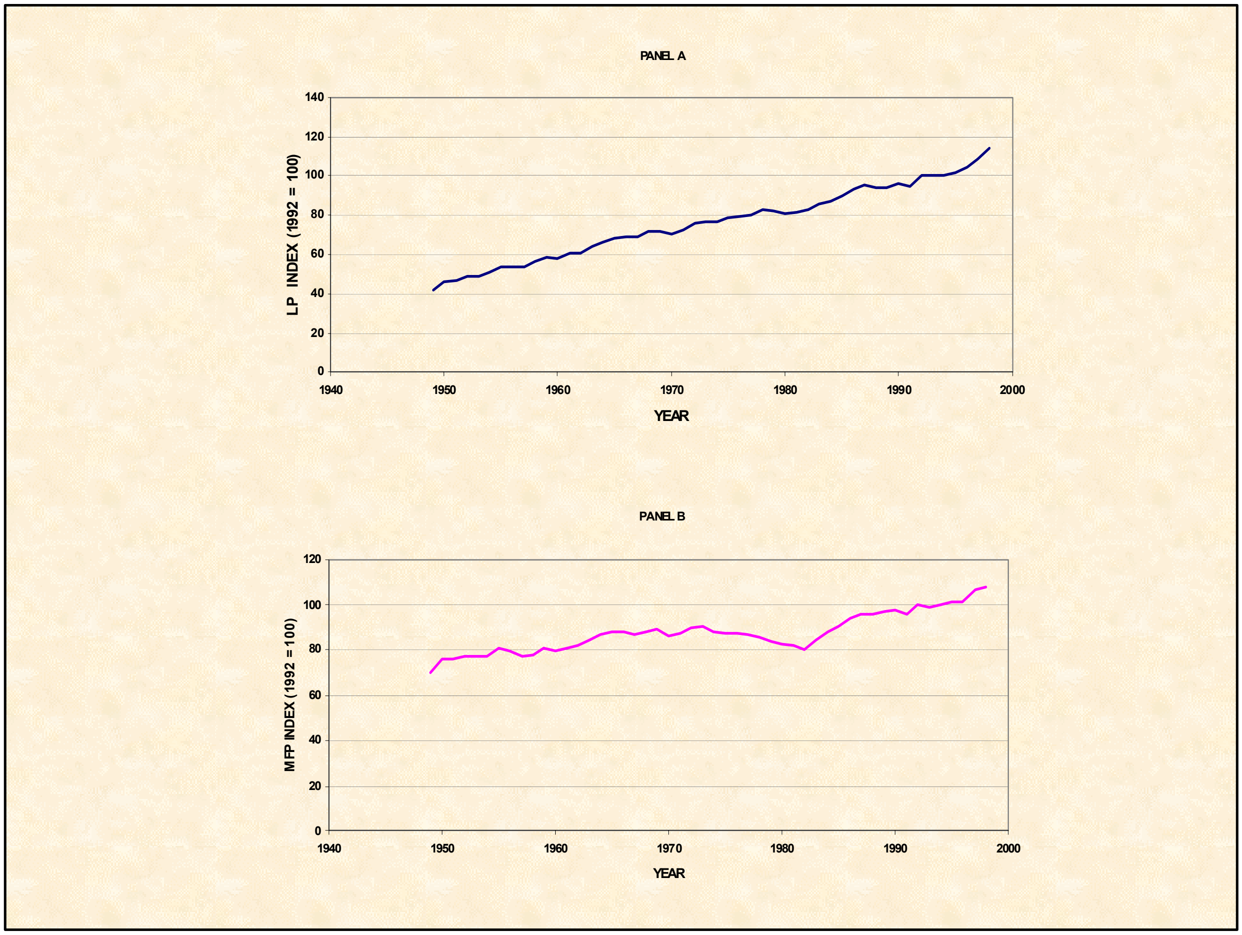


Figure 28. Stone, clay, glass, and concrete products productivity indexes, 1949-98 (data from U.S. Department of Labor, Bureau of Labor Statistics, 1999).

Reviewing figure 28, panel A, the LP for this group displays a consistent, increasing rate with a brief pause in the late 1970s continuing for several years. The MFP index, shown in panel B, increases at a more gradual rate until, again in the 1970s; there is a pronounced dip. The slowing economy, due to the double-digit inflation as a result of the oil crisis is evidenced in both the LP and MFP indexes being flat to slightly down during this time frame.

Productivity growth trends have generally increased after WW II with several exceptions. These stagnant periods were usually associated with recession, for example, 1970s oil crisis, but technology has continued to provide the means for both higher outputs and shrinking inputs.

Technology and Productivity in the Copper Industry

Reviewing figure 29, the copper industry labor productivity index had a flat to slightly increasing trend from the 1950s through the 1970s. The 1980s saw a spike up in the index, primarily as a result of management and labor negotiations that ultimately led to dramatic decreases in labor at copper mining facilities (Wilburn, Goonan, Bleiwas, 2001, p. 121). In 1970, world copper reserves were estimated at 280 million tons of contained metal (D.L. Edelstein, USGS, oral commun., 2000). By 1982, world copper reserves had risen to 350 million tons of contained metal (D.L. Edelstein, U.S. Geological Survey, oral commun., 2000) partly as a result of the development of solvent extraction – electrowinning, which could treat lower grade ores. From 1987 to 1997, the labor productivity index resumed its steady increasing trend with the average annual increase of 1.7 percent (U.S. Department of Labor, Bureau of Labor Statistics, 1999).

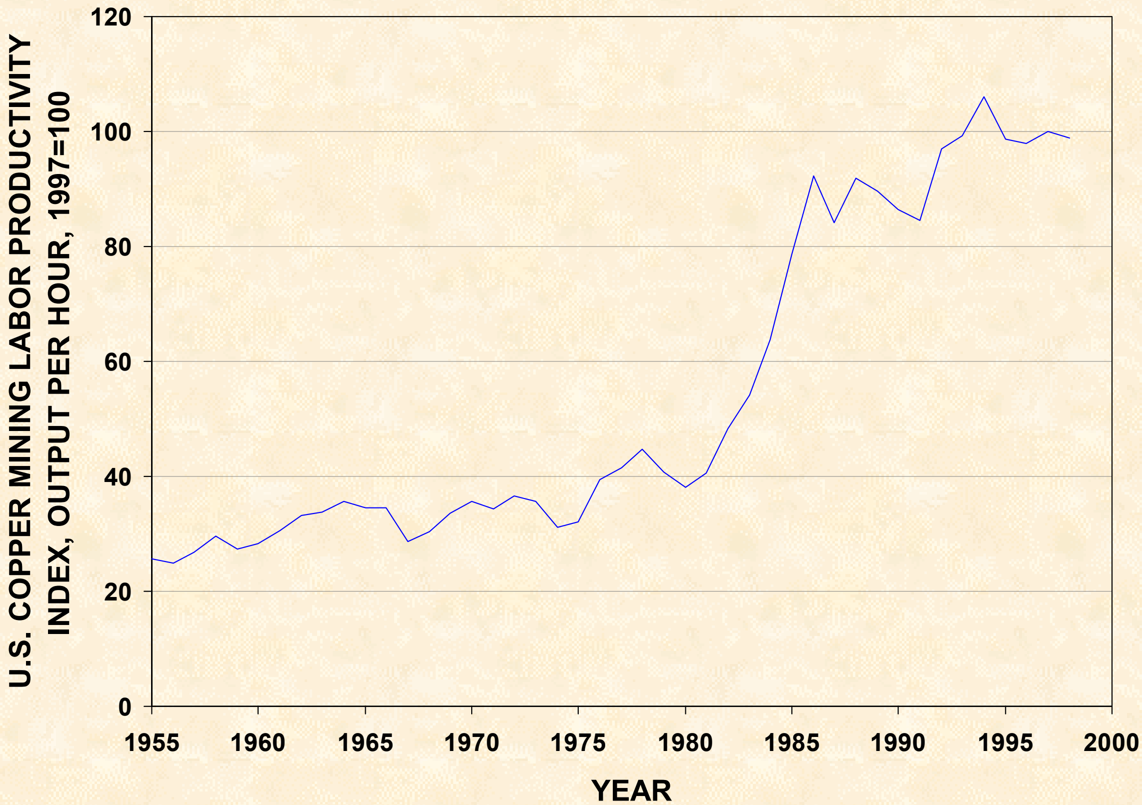


Figure 29. Copper industry labor productivity index, 1955-98 (data from U.S. Department of Labor, Bureau of Labor Statistics, 1999).

Production costs

Production costs have a major impact on the amount of mineral materials that are supplied to the market. The quantity producers are willing to sell is a result of their production costs and the market price of the commodity. Producers try to keep their production costs as low as possible to maintain a competitive place in the marketplace even if prices fall. Under normal circumstances, if prices fall below costs, operations will tend to shut down, thereby decreasing the supply of material to the marketplace. As the discussion in Appendix A explains, when this happens, market forces work to establish a new equilibrium price. If the new equilibrium price is high enough, closed producers may reopen or new operations may be developed to supply material to the market.

Table 4 contains cost data for selected mining industries. It is adapted from data published by the U.S. Census Bureau who compile the data from the economic census that is conducted every 5 years. The Census reports include such statistics as number of establishments, employment, payroll, value added by mining, cost of supplies used, value of shipments and receipts, capital expenditures, and other measures for each segment of the mining industry for 1997. This table (4) reports only selected costs; therefore total costs of mining cannot be derived from this table. As shown in the table, production costs are made up of operating costs which include for example, energy, labor, material inputs, overhead, reclamation, and taxes and capital costs such as acquisition, capital equipment renewal, and exploration.

Table 4. 1997 mining costs, in thousand dollars.

[Data from U.S. Census Bureau, 1999; NA, not available]

Production costs	Industrial Minerals								Metals				
	Clay and ceramic	Construction sand and gravel	Crushed granite	Crushed limestone	Crushed stone, other	Dimension stone	Kaolin and ball clay	Potash, soda, and borates	Copper	Gold	Iron	Lead and zinc	Silver
Operating Costs													
Direct													
Supplies, material, and purchased machinery installed	157,225	745,100	420,050	1,092,445	278,979	18,989	210,139	300,819	1,333,575	1,597,678	603,797	163,119	28,272
Purchased fuels and purchased electricity	62,278	329,271	88,302	346,968	91,208	8,200	99,151	172,648	410,879	358,337	375,972	28,879	9,221
Production, development, and exploration wages	87,135	679,673	214,162	738,316	208,761	30,827	90,108	177,739	446,646	674,983	330,553	67,623	29,248
Indirect													
Total depreciation and depletion charges during the year	318,269	318,060	124,395	408,265	111,027	6,074	73,045	94,404	303,696	643,284	128,570	54,633	16,435
Capital Expenditures													
Exploration and development	1,135	12,273	16,132	12,378	11320	531	NA	NA	88,870	216,369	9,420	16,108	NA
Mineral land and rights	1,562	53,600	18,960	29,956	9,998	1,120	2,779	14,694	19,377	207,213	106	NA	6
Buildings, structures, machinery, and equipment	71,078	358,187	183,924	492,447	123,101	9,050	76,433	150,499	440,163	922,668	81,437	93,499	NA

Operating costs include both direct and indirect costs. Direct costs, or variable costs, are those items such as labor, materials, and supplies, which are consumed directly in the production process and which are used roughly in direct proportion to the level of production. On the other hand, indirect costs, or fixed costs, are expenditures that are independent of the level of production – at least over certain ranges. Examples of fixed costs include such items as office expenses (buildings, staff), insurance, and property tax. The relatively high level of fixed costs in mining usually means that the break-even production level for mining facilities is closer to capacity than for firms with lower fixed costs. This is a major contributing factor in why operators attempt to run mines at capacity, often employing three-shift, seven-day-per-week work schedules (Gentry and O'Neil, 1984, p.18).

The production of minerals is a highly capital-intensive activity; the greater the output over which the capital costs can be spread, the lower the unit production cost. The larger the output at the site, the greater the use of cost reducing bulk production and transportation technologies. A small producer, constrained by a limited local market may be forced out of business because of higher production costs. Larger producers can serve several markets and since they have higher production volumes, they may be able to take advantage of economies-of-scale and achieve lower per unit production costs than smaller producers. This has been one factor that has favored the large multinational companies in relation to small local producers.

The physical characteristics of a particular mineral deposit are only one set among the many variables that affect the overall production cost at each site. Nevertheless, all other things being equal, geology and physical geography do play a role in determining which supply sources will be developed first. The size and geometry of the deposit will affect the production level, with large deposits allowing economies of scale to be achieved. The quality of the mineral and the possibility of producing co-products or by-products from the same deposit will influence per unit production costs. Ores of low metal content normally will be more expensive to mine, since a high proportion of the extracted material will be waste, and even more important, such ores will involve higher processing costs. The structure of the deposit and its surroundings also affects production costs. Such factors as whether the deposit can be mined using surface methods, the thickness of the overburden, and whether de-watering of the mine will be necessary all affect the costs of production.

Capital costs

In addition to operating costs, mining operations clearly must also consider capital costs. Capital costs are those expenditures made to acquire or develop capital assets, the benefits from which will be derived over several years. Capital costs include such items as mining machinery and equipment, mine development, exploration and property acquisition, and working capital. The largest share of capital costs is incurred to get the project started, but some capital expenditures are made yearly throughout the life of the operation (Gentry and O'Neil, 1984, p. 18). The mining industry is characterized by a high degree of capital intensity because of the large-scale nature of modern mining activities. In the category of assets per unit of sales, mining ranks near the top of all industrial sectors (Gentry and O'Neil, 1984, p. 17).

Average capital costs for capacity expansions at existing mines are approximately one-half the cost for nonproducing deposits (Porter and Peterson, 1992). This is because for completely new mining operations in areas not already established as mining sites, the costs of infrastructure (hospitals, housing, power plants, recreation facilities, schools, transport and water) are incurred. These costs can dwarf the capital costs of the mine or processing plant. Significant cost advantages, therefore, accrue to sites where the mining companies can use existing services or for those projects that involve the expansion of production at existing mining or processing sites. If a company has to pay for all the infrastructure, then the mineral deposit would need to be very large, so that the capital costs could be spread over enough units of output to allow them to be competitively priced.

Capital costs also affect output levels once production is underway. According to economic theory, firms will cut output as prices fall and high-cost producers will shut down completely. However in practice, since the capital costs are fixed and do not vary with output, firms may opt to maintain output levels as long as the variable costs are covered and at least some contribution is being made to fixed costs (Rees, 1985, p. 104). Some companies may be able to maintain loss-making output levels for years, and may find this preferable to abandoning the plant and losing all the fixed assets. This tends to mean that production levels need not be responsive to a price fall, supplies continue to exceed demands and prices are driven still lower. This is one of the factors contributing to metal price volatility as explained on page 43.

Strategies for efficient materials usage

New product designs have altered and typically lessened the amount of materials used to manufacture products, thereby extending the life of mineral deposits. An example is the design of thin walls for metal beverage containers. This resulted in using less material; therefore, more aluminum is available for future use. This helps to hold down metal prices, as more costly deposits do not need to be developed to meet demand. Products are continually reengineered, for example through substitution of plastic for metal in plumbing and automobile parts, to meet product requirements while still meeting performance criteria.

Substitution occurs when a different material now satisfies a need that had previously been satisfied by another material. Substitution can occur in different ways. A new material can replace the material in a specific product such as the use of aluminum for copper in long distance electrical transmission lines or plastic replacing steel in automobile bumpers. See the sidebar: The copper penny. A more subtle form of material substitution occurs when a new product using different materials replaces the function of an original product, such as cell phones using airwaves instead of copper wires used by conventional phones. Substitution contributes to efficient material usage by utilizing more economically available materials. In this way it also alleviates materials scarcity. If a material becomes relatively scarce, thus more expensive, a less expensive, more abundant material, available at a lower price, generally replaces it.

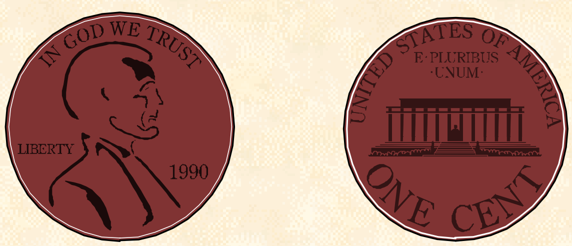
Recycling is recovering the material contained in a product at the end of that product's useful life. It occurs when the value of the recycled material is sufficient to make recovering profitable.

This can occur through natural market forces or when regulations or taxes make recycling financially attractive. The price received for recycled material governs the amount of material that is recycled. When materials are recycled they become valuable resources instead of waste. By supplementing the quantity of material available to the market, recycling conserves virgin material and makes more material available to the market. Recycling, including composting, diverted 64 million tons of material away from landfills and incinerators in 1999. In 1999, the United States recycled 28 percent of its waste, a rate that has almost doubled during the past 15 years (U.S. Environmental Protection Agency, 2002§).

Source reduction means utilizing less material to attain the same economic benefit. This can be accomplished by changing the design or manufacturing process of these products so less material is used. Source reduction results in less material entering the disposal stream and when a product is made using less material then more products can be made with a given quantity of material. Source reduction has the effect of reducing the physical requirement for materials. Source reduction saves natural resources, reduces waste, and reduces costs.

The Copper Penny

The U.S. one cent coin, called the penny, is an example of how substitution occurs. The penny was primarily copper from its inception in 1793 until 1982. In 1980, the penny was 95 percent copper and 5 percent zinc and weighed 3.11 grams (U.S. Mint, 2001§). Using this information, it can be calculated that approximately 153 pennies would contain a pound of copper. In February 1980, the United States producer price of refined copper reached $1.34 per pound (U.S. Bureau of Mines, 1981b, p. 41). If the price of copper were to reach more than $1.53, then the value of the copper in a penny would be more than one cent. In 1982, the Mint changed the composition of the penny to 97.5 percent zinc and 2.5 percent copper. The new pennies weigh 2.5 grams, about 20 percent less than the pennies they replaced, and are less expensive to make (U.S. Mint, 2001§). The price of copper has never reached $1.53 per pound, but it got close enough to trigger the mint to replace it with a less expensive material.



Summary

Although the U.S. economy generally continues its increasing consumption trend (figure 30), the international supply of minerals has been able to keep pace. Interestingly, the historical trend of mineral prices in constant dollars (figure 30) continues to decline due to the impact of globalization, technological improvements, productivity increases, and efficient material use.

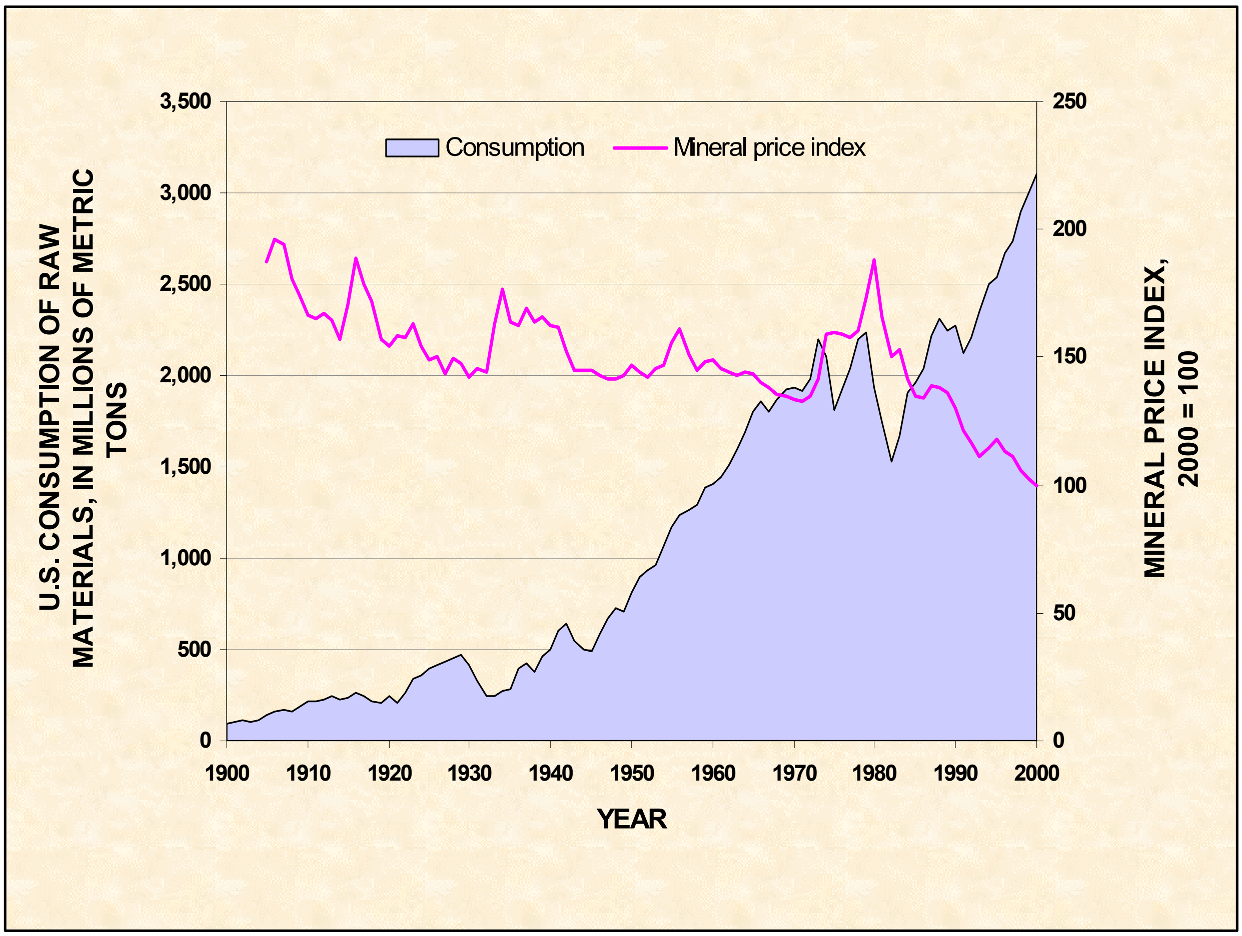


Figure 30. U.S. mineral price index, in constant 2000 dollars, versus U.S. consumption of raw materials, 1900-2000 (consumption data from Wagner, 2002).

As shown by the previous discussions, many economic drivers are at work simultaneously to impact minerals markets and supply. To an economist, a rising long-term price for a commodity indicates increasing scarcity of supply relative to demand. This is what we should expect with minerals as depletion progresses. However, in general, mineral prices have historically fallen in real terms. Therefore, the data show that supply has grown faster than demand. Not all metal prices have decreased in real terms. Some minerals, such as iron ore and gold, have experienced price increases, but it cannot be assumed that recent short-term price increases for all mineral commodities result from increasing long-run scarcity. There are a variety of reasons for mineral price increases, and these reasons are as much political as they are economic and geological. Prices for a commodity are, however, relevant. If mineral prices rise, the joint effect will be to cut demand, increase supply, and encourage recycling. On the demand side, an immediate tendency will be to turn away from use of expensive minerals and use less expensive substitutes. At the same time higher prices retard demand, they also increase supply. Exploration is stimulated and mineral deposits that were formerly too costly to operate may become working mines. Indeed, there is a strong incentive to find new technologies to work these deposits economically. If new waste treatment regulations threaten to increase operating costs, operators may seek ways to reduce the volume of waste, or find more efficient ways to treat it. Other production problems could be approached in the same way. In addition, new technologies can result in cost effective mining of unconventional deposits, increasing reserves of a commodity. Thus the opportunity for technology to augment supplies is extensive. Where new technology permits an unconventional type of deposit to be mined, the increase could be very large. For example, the quantities of manganese, copper, and nickel on the deep sea floor dwarf conventional sources, but recovering them is still too expensive (Brooks, 1973, p. 4).

There is strong evidence indicating that vast quantities of mineral resources exist that could be mined. Further, either as their price goes up or as their cost goes down (which is to say, as technology of extraction improves), the volume of mineable material could increase significantly (Brooks, 1973, p. 7). "Since 1800, the trend of prices for the common metals, measured not only by monetary units but by the cost in human effort, has been almost steadily downward…" (Hewett, 1929). As shown by the productivity section of this report (figure 28) this trend has continued into the 21st century.

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APPENDIX A: SUPPLY-DEMAND RELATION THEORY

Figure A1 is a schematic of the way market pricing ideally reconciles public demand and supply with business supply and demand. The markets serve as one connecting device between the public and business.

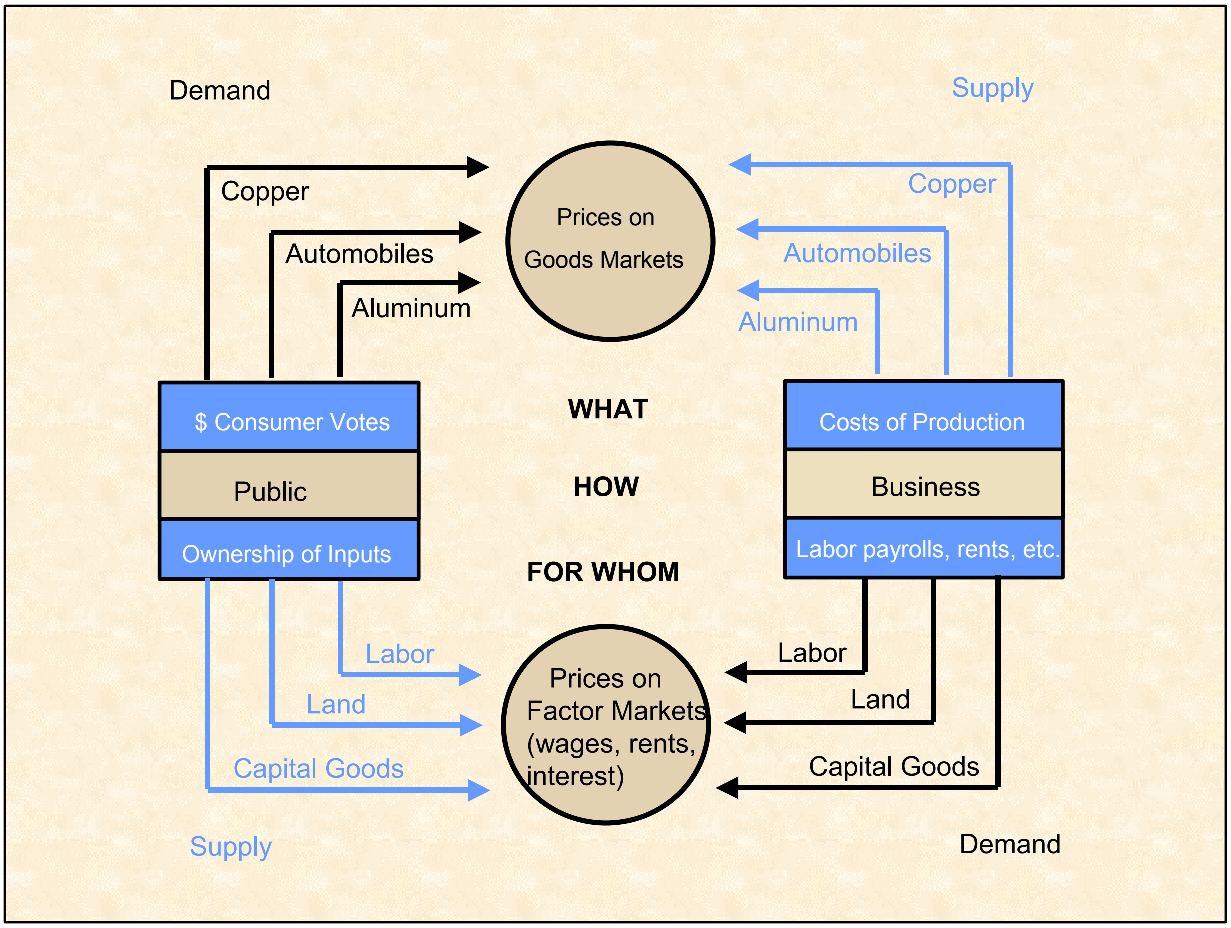

Figure A1. The competitive price system (adapted from Samuelson, 1961).

Figure A1 shows how the competitive price system uses supply-demand markets to solve basic economic problems – what, how, and for whom. Demand relations are shown in black lines; and supply relations in blue lines. Notice that consumer dollar votes of demand interact in the goods markets (upper half of schematic) with business-cost supply decisions, thus helping determine "What" is produced. Also shown is how business demand for inputs or productive factors meets the public's supply of labor and other inputs in the factor markets (lower half of schematic) to help determine wage, rent, and interest income – that is, "For Whom" goods are produced. Business competition to buy factor inputs and sell goods most cheaply determines "How" goods are to be produced. It is important to understand that all parts of this diagram interact with one another.

It is also important to remember that this schematic represents economic theory in a perfect market and does not take externalities into account. Externalities (or external costs and benefits) are simply the uncompensated side effects of any economic or social activity that are not considered by individuals when making private decisions. The word 'uncompensated' is important as it serves to exclude all the external costs and benefits that arise in the course of normal market transactions. Externalities occur when the by-products of an activity result in costs or benefits to other people, which go uncompensated by exchange of money or goods. Whenever producers or consumers make usage decisions on the basis of their own private costs and benefits and are allowed to neglect the external effects of their actions, the usage patterns are likely to deviate markedly from those that are socially optimal or desirable (Rees, 1985, p. 244).

This next section will explain how supply and demand work together in a competitive market to reach an equilibrium point for a commodity. Additional examples of the workings of supply and demand are found in the main text of this report.

Supply and demand schedules

As people's desires and needs change, as technologies used to produce the goods change, as supplies of natural resources and other productive factors change, the marketplace registers changes in the prices and the quantities sold of commodities. For example, assuming figure A2 represents the supply-demand situation for copper where markets with large numbers of buyers and sellers are free from government interference or monopolization, theoretically, an equilibrium price will be generated. It is important to note that for illustrative purposes, straight lines are used to represent the supply and demand curves. For more detail on the supply-demand relation see Miller, 1998.

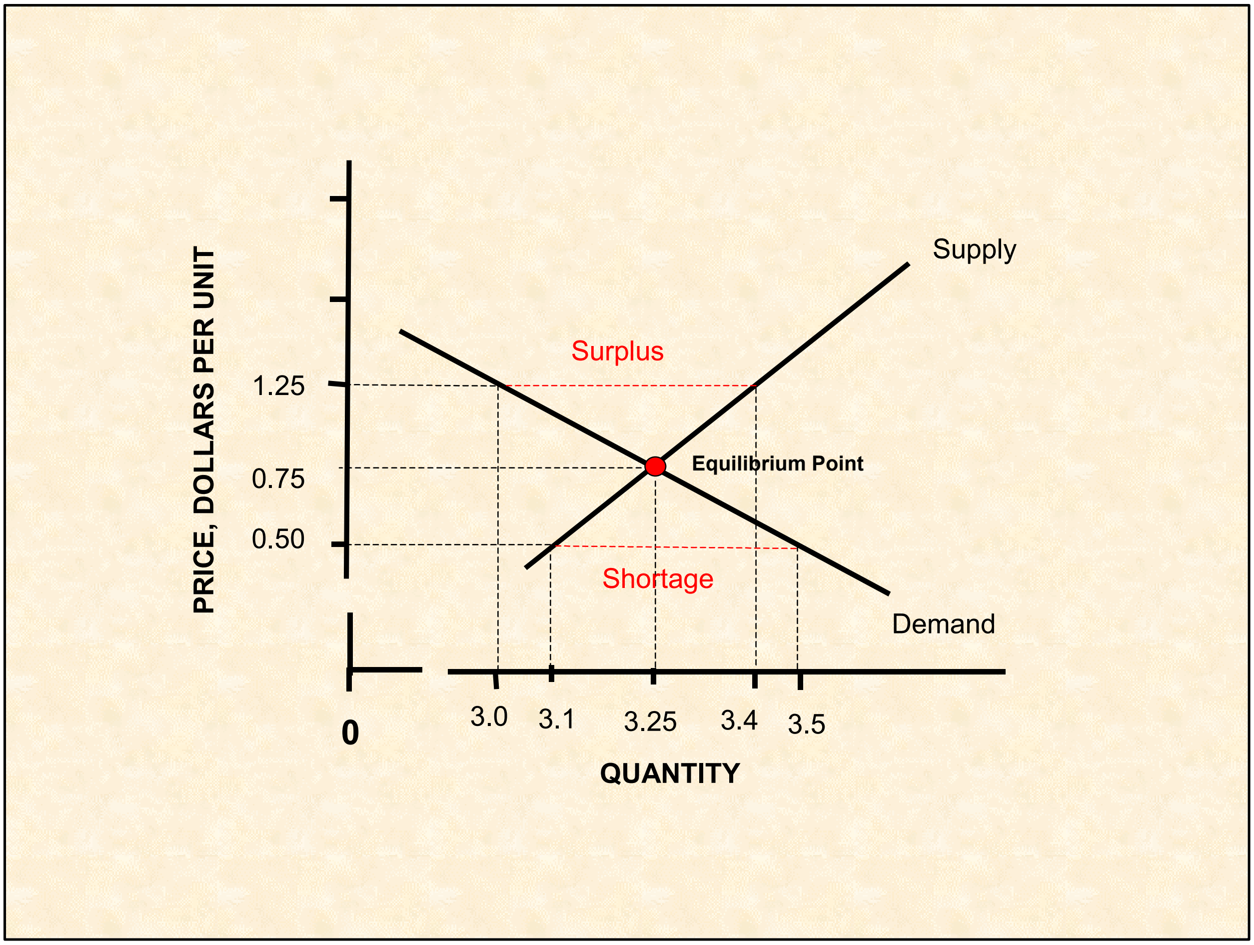

Figure A2. Hypothetical supply-demand situation for copper (adapted from Truett and Truett, 1982).

Figure A2 shows this equilibrium price at $0.75 per unit. Why does this price hold? What would happen if another price were in effect? Suppose the price were $1.25 per unit. Figure A2 shows that sellers would bring 3.4 million units of copper to market, but buyers would purchase only 3.0 million units of copper. There would be a surplus of copper. Some sellers would have surplus unsold copper and their production activities might have to taper off. In order to sell this excess copper, the sellers would cut their price. Since the quantity demanded by buyers is greater at lower prices, the price-cutting would alleviate the inventory problem. In addition, other sellers would bring less copper to the market at lower prices, since the price might get so low that some suppliers could not cover their production costs.

If the price were below $0.75 per unit instead of above it, market forces would move the market toward equilibrium at the $0.75 per unit price. For example, if the price were at $0.50 per unit, the amount of copper brought to the market would be 3.1 million units, but buyers would want to purchase 3.5 million units. There would be a shortage of copper. Some sellers would run out of copper, and some buyers would be unable to purchase copper. Of course, some sellers might attempt to charge a higher price and still sell all their output. Some buyers would be willing to pay more for copper as they became aware of the shortage. All these actions would move the price upward and close the gap between quantity demanded 3.5 million and quantity supplied 3.1 million. The price would rise until the $0.75 per unit level is reached. At this point, the quantities demanded and supplied would be the same, and the market would be in equilibrium. The equilibrium market price and quantity traded of a good will not change as long as both the demand and supply curve for the item does not shift. However, a shift in one or both of these curves will lead to the establishment of a new equilibrium position.

Figure A3 contains several panels that summarize how shifts in demand and supply can affect equilibrium price and quantity. In panel (a), the price rises because demand has increased (shifted outward) with no change in supply. The equilibrium point ‘A’ will not be maintained after the shift from the line ‘Demand 1’ to the line ‘Demand 2’. In the copper example, an increase in the price of aluminum might cause such an adjustment, because some consumers would substitute copper for the more expensive aluminum. When substitution of one commodity for another occurs, the quantity traded at the new equilibrium point 'B' increases to a new amount between 3.25 and 3.5 even though the price has risen to $0.82 per unit.

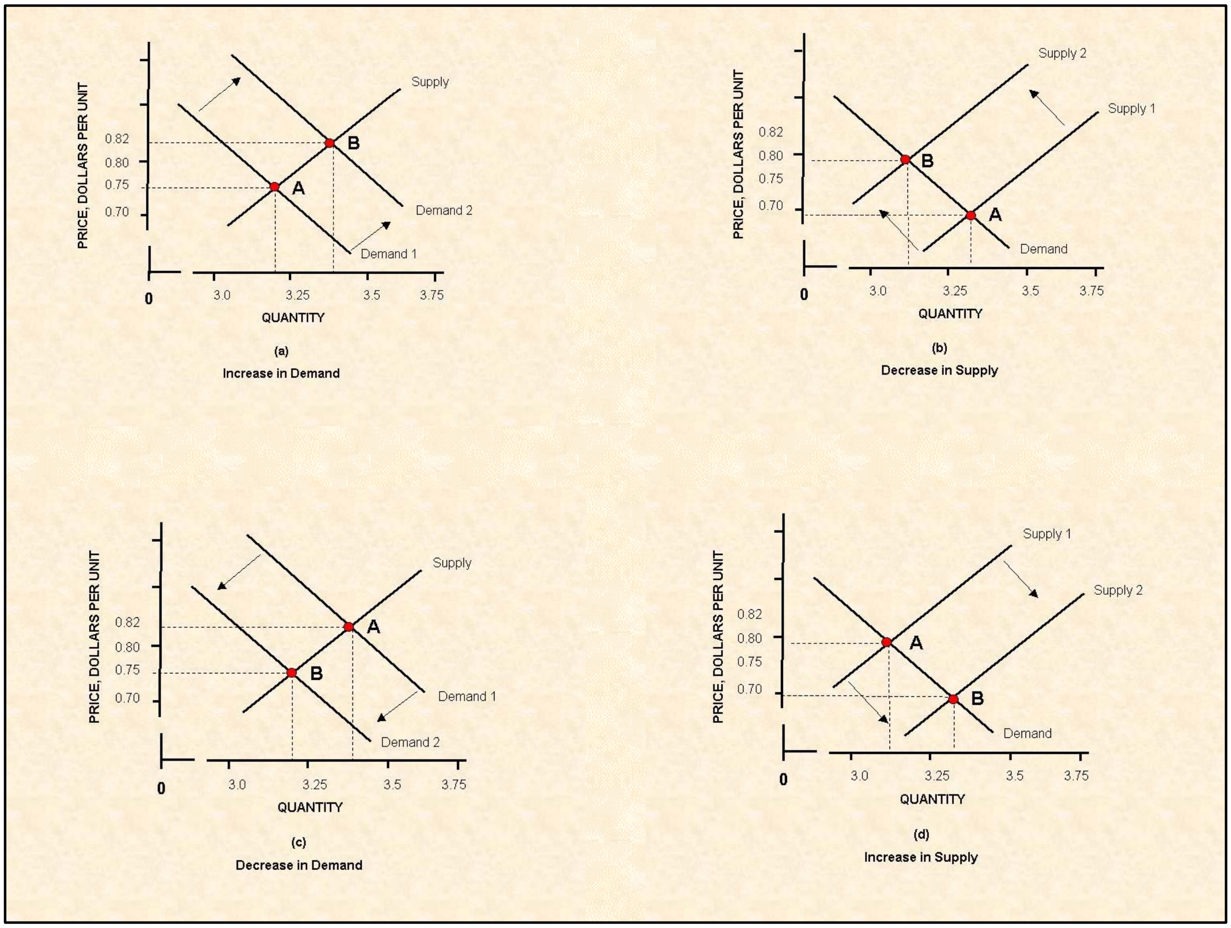

Figure A3. Equilibrium price and quantity changes as a result of shifts in supply and demand (adapted from Truett and Truett, 1982).

In panel (b), the price at the new equilibrium point 'B' also rises, but this time the quantity falls from approximately 3.3 to 3.1. This results when supply decreases (shifts inward), but demand does not change. In the copper example, an increase in the wages of mine workers or in the price of fuel could produce such an adjustment.

Panels (c) and (d) show shifts in demand and supply that result in a lowering of the equilibrium price. In panel (c), demand decreases and supply remains unchanged. Thus both the equilibrium price and the equilibrium quantity fall. Panel (d) gives the same price result, but the quantity increases because the supply curve has shifted outward (increase) along an unchanging demand curve. In the copper example, an abundant supply of the substitute aluminum, or a decrease in the desirability of material, asbestos, and mercury for example, could cause a shift such as that in panel (c), whereas a decision to develop a new large scale copper deposit could lead to a supply increase such as that shown in panel (d).

Finally, Figure A4 illustrates three possible results when both supply and demand for a particular good or service changes. In panel (a), the price rises because growth in demand has been large relative to growth in supply. However, in panel (b), the price falls because the outward shift of the supply curve is large relative to the outward shift of the demand curve. In panel (c) the price remains the same even though both curves shift outward. In this case, intersection B will be directly to the right of the initial equilibrium point at intersection A. In all three cases, the quantity traded increases. Such shifts help explain why, when economic growth takes place and the quantity of output in the market increases, some prices remain unchanged while others rise or fall.

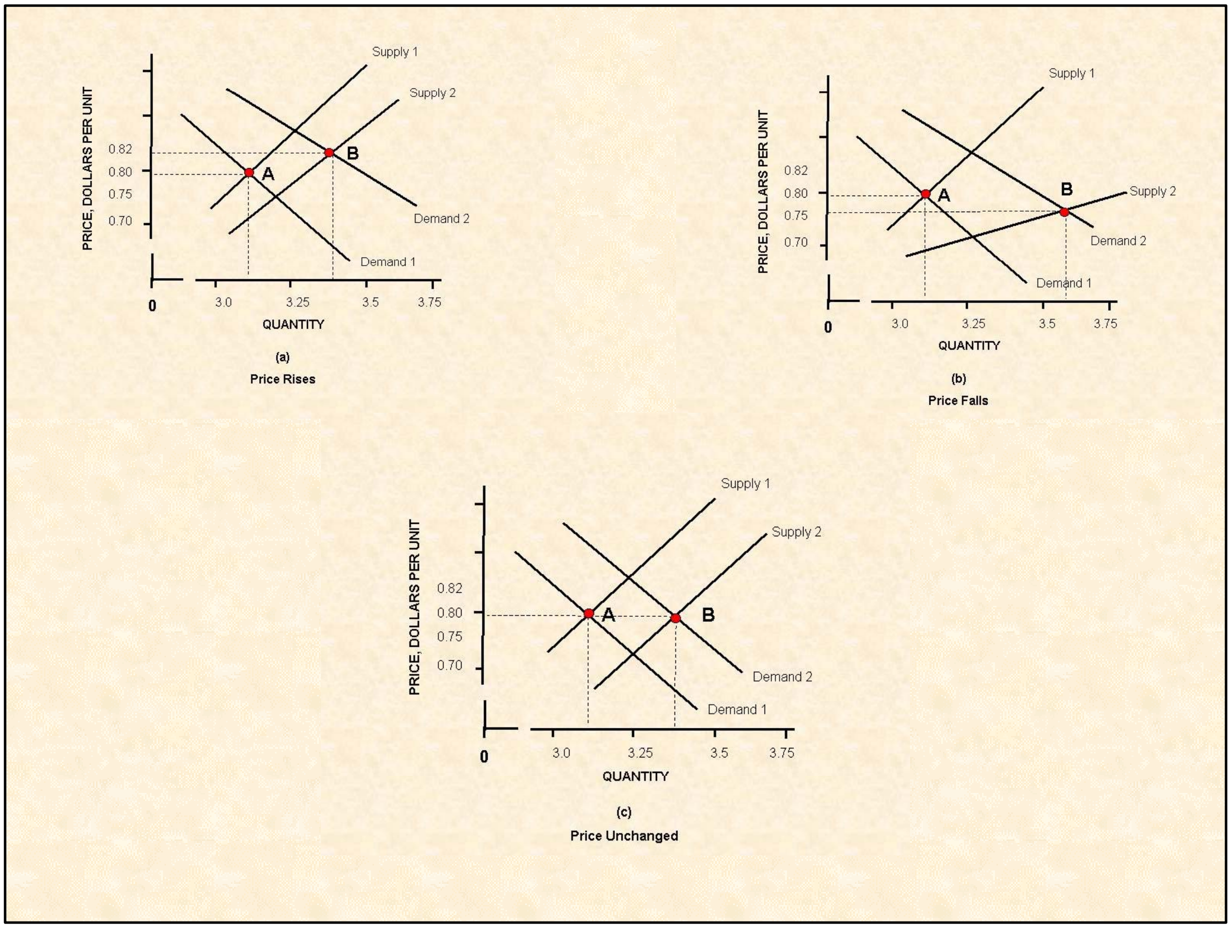

Figure A4. Equilibrium price or quantity impacts of supply or demand increases (adapted from Truett and Truett, 1982).

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APPENDIX B: PRICES

The U.S. Geological Survey developed price indexes for key U.S. mineral raw materials[13]. By constructing an index, it is possible to summarize the price changes of multiple mineral commodities into a single number that indicates the extent to which mineral prices have changed relative to those in another year. Specifically an index number is defined as a ratio (generally expressed in percentage terms) of one value to another where one of the values summarizes a given group of items and the other value summarizes a base group of items. The "base" group is used as a basis of comparison with the "given" group.

In order to more accurately reflect changes in prices as experienced by the consumer, a weighted price index was used. In a weighted price index, the various prices are given unequal importance with the weights most often used based upon a quantity measurement. Therefore, a commodity included in the price index that is heavily produced or consumed would have a greater impact on the index. The Laspeyres price index, a weighted price index, was used in construction of the price indexes. The mathematical formula for the Laspeyres price index (Mansfield, 1987) is shown below.

$$Laspeyres\ Price\ Index = \frac{\sum_{i=1}^{m} Q_{0i}P_{1i}}{\sum_{i=1}^{m} Q_{0i}P_{0i}} * 100$$

[13] Includes the industrial mineral commodities: cement, clays, lime, phosphate rock, salt, sand and gravel, stone (crushed), and the metals: copper, gold, iron ore, lead and zinc.

where,

Q_{0i} = quantity of mineral commodity *i* produced (mined) in the base year (0)
P_{1i} = price of mineral commodity *i* for a given year (1)
P_{0i} = price of mineral commodity *i* for the base year (0)

and,

i = 1 | *m*, where *m* is a mineral commodity

Multiplying the price of each commodity in the given year by the quantity of that commodity produced in the base year and then summing over all commodities derives the value in the given year using given year prices and base year quantities. This sum is the numerator of the equation. Multiplying the price of each commodity in the base year by the quantity produced in the base year and then summing over all commodities derives the value of mineral production for these commodities in the base year. This sum is the denominator of the equation. The result of the division of the numerator by the denominator is an index that reflects relative changes in prices for all of the included commodities with the weight of each commodity determined by its quantity of production in the base year.

Therefore, by definition, the Laspeyres price index is the ratio, expressed as a percentage, of the total value of raw mineral commodities produced in a given year based upon the quantity of each raw mineral commodity produced in the base year to the total value of these same mineral commodities in the base year.

The United States mine production[14] composite price index (figure B1) was computed using data for the seven highest total value of production industrial mineral commodities (cement, clay,

[14] This index includes cement even though it is not mined but is the product of mined materials.

crushed stone, lime, phosphate rock, salt, and sand and gravel) and the five highest total value of production metal commodities (copper, gold, iron ore, lead, and zinc). During the year 2000, these commodities accounted for 88 percent of the value of industrial mineral mine production and 89 percent of the value of metal mine production in the United States as shown in table B1. Even though aluminum is produced and consumed in large quantities in the United States, it is not included in this index because the production of bauxite (the ore from which aluminum is derived) is not significant in the United States. However, a discussion of aluminum prices is included because of the economic importance of aluminum production in the United States.

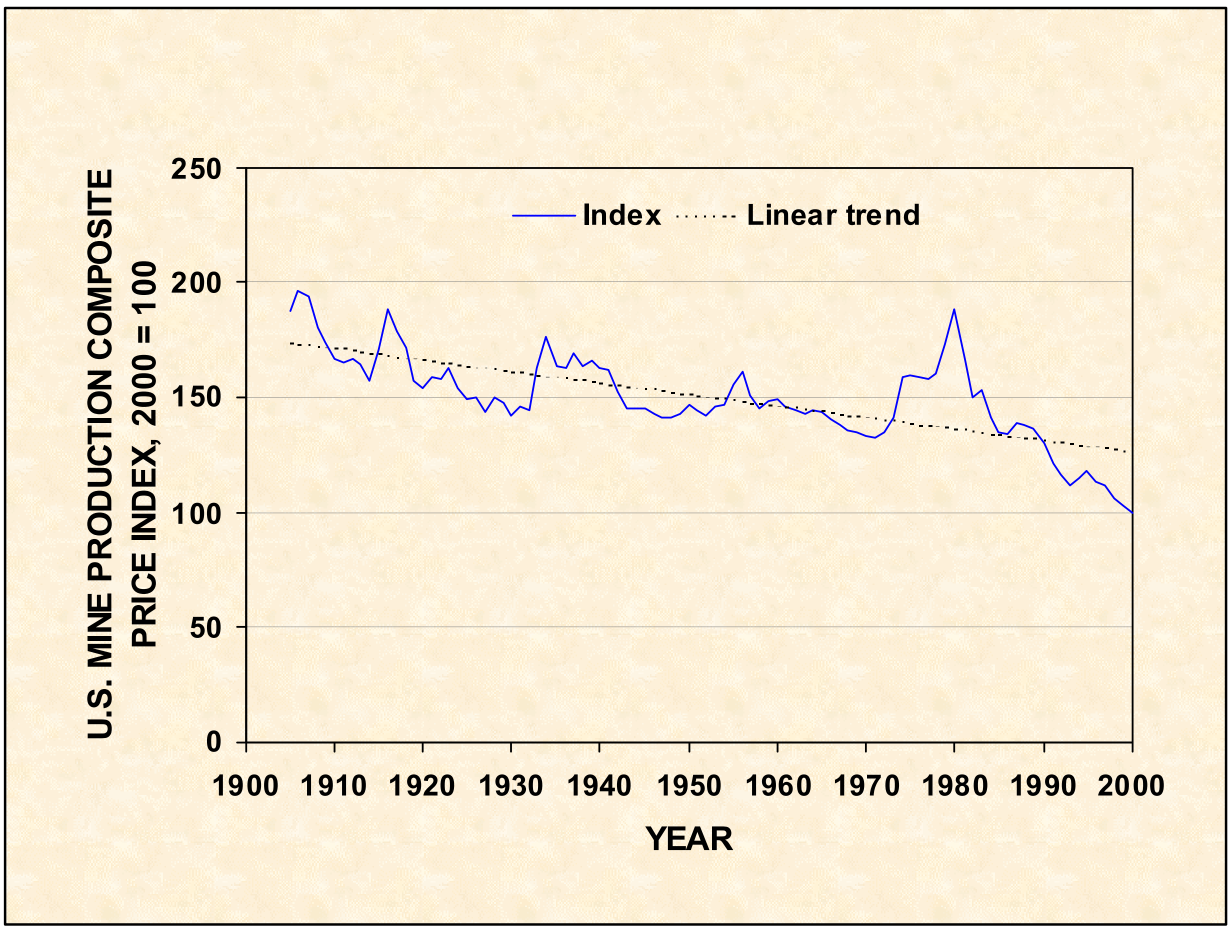

Figure B1. U.S. mine production composite price index, in constant 2000 dollars, 1905-2000.

Table B1. Value of nonfuel mineral production in the United States in the year 2000.

[Adapted from Smith, 2002]

Material	Million dollars	Percent
Industrial minerals		
Cement	6,891	23.6
Clays	1,529	5.2
Lime	1,180	4.0
Phosphate rock, marketable[1]	932	3.2
Salt	1,040	3.6
Sand and gravel	5,946	20.4
Stone, crushed	8,390	28.7
Other industrial minerals	3,292	11.3
Total	29,200	100.0
Metals		
Copper	2,810	27.5
Gold	3,180	31.2
Iron ore, usable[2]	1,560	15.3
Lead	439	4.3
Zinc	1,020	10.0
Other metals	1,191	11.7
Total	10,200	100.0

[1] The product of additional processing and condensing to the point of salability (S.M. Jasinski, U.S. Geological Survey, oral commun., 2002).
[2] Agglomerates, concentrates, direct-shipping ore, and byproduct ore for consumption (U.S. Geological Survey, 2001a, p. 83).

As table B1 shows, the value of industrial minerals is more than double that of metals. Therefore the composite price index is predominantly influenced by the prices of the key industrial minerals – crushed stone, cement, and sand and gravel. Table B2 shows the current dollar prices for these selected commodities while Table B3 shows the same commodities in terms of constant 2000 dollars. Current dollars are converted to constant dollars through the use of the Consumer Price Index that is shown in Table B4. The prices in table B2 were developed from data contained in Historical statistics for mineral commodities in the United States (U.S. Geological Survey, 2001). These prices may or may not match published market prices. When they don't match published market prices it is because they reflect an average of various market prices.

Table B2. Prices of selected mineral commodities in current dollars.

[Data from U.S. Geological Survey, 2001; NA, not available. Aluminum is not a component of the price index.]

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per lb	$ per lb	$ per troy oz	$ per ton	$ per ton	$ per ton
1900	4.00	2.38	NA	3.54	2.62	NA	1.84	0.33	0.16	18.94	2.35	100	97
1901	4.50	2.61	NA	3.52	2.53	NA	1.84	0.33	0.16	18.97	1.68	97	90
1902	5.34	2.26	NA	3.10	1.87	0.85	1.84	0.33	0.12	18.94	1.82	90	106
1903	5.88	2.42	NA	3.31	2.19	0.96	1.84	0.33	0.13	18.94	1.88	93	119
1904	4.79	2.32	4.05	3.45	2.15	0.59	1.84	0.35	0.13	18.91	1.55	95	112
1905	5.26	2.31	4.17	3.42	1.85	0.55	0.65	0.35	0.16	18.88	1.75	99	130
1906	6.16	2.41	4.30	4.06	1.86	0.42	0.65	0.36	0.19	18.91	2.09	126	135
1907	6.14	2.53	4.51	4.63	2.02	0.38	0.69	0.45	0.20	18.94	2.53	119	128
1908	4.93	2.44	4.42	4.72	2.06	0.39	0.67	0.29	0.13	18.94	2.25	93	101
1909	4.76	2.49	4.38	2.41	2.18	0.34	0.68	0.22	0.13	18.94	2.13	95	119
1910	5.33	2.38	4.43	1.80	2.05	0.33	0.65	0.22	0.13	18.91	2.46	97	119
1911	5.32	2.51	4.45	1.52	2.11	0.35	0.65	0.20	0.13	18.91	1.98	97	126
1912	4.99	2.40	4.36	1.60	2.22	0.38	0.65	0.22	0.16	18.94	1.95	99	152
1913	6.06	2.43	4.54	1.08	2.32	0.34	0.67	0.24	0.16	18.91	2.12	97	123
1914	5.54	2.74	4.33	1.64	2.31	0.34	0.67	0.19	0.13	18.97	1.76	86	112
1915	5.18	2.49	4.39	2.39	2.42	0.34	0.66	0.34	0.17	19.16	1.83	104	313
1916	6.61	2.70	5.01	2.70	2.36	0.37	0.72	0.61	0.28	19.38	2.40	152	300
1917	8.14	3.23	6.93	2.82	3.15	0.51	0.78	0.52	0.29	19.56	3.12	190	196
1918	9.65	3.63	9.22	3.06	4.10	0.68	1.03	0.34	0.25	19.75	3.46	157	176
1919	10.32	4.76	9.75	4.17	4.34	0.70	1.18	0.32	0.18	19.94	3.20	128	154
1920	12.12	4.80	11.60	4.71	4.82	0.87	1.33	0.33	0.18	20.53	4.14	181	172

Table B2. Prices of selected mineral commodities in current dollars-*Continued.*

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per lb	$ per lb	$ per troy oz	$ per ton	$ per ton	$ per ton
1921	11.22	5.02	10.80	3.68	5.43	0.78	1.31	0.22	0.13	20.59	3.00	104	104
1922	10.38	4.86	10.10	2.73	4.46	0.80	1.17	0.19	0.14	20.75	3.32	126	126
1923	11.13	4.66	10.80	2.65	4.30	0.77	1.27	0.25	0.15	20.65	3.44	163	148
1924	10.50	4.42	10.70	2.53	4.17	0.69	1.19	0.27	0.13	20.68	2.83	183	139
1925	10.20	4.48	10.30	2.22	3.90	0.69	1.16	0.27	0.14	20.65	2.57	201	169
1926	9.89	4.96	10.00	2.64	3.75	0.67	1.25	0.27	0.14	20.62	2.52	186	163
1927	9.43	4.90	9.65	2.94	3.61	0.64	1.13	0.25	0.13	20.65	2.50	150	138
1928	9.11	4.87	9.01	3.13	3.65	0.66	1.23	0.24	0.15	20.68	2.45	139	133
1929	8.66	4.78	8.64	3.04	3.53	0.66	1.10	0.24	0.18	20.62	2.65	151	143
1930	8.42	4.60	8.33	3.15	3.42	0.65	1.08	0.24	0.13	20.59	2.47	122	101
1931	6.51	4.57	7.60	3.19	3.23	0.63	1.11	0.23	0.08	22.49	2.36	94	80
1932	5.95	4.80	6.92	2.70	3.43	0.54	1.04	0.23	0.06	20.68	1.41	70	64
1933	7.83	4.63	6.92	2.60	3.23	0.55	0.96	0.23	0.07	26.34	3.52	85	89
1934	9.06	4.64	7.89	2.72	3.31	0.58	1.10	0.23	0.09	34.84	2.64	85	92
1935	8.81	4.42	8.03	2.64	3.04	0.55	0.99	0.20	0.09	34.84	2.66	90	96
1936	8.61	4.28	7.92	2.13	2.78	0.56	1.01	0.21	0.10	34.84	2.64	104	108
1937	8.45	4.45	8.04	2.45	2.88	0.57	1.12	0.20	0.13	34.84	2.82	132	144
1938	8.26	4.99	7.95	2.42	3.19	0.53	1.07	0.20	0.10	34.84	2.56	104	102
1939	8.43	4.68	7.79	2.48	2.91	0.52	1.03	0.20	0.11	34.52	2.99	111	113
1940	8.45	4.30	7.66	2.57	2.82	0.51	1.02	0.19	0.12	33.90	2.52	114	140

Table B2. Prices of selected mineral commodities in current dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per lb	$ per lb	$ per troy oz	$ per ton	$ per ton	$ per ton
1941	8.61	3.96	7.79	2.65	2.91	0.56	1.07	0.16	0.12	33.90	2.65	128	165
1942	8.89	3.77	8.01	3.17	3.07	0.68	1.08	0.15	0.12	33.90	2.61	143	182
1943	9.16	2.05	8.20	3.36	3.01	0.72	1.12	0.15	0.12	33.90	2.62	143	182
1944	9.60	2.23	8.29	3.58	3.07	0.71	1.16	0.15	0.12	33.90	2.69	143	182
1945	9.56	2.46	8.55	3.85	3.14	0.73	1.19	0.15	0.12	34.84	2.72	143	182
1946	10.09	2.15	9.39	4.30	3.27	0.74	1.28	0.15	0.14	34.84	3.01	179	192
1947	11.14	2.35	10.40	5.04	3.58	0.83	1.36	0.15	0.21	34.84	3.44	323	232
1948	12.78	2.41	11.40	5.75	3.65	0.88	1.41	0.16	0.22	34.84	3.88	398	299
1949	13.49	2.39	12.10	5.63	3.80	0.85	1.46	0.17	0.20	31.73	4.46	339	268
1950	13.78	2.58	12.30	5.71	3.97	0.88	1.49	0.18	0.22	34.84	4.92	293	306
1951	14.89	3.14	12.90	5.87	3.80	0.91	1.49	0.19	0.24	34.84	5.40	386	397
1952	14.89	3.33	13.00	6.04	4.00	0.90	1.52	0.19	0.24	34.52	6.21	363	357
1953	15.71	3.13	12.80	6.14	4.15	0.93	1.55	0.21	0.29	34.84	6.81	297	239
1954	16.30	3.05	13.00	6.29	5.63	1.00	1.48	0.22	0.30	35.15	6.76	310	236
1955	16.95	3.02	13.40	6.23	5.99	1.00	1.52	0.24	0.38	35.15	7.21	334	271
1956	18.06	3.35	14.10	6.50	6.20	1.05	1.53	0.24	0.42	35.15	7.68	353	297
1957	18.82	3.49	14.50	6.29	6.88	1.04	1.54	0.25	0.30	34.84	8.10	323	251
1958	19.17	3.40	14.50	6.29	7.12	1.05	1.54	0.25	0.26	35.15	8.27	267	227
1959	19.35	3.33	14.50	6.18	6.83	1.09	1.56	0.25	0.31	35.15	8.48	269	253
1960	19.76	3.44	14.70	6.82	6.97	1.12	1.55	0.26	0.32	35.15	8.35	263	286

Table B2. Prices of selected mineral commodities in current dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per lb	$ per lb	$ per troy oz	$ per ton	$ per ton	$ per ton
1961	19.64	3.41	14.80	7.16	6.87	1.10	1.54	0.26	0.30	35.15	9.13	240	255
1962	19.41	3.46	15.00	7.11	6.69	1.13	1.55	0.24	0.31	35.15	8.82	212	256
1963	18.94	3.60	15.10	7.15	6.64	1.13	1.56	0.23	0.31	35.15	9.22	246	265
1964	18.88	3.60	15.30	7.16	7.00	1.14	1.61	0.24	0.32	35.15	9.46	300	299
1965	18.65	3.68	15.30	7.08	6.85	1.16	1.58	0.24	0.35	35.15	9.25	353	320
1966	18.47	3.82	14.60	7.39	6.95	1.16	1.59	0.24	0.36	35.15	9.50	333	320
1967	18.59	3.98	14.80	7.31	7.11	1.19	1.61	0.25	0.38	35.15	9.64	309	305
1968	18.71	4.03	14.80	6.76	7.27	1.23	1.64	0.26	0.41	40.12	9.78	291	298
1969	18.94	4.25	15.40	6.29	7.17	1.26	1.70	0.27	0.47	41.68	10.15	329	323
1970	19.71	4.22	16.30	5.99	7.32	1.30	1.75	0.29	0.58	36.39	10.39	346	338
1971	20.95	4.22	17.50	5.94	7.59	1.37	1.89	0.29	0.52	41.37	10.92	306	356
1972	22.70	4.53	18.60	5.56	7.27	1.45	1.90	0.25	0.51	58.47	12.09	331	391
1973	24.50	4.86	19.20	6.11	7.68	1.52	1.98	0.26	0.60	97.98	12.75	359	456
1974	29.53	5.83	24.30	10.93	8.55	1.73	2.20	0.43	0.77	159.87	15.50	496	793
1975	34.62	7.17	30.30	20.16	9.89	1.87	2.59	0.35	0.64	161.43	19.44	474	859
1976	37.75	8.31	33.30	18.84	10.75	2.21	2.59	0.41	0.70	125.35	22.56	509	816
1977	40.52	9.10	36.90	15.90	11.47	2.40	2.71	0.48	0.67	148.36	25.00	677	758
1978	45.38	10.62	40.50	17.07	12.84	2.55	2.91	0.51	0.66	193.46	27.74	743	683
1979	51.38	12.93	45.50	18.40	12.96	2.73	3.28	0.71	0.92	307.61	30.79	1,160	822
1980	56.57	15.44	49.00	20.22	17.92	3.19	3.66	0.76	1.01	612.74	34.48	937	825

Table B2. Prices of selected mineral commodities in current dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per ton	$ per lb	$ per lb	$ per troy oz	$ per ton	$ per ton	$ per ton
1981	57.83	18.72	51.80	23.89	18.06	3.46	3.95	0.60	0.84	460.33	37.46	805	983
1982	56.69	18.83	54.50	24.03	19.53	3.55	4.07	0.47	0.73	376.35	38.68	562	848
1983	55.61	19.48	56.30	22.85	19.04	3.62	4.27	0.68	0.77	423.01	46.31	478	913
1984	57.18	19.85	56.40	22.84	18.97	3.60	4.33	0.61	0.67	360.80	39.92	564	1,070
1985	55.92	18.41	57.00	23.23	20.35	3.74	4.46	0.49	0.67	317.26	38.58	421	890
1986	54.78	19.80	57.90	21.57	20.01	3.76	4.59	0.56	0.66	367.02	34.22	485	838
1987	54.41	17.31	55.20	18.87	20.67	4.01	4.82	0.72	0.83	478.99	29.64	791	924
1988	54.80	21.47	53.00	18.70	19.80	4.08	4.82	1.10	1.21	438.56	28.33	818	1,330
1989	54.80	25.24	54.90	20.76	22.04	4.35	4.84	0.88	1.31	382.57	31.31	869	1,810
1990	55.34	23.96	57.10	22.29	22.39	4.31	5.18	0.74	1.23	385.68	30.89	1,010	1,640
1991	55.46	23.29	57.00	22.28	22.32	4.37	5.31	0.59	1.09	363.91	30.11	739	1,160
1992	55.30	22.43	58.80	22.28	23.07	4.40	5.31	0.58	1.07	345.25	28.58	774	1,290
1993	56.36	22.44	57.70	21.29	23.66	4.45	5.30	0.53	0.92	360.80	25.79	699	1,020
1994	61.88	23.25	58.60	22.03	24.94	4.61	5.38	0.71	1.11	385.68	25.16	820	1,090
1995	67.84	24.18	59.50	21.75	24.51	4.71	5.36	0.86	1.38	385.68	27.73	933	1,230
1996	71.19	23.58	61.50	23.40	24.71	4.78	5.40	0.71	1.09	388.79	28.90	1,080	1,127
1997	73.49	22.24	61.00	24.40	24.46	4.86	5.64	0.77	1.07	332.81	29.92	1,030	1,423
1998	76.45	27.02	60.40	25.46	24.17	4.92	5.39	0.66	0.79	295.17	31.16	998	1,134
1999	76.45	20.40	60.40	30.56	25.00	5.08	5.35	0.66	0.76	279.93	26.77	964	1,179
2000	78.56	18.74	60.60	24.14	24.02	5.18	5.39	0.75	0.88	279.93	25.81	961	1,226

Table B3. Prices of selected mineral commodities in constant dollars.

[Data from U.S. Geological Survey, 2001; NA, not available. Aluminum is not a component of the price index.]

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per lb	2000$ per lb	2000$ per tr. oz	2000$ per ton	2000$ per ton	2000$ per ton
1900	83.33	49.58	NA	73.75	54.03	NA	38.33	6.74	3.34	390.64	48.96	2,083	2,021
1901	93.75	54.38	NA	73.33	52.25	NA	38.33	6.81	3.32	391.28	35.00	2,021	1,875
1902	106.80	45.20	NA	62.00	37.11	16.83	36.80	6.54	2.30	375.61	36.40	1,800	2,120
1903	113.08	46.54	NA	63.65	41.91	18.42	35.38	6.30	2.52	361.70	36.15	1,788	2,288
1904	92.12	44.62	77.88	66.35	41.09	11.32	35.38	6.68	2.44	361.11	29.81	1,827	2,154
1905	101.15	44.42	80.19	65.77	35.30	10.54	12.50	6.68	2.98	360.51	33.65	1,904	2,500
1906	118.46	46.35	82.69	78.08	35.53	8.00	12.50	6.84	3.68	361.11	40.19	2,423	2,596
1907	113.70	46.85	83.52	85.74	37.13	7.02	12.78	8.29	3.68	348.78	46.85	2,204	2,370
1908	94.81	46.92	85.00	90.77	39.40	7.46	12.88	5.48	2.52	361.70	43.27	1,788	1,942
1909	91.54	47.88	84.23	46.35	41.67	6.58	13.08	4.20	2.50	361.70	40.96	1,827	2,288
1910	98.70	44.07	82.04	33.33	37.79	6.20	12.04	4.11	2.37	348.21	45.56	1,796	2,204
1911	98.52	46.48	82.41	28.15	38.80	6.41	12.04	3.70	2.31	348.21	36.67	1,796	2,333
1912	89.11	42.86	77.86	28.57	39.50	6.69	11.61	3.91	2.93	336.76	34.82	1,768	2,714
1913	106.32	42.63	79.65	18.95	40.30	5.85	11.75	4.10	2.70	328.94	37.19	1,702	2,158
1914	95.52	47.24	74.66	28.28	39.72	5.83	11.55	3.20	2.29	326.72	30.34	1,483	1,931
1915	87.80	42.20	74.41	40.51	41.25	5.76	11.19	5.80	2.98	326.66	31.02	1,763	5,305
1916	104.92	42.86	79.52	42.86	37.35	5.87	11.43	9.59	4.49	306.13	38.10	2,413	4,762
1917	110.00	43.65	93.65	38.11	42.38	6.81	10.54	6.94	3.93	263.20	42.16	2,568	2,649
1918	109.66	41.25	104.77	34.77	46.78	7.75	11.70	3.82	2.81	225.24	39.32	1,784	2,000
1919	103.20	47.60	97.50	41.70	43.16	7.01	11.80	3.20	1.81	198.45	32.00	1,280	1,540
1920	104.48	41.38	100.00	40.60	41.48	7.51	11.47	2.82	1.51	176.75	35.69	1,560	1,483

Table B3. Prices of selected mineral commodities in constant dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per lb	2000$ per lb	2000$ per tr oz	2000$ per ton	2000$ per ton	2000$ per ton
1921	107.88	48.27	103.85	35.38	52.28	7.50	12.60	2.13	1.22	198.08	28.85	1,000	1,000
1922	105.92	49.59	103.06	27.86	45.68	8.20	11.94	1.92	1.39	212.65	33.88	1,286	1,286
1923	112.42	47.07	109.09	26.77	43.27	7.71	12.83	2.56	1.48	207.98	34.75	1,646	1,495
1924	106.06	44.65	108.08	25.56	42.01	6.91	12.02	2.72	1.34	208.29	28.59	1,848	1,404
1925	100.00	43.92	100.98	21.76	38.36	6.83	11.37	2.68	1.41	203.22	25.20	1,971	1,657
1926	96.02	48.16	97.09	25.63	36.45	6.54	12.14	2.63	1.37	200.62	24.47	1,806	1,583
1927	93.37	48.51	95.54	29.11	35.77	6.37	11.19	2.51	1.29	204.39	24.75	1,485	1,366
1928	92.02	49.19	91.01	31.62	36.80	6.64	12.42	2.45	1.49	208.29	24.75	1,404	1,343
1929	87.47	48.28	87.27	30.71	35.52	6.60	11.11	2.45	1.85	207.66	26.77	1,525	1,444
1930	86.80	47.42	85.88	32.47	35.29	6.70	11.13	2.45	1.37	212.32	25.46	1,258	1,041
1931	73.98	51.93	86.36	36.25	36.56	7.11	12.61	2.64	0.95	254.76	26.82	1,068	909
1932	74.38	60.00	86.50	33.75	43.11	6.74	13.00	2.93	0.73	259.98	17.63	875	800
1933	104.40	61.73	92.27	34.67	42.85	7.25	12.80	3.09	0.96	348.97	46.93	1,133	1,187
1934	116.15	59.49	101.15	34.87	42.52	7.50	14.10	3.01	1.11	447.67	33.85	1,090	1,179
1935	110.13	55.25	100.38	33.00	38.17	6.91	12.38	2.51	1.12	437.86	33.25	1,125	1,200
1936	106.30	52.84	97.78	26.30	36.05	6.93	12.47	2.54	1.20	431.56	32.59	1,284	1,333
1937	100.60	52.98	95.71	29.17	34.42	6.76	13.33	2.38	1.60	416.58	33.57	1,571	1,714
1938	100.73	60.85	96.95	29.51	38.99	6.49	13.05	2.44	1.25	425.44	31.22	1,268	1,244
1939	104.07	57.78	96.17	30.62	36.08	6.47	12.72	2.48	1.39	427.71	36.91	1,370	1,395
1940	104.32	53.09	94.57	31.73	34.65	6.24	12.59	2.30	1.42	417.00	31.11	1,407	1,728

Table B3. Prices of selected mineral commodities in constant dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per lb	2000$ per lb	2000$ per tr oz	2000$ per ton	2000$ per ton	2000$ per ton
1941	101.29	46.59	91.65	31.18	35.14	6.59	12.59	1.93	1.41	397.15	31.18	1,506	1,941
1942	93.58	39.68	84.32	33.37	32.44	7.23	11.37	1.58	1.27	358.16	27.47	1,505	1,916
1943	91.60	20.50	82.00	33.60	29.95	7.20	11.20	1.49	1.20	337.46	26.20	1,430	1,820
1944	94.12	21.86	81.27	35.10	30.00	6.94	11.37	1.47	1.18	331.71	26.37	1,402	1,784
1945	91.05	23.43	81.43	36.67	30.08	6.97	11.33	1.44	1.15	333.26	25.90	1,362	1,733
1946	89.29	19.03	83.10	38.05	28.89	6.51	11.33	1.32	1.24	307.63	26.64	1,584	1,699
1947	85.69	18.08	80.00	38.77	27.67	6.40	10.46	1.16	1.64	269.00	26.46	2,485	1,785
1948	91.29	17.21	81.43	41.07	26.09	6.27	10.07	1.12	1.59	248.91	27.71	2,843	2,136
1949	97.75	17.32	87.68	40.80	27.47	6.18	10.58	1.23	1.41	229.54	32.32	2,457	1,942
1950	98.43	18.43	87.86	40.79	28.38	6.27	10.64	1.26	1.54	248.91	35.14	2,093	2,186
1951	98.61	20.79	85.43	38.87	25.19	6.05	9.87	1.26	1.62	230.72	35.76	2,556	2,629
1952	96.69	21.62	84.42	39.22	26.02	5.84	9.87	1.26	1.59	224.35	40.32	2,357	2,318
1953	101.35	20.19	82.58	39.61	26.77	6.03	10.00	1.35	1.87	224.67	43.94	1,916	1,542
1954	104.49	19.55	83.33	40.32	36.03	6.38	9.49	1.40	1.92	224.99	43.33	1,987	1,513
1955	108.65	19.36	85.90	39.94	38.48	6.43	9.74	1.52	2.41	225.83	46.22	2,141	1,737
1956	114.30	21.20	89.24	41.14	39.25	6.65	9.68	1.52	2.66	222.51	48.61	2,234	1,880
1957	115.46	21.41	88.96	38.59	42.19	6.38	9.45	1.56	1.85	213.48	49.69	1,982	1,540
1958	114.11	20.24	86.31	37.44	42.42	6.27	9.17	1.48	1.57	209.42	49.23	1,589	1,351
1959	114.50	19.70	85.80	36.57	40.41	6.45	9.23	1.46	1.83	207.98	50.18	1,592	1,497
1960	114.88	20.00	85.47	39.65	40.57	6.54	9.01	1.51	1.88	204.47	48.55	1,529	1,663

Table B3. Prices of selected mineral commodities in constant dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per lb	2000$ per lb	2000$ per tr oz	2000$ per ton	2000$ per ton	2000$ per ton
1961	112.87	19.60	85.06	41.15	39.57	6.34	8.85	1.47	1.75	202.42	52.47	1,379	1,466
1962	110.91	19.77	85.71	40.63	38.15	6.43	8.86	1.36	1.77	200.41	50.40	1,211	1,463
1963	106.40	20.22	84.83	40.17	37.37	6.38	8.76	1.27	1.74	197.79	51.80	1,382	1,489
1964	104.89	20.00	85.00	39.78	38.86	6.31	8.94	1.32	1.80	195.24	52.56	1,667	1,661
1965	101.91	20.11	83.61	38.69	37.47	6.32	8.63	1.34	1.93	192.14	50.55	1,929	1,749
1966	98.24	20.32	77.66	39.31	36.95	6.17	8.46	1.30	1.91	186.80	50.53	1,771	1,702
1967	95.82	20.52	76.29	37.68	36.66	6.15	8.30	1.29	1.96	181.21	49.69	1,593	1,572
1968	92.62	19.95	73.27	33.47	35.98	6.08	8.12	1.27	2.04	198.54	48.42	1,441	1,475
1969	88.92	19.95	72.30	29.53	33.63	5.93	7.98	1.28	2.23	195.56	47.65	1,545	1,516
1970	87.60	18.76	72.44	26.62	32.49	5.77	7.73	1.27	2.58	161.51	46.18	1,538	1,502
1971	89.15	17.96	74.47	25.28	32.29	5.84	8.09	1.23	2.21	175.89	46.47	1,302	1,515
1972	93.42	18.64	76.54	22.88	29.93	5.98	7.82	1.03	2.12	240.89	49.75	1,362	1,609
1973	94.96	18.84	74.42	23.68	29.80	5.90	7.67	1.02	2.31	379.99	49.42	1,391	1,767
1974	103.25	20.38	84.97	38.22	29.85	6.03	7.69	1.51	2.70	558.42	54.20	1,734	2,773
1975	110.96	22.98	97.12	64.62	31.65	5.99	7.92	1.11	2.05	516.69	62.31	1,519	2,753
1976	114.39	25.18	100.91	57.09	32.53	6.69	7.85	1.25	2.11	379.35	68.36	1,542	2,473
1977	115.11	25.85	104.83	45.17	32.58	6.83	7.73	1.36	1.90	421.59	71.02	1,923	2,153
1978	119.74	28.02	106.86	45.04	33.91	6.73	7.68	1.35	1.74	510.96	73.19	1,960	1,802
1979	121.75	30.64	107.82	43.60	30.74	6.48	7.82	1.68	2.19	729.63	72.96	2,749	1,948
1980	118.10	32.23	102.30	42.21	37.46	6.67	7.64	1.59	2.12	1,280.50	71.98	1,956	1,722

Table B3. Prices of selected mineral commodities in constant dollars-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold	Iron ore	Lead	Zinc
	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per ton	2000$ per lb	2000$ per lb	2000$ per tr oz	2000$ per ton	2000$ per ton	2000$ per ton
1981	109.53	35.45	98.11	45.25	34.22	6.55	7.48	1.13	1.60	872.05	70.95	1,525	1,862
1982	101.23	33.63	97.32	42.91	34.85	6.33	7.27	0.84	1.30	671.58	69.07	1,004	1,514
1983	96.21	33.70	97.40	39.53	32.91	6.25	7.39	1.18	1.32	731.34	80.12	827	1,580
1984	94.83	32.92	93.53	37.88	31.44	5.97	7.18	1.01	1.11	597.98	66.20	935	1,774
1985	89.47	29.46	91.20	37.17	32.56	5.98	7.14	0.78	1.07	507.73	61.73	674	1,424
1986	86.13	31.13	91.04	33.92	31.43	5.91	7.22	0.88	1.04	576.65	53.81	763	1,318
1987	82.44	26.23	83.64	28.59	31.33	6.08	7.30	1.10	1.25	726.08	44.91	1,198	1,400
1988	79.77	31.25	77.15	27.22	28.82	5.93	7.02	1.60	1.75	638.38	41.24	1,191	1,936
1989	76.11	35.06	76.25	28.83	30.60	6.04	6.72	1.22	1.82	531.28	43.49	1,207	2,514
1990	72.91	31.57	75.23	29.37	29.50	5.68	6.82	0.97	1.62	508.15	40.70	1,331	2,161
1991	70.11	29.44	72.06	28.17	28.23	5.52	6.71	0.75	1.38	460.10	38.07	934	1,466
1992	67.85	27.52	72.15	27.34	28.32	5.40	6.52	0.71	1.32	423.75	35.07	950	1,583
1993	67.18	26.75	68.77	25.38	28.20	5.30	6.32	0.64	1.09	429.96	30.74	833	1,216
1994	71.87	27.00	68.06	25.59	28.98	5.35	6.25	0.83	1.29	448.14	29.22	952	1,266
1995	76.66	27.32	67.23	24.58	27.69	5.32	6.06	0.97	1.56	435.79	31.33	1,054	1,390
1996	78.14	25.88	67.51	25.69	27.12	5.24	5.93	0.78	1.20	426.71	31.72	1,186	1,237
1997	78.85	23.86	65.45	26.18	26.24	5.22	6.05	0.83	1.15	357.07	32.10	1,105	1,527
1998	80.73	28.53	63.78	26.88	25.53	5.20	5.69	0.69	0.83	311.83	32.90	1,054	1,197
1999	79.06	21.10	62.46	31.60	25.84	5.25	5.53	0.68	0.78	289.34	27.68	997	1,219
2000	78.56	18.74	60.60	24.14	24.02	5.18	5.39	0.75	0.88	279.93	25.81	961	1,226

Table B4. Consumer Price Index, 2000 = 100.

[Adapted from U.S Census Bureau, 1975 and U.S. Department of Labor, Bureau of Labor Statistics, 2001§]

Year	Index	Year	Index	Year	Index	Year	Index	Year	Index
1900	4.85	1920	11.61	1940	8.13	1960	17.19	1980	47.85
1901	4.85	1921	10.39	1941	8.54	1961	17.36	1981	52.79
1902	5.04	1922	9.76	1942	9.47	1962	17.54	1982	56.04
1903	5.24	1923	9.93	1943	10.05	1963	17.77	1983	57.84
1904	5.24	1924	9.93	1944	10.22	1964	18.00	1984	60.34
1905	5.24	1925	10.16	1945	10.45	1965	18.29	1985	62.49
1906	5.24	1926	10.28	1946	11.32	1966	18.82	1986	63.65
1907	5.43	1927	10.10	1947	12.95	1967	19.40	1987	65.97
1908	5.24	1928	9.93	1948	14.00	1968	20.21	1988	68.70
1909	5.24	1929	9.93	1949	13.82	1969	21.31	1989	72.01
1910	5.43	1930	9.70	1950	14.00	1970	22.53	1990	75.90
1911	5.43	1931	8.83	1951	15.10	1971	23.52	1991	79.09
1912	5.62	1932	7.96	1952	15.39	1972	24.27	1992	81.48
1913	5.75	1933	7.55	1953	15.51	1973	25.78	1993	83.91
1914	5.81	1934	7.78	1954	15.62	1974	28.63	1994	86.06
1915	5.87	1935	7.96	1955	15.56	1975	31.24	1995	88.50
1916	6.33	1936	8.07	1956	15.80	1976	33.04	1996	91.11
1917	7.43	1937	8.36	1957	16.32	1977	35.19	1997	93.21
1918	8.77	1938	8.19	1958	16.78	1978	37.86	1998	94.66
1919	10.05	1939	8.07	1959	16.90	1979	42.16	1999	96.75
								2000	100.00

Table B5. Price indexes, in constant 2000 dollars.

Year	Composite	Metals	Industrial minerals	Year	Composite	Metals	Industrial minerals
1900	NA	228.4	NA	1950	146.7	140.3	149.0
1901	NA	216.6	NA	1951	143.9	147.6	142.6
1902	NA	181.1	NA	1952	142.5	145.1	141.5
1903	NA	188.4	NA	1953	145.4	148.1	144.4
1904	284.1	180.1	321.5	1954	146.8	149.3	145.9
1905	187.6	205.1	181.4	1955	155.7	171.8	150.0
1906	196.1	237.7	181.1	1956	161.2	183.4	153.2
1907	194.3	237.8	178.6	1957	150.8	150.1	151.1
1908	180.8	190.1	177.4	1958	145.1	135.9	148.5
1909	174.0	191.3	167.8	1959	148.4	147.0	149.0
1910	166.4	187.3	158.8	1960	148.6	148.3	148.7
1911	164.8	180.3	159.2	1961	145.6	143.5	146.3
1912	166.9	202.5	154.1	1962	144.3	141.5	145.3
1913	164.7	189.5	155.7	1963	143.0	142.6	143.1
1914	157.0	167.3	153.2	1964	144.4	147.6	143.3
1915	170.2	224.7	150.6	1965	143.3	152.8	139.9
1916	188.8	277.7	156.8	1966	139.9	150.1	136.3
1917	178.5	236.9	157.4	1967	137.9	148.6	134.1
1918	172.1	181.7	168.7	1968	135.7	150.7	130.3
1919	157.1	130.9	166.6	1969	134.5	157.3	126.3
1920	154.1	121.2	165.9	1970	133.7	164.1	122.7
1921	158.5	101.8	178.9	1971	132.7	152.4	125.7
1922	157.8	117.4	172.3	1972	134.9	160.7	125.7
1923	162.8	124.1	176.7	1973	141.2	186.1	125.0
1924	154.0	114.9	168.0	1974	159.3	236.3	131.6
1925	149.2	117.5	160.6	1975	159.9	212.8	140.9
1926	150.1	113.8	163.1	1976	159.1	199.2	144.7
1927	143.3	108.1	155.9	1977	158.0	198.2	143.5
1928	149.9	114.9	162.5	1978	160.3	202.3	145.2
1929	147.4	130.3	153.6	1979	173.1	250.6	145.2
1930	142.3	108.1	154.7	1980	188.2	310.4	144.2
1931	145.3	97.5	162.5	1981	165.8	239.3	139.4
1932	144.3	82.3	166.6	1982	150.0	196.6	133.2
1933	163.3	126.3	176.7	1983	152.8	212.3	131.4
1934	176.4	135.0	191.3	1984	141.7	180.7	127.6
1935	163.5	134.0	174.1	1985	134.5	160.6	125.1
1936	162.7	137.7	171.7	1986	134.0	161.9	124.0
1937	169.2	155.5	174.2	1987	138.6	184.9	121.9
1938	164.0	136.5	173.9	1988	138.2	193.9	118.2
1939	165.7	147.7	172.2	1989	135.9	189.6	116.6
1940	162.4	146.3	168.3	1990	130.0	175.3	113.8
1941	161.6	146.0	167.2	1991	121.0	150.7	110.3
1942	152.4	133.8	159.1	1992	116.9	143.0	107.5
1943	145.0	126.1	151.8	1993	111.2	128.8	104.8
1944	145.1	124.4	152.6	1994	114.8	138.1	106.5
1945	145.2	123.0	153.2	1995	117.7	149.2	106.3
1946	142.9	124.0	149.7	1996	113.3	134.8	105.6
1947	141.8	138.7	142.9	1997	111.5	126.8	106.0
1948	141.4	140.2	141.8	1998	105.8	107.4	105.2
1949	143.1	130.8	147.5	1999	102.2	99.2	103.3
				2000	100.0	100.0	100.0

Overall, the trend of the inflation-adjusted prices shown in the composite price index figure B1 decreased throughout the 20th century at an average annual rate of less than 1 percent for the years 1905 to 2000. This downward trend occurred even though the use of mineral materials in the United States increased during this time frame to meet the needs of the growing economy. The declining long-term price trend is an indication that adequate sources of supply exist, competition within the industry is prevalent, and the costs of production have decreased.

Figure B2 shows that industrial mineral commodity prices decreased during the 20th century. Since industrial minerals account for two-thirds of the total value of mineral production included in the U.S. economy, the pattern of this figure closely resembles figure B1, the index of composite prices. Industrial minerals such as cement, crushed stone, and sand and gravel are crucial to the U.S. construction industry.

Among the many reasons why raw construction mineral prices have declined were the advances made in excavation and earth moving equipment. Initially, mining was done by hand. Steam shovels were introduced in the early 20th century, which were soon after replaced by gasoline, diesel, and electric powered equipment. There were also vast improvements in transportation and other infrastructure during the century. These improvements allowed the industry to lower costs that enabled them to reduce real prices and still operate at a profit.

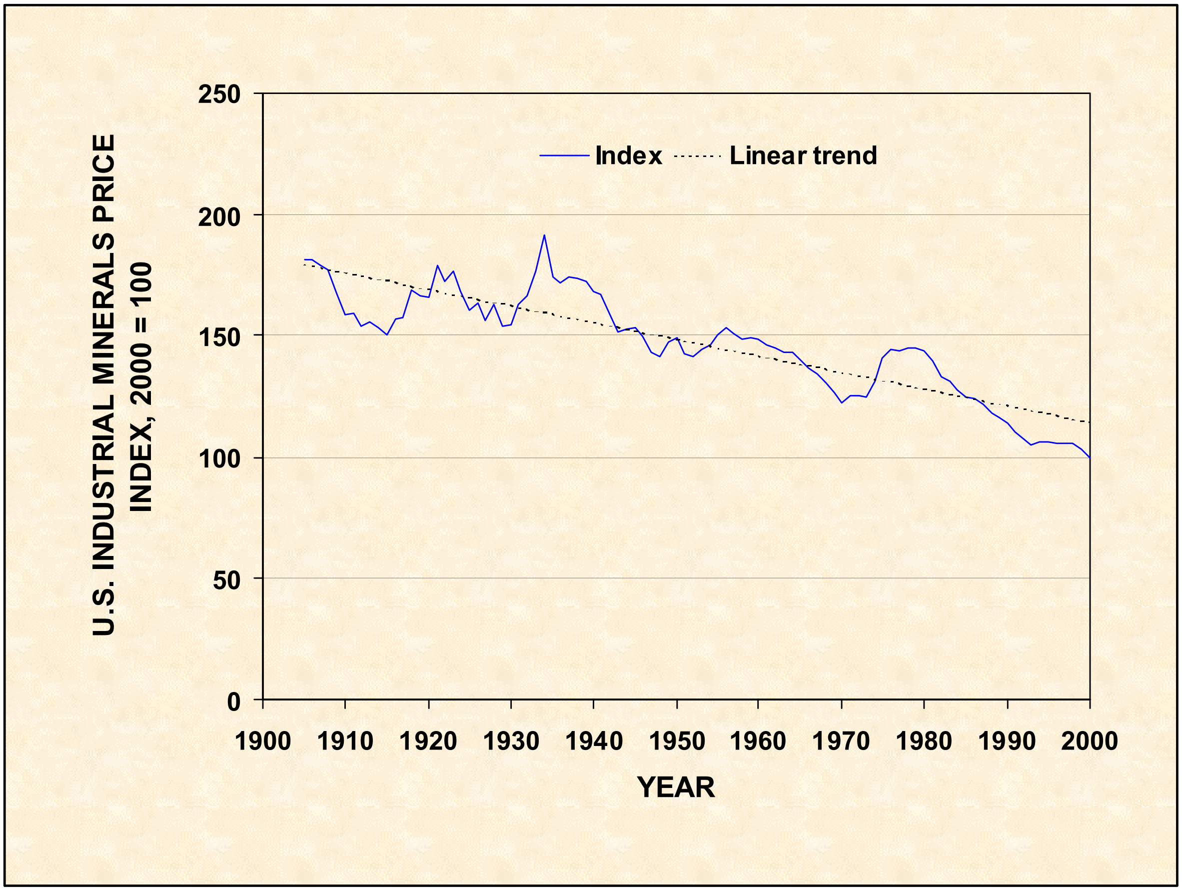

Figure B2. U.S. industrial minerals price index, in constant 2000 dollars, 1905-2000.

Cement accounts for more than 20 percent of the value of production of industrial minerals included in the composite index and in the year 2000 was the industrial mineral with the second largest value of nonfuel mineral production in the United States ($6,901 million), see table B1. Most cement was used in the construction of bridges, buildings, highways, and other infrastructure. The price history of cement is shown in figure B3. The trend line for the constant dollar price of cement shows that, overall, the price declined during the 20th century. The real price was above $110 per ton briefly at the beginning of the century, and again during the "roaring twenties." The lack of economic activity during the depression drove the price below

$75 per ton in 1931 and 1932. The real price rose above $110 per ton in 1934 and 1935, probably as a result of the large public works projects undertaken by the government. The Hoover Dam, which used massive amounts of cement, was completed in 1936. The price went above $110 during the growth period of the late 1950s and early 1960s. It went below $80 during the oil crisis of the early 1970s, but recovered to a peak of almost $110 in 1979. It declined to a low of less than $66 in 1993 and has since increased above $80 spurred by the economic boom of the 1990s.

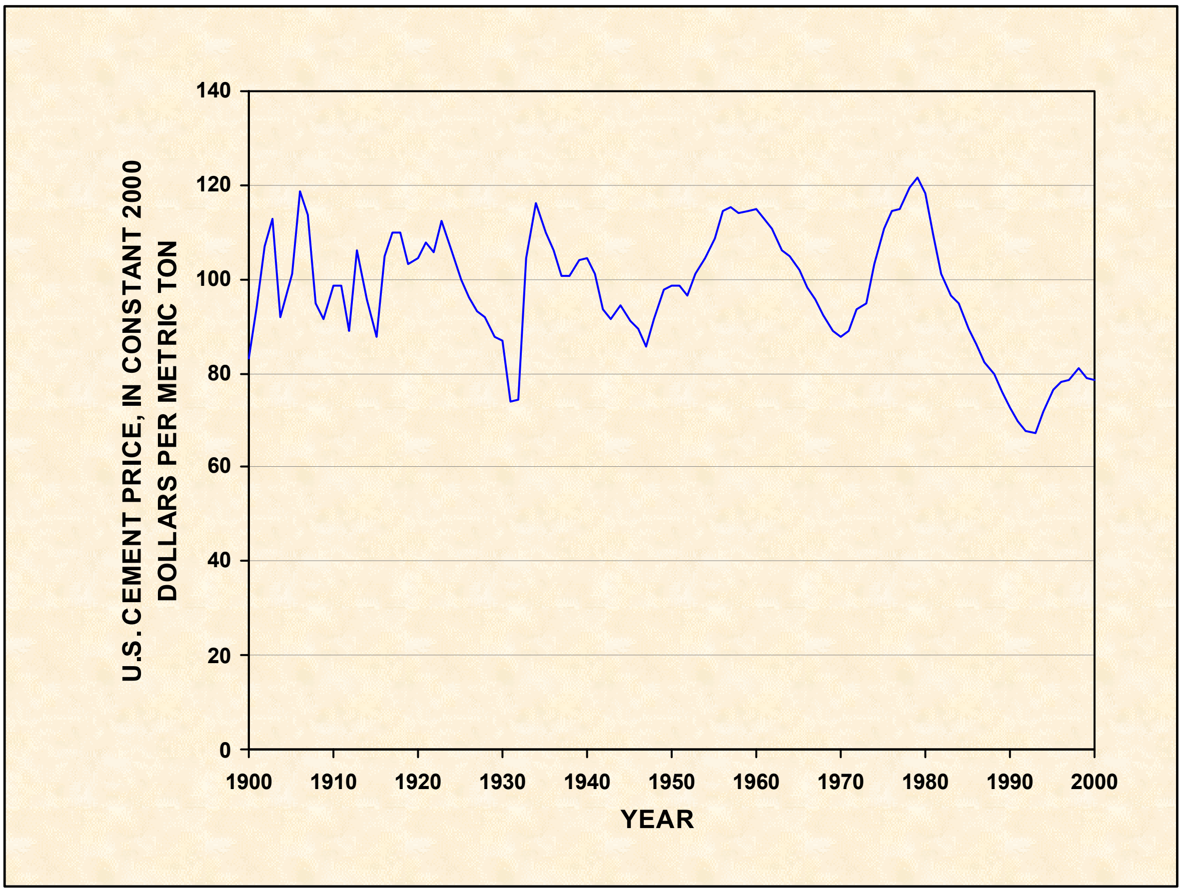

Figure B3. U.S. cement price, in constant 2000 dollars, 1900-2000 (data from van Oss and Kelly, 2001).

The clay price shown in figure B4 is the weighted average unit value price for six types of clays. The clays are ball clay, bentonite, common clay, fire clay, fuller's earth, and kaolin. The figure shows the average unit price of these clays, in constant 2000 dollars. It rose to a peak in the 1930s (during the Great Depression) largely because the price stayed relatively level as the price deflator declined, resulting in an increase in the constant dollar price. The constant dollar price fell sharply to an historical bottom at the end of World War II because clays were not a high priority for the war effort. After World War II, the clay price held steady in a narrow range until the 1970s, when it again increased sharply, leveling off in the 1980s. The overall average trend in clay prices for the century shows a slight decline.

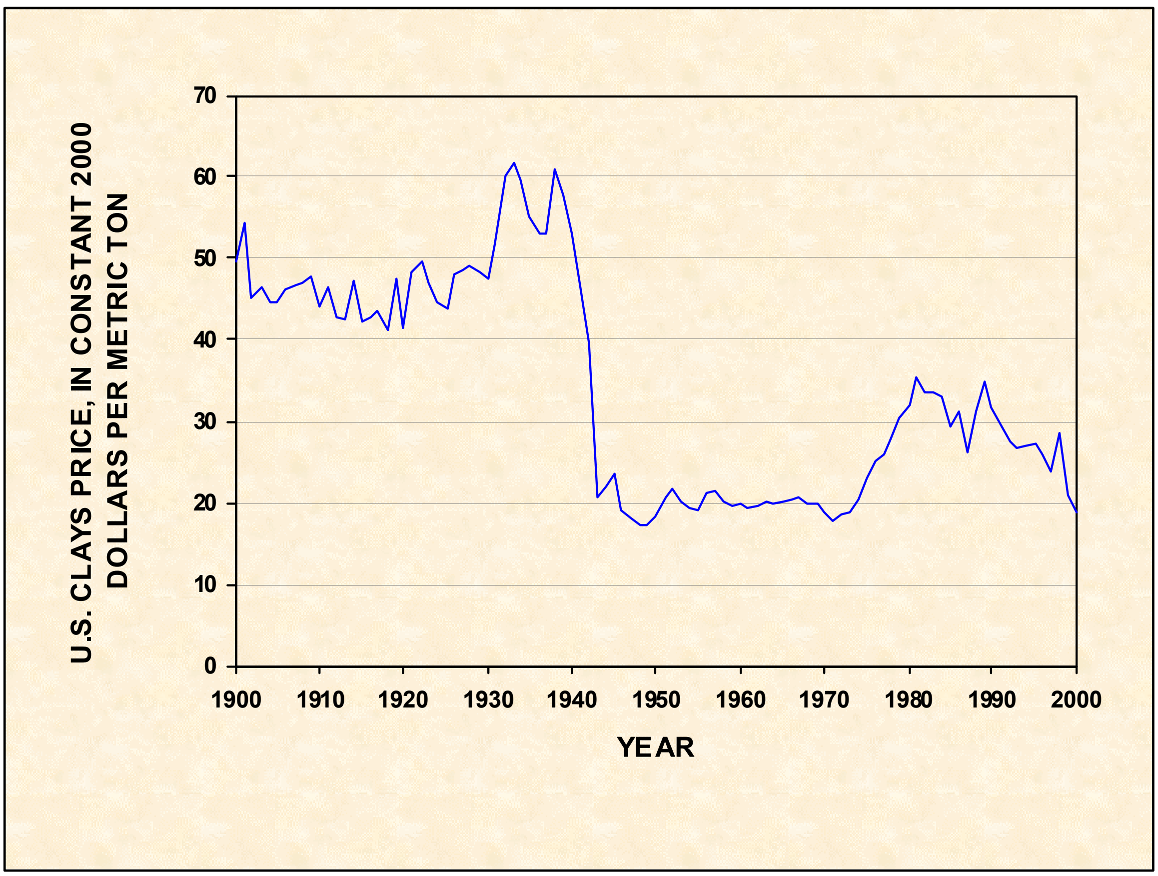

Figure B4. U.S. clay price, in constant 2000 dollars, 1900-2000 (data from Buckingham and Virta, 2001).

Lime is widely used in manufacturing and construction. Figure B5 shows the price of lime reacting to various conditions in the economy. Over the 20th century, lime prices remained fairly constant, with a slightly declining trend. This price stability was partly due to lime markets being broad based and therefore, not subjected to sudden price fluctuations. Additionally, lime production is energy intensive; so high-energy prices were reflected in lime prices in the 1980s. Recently, moderating energy prices have contributed to lower lime prices.

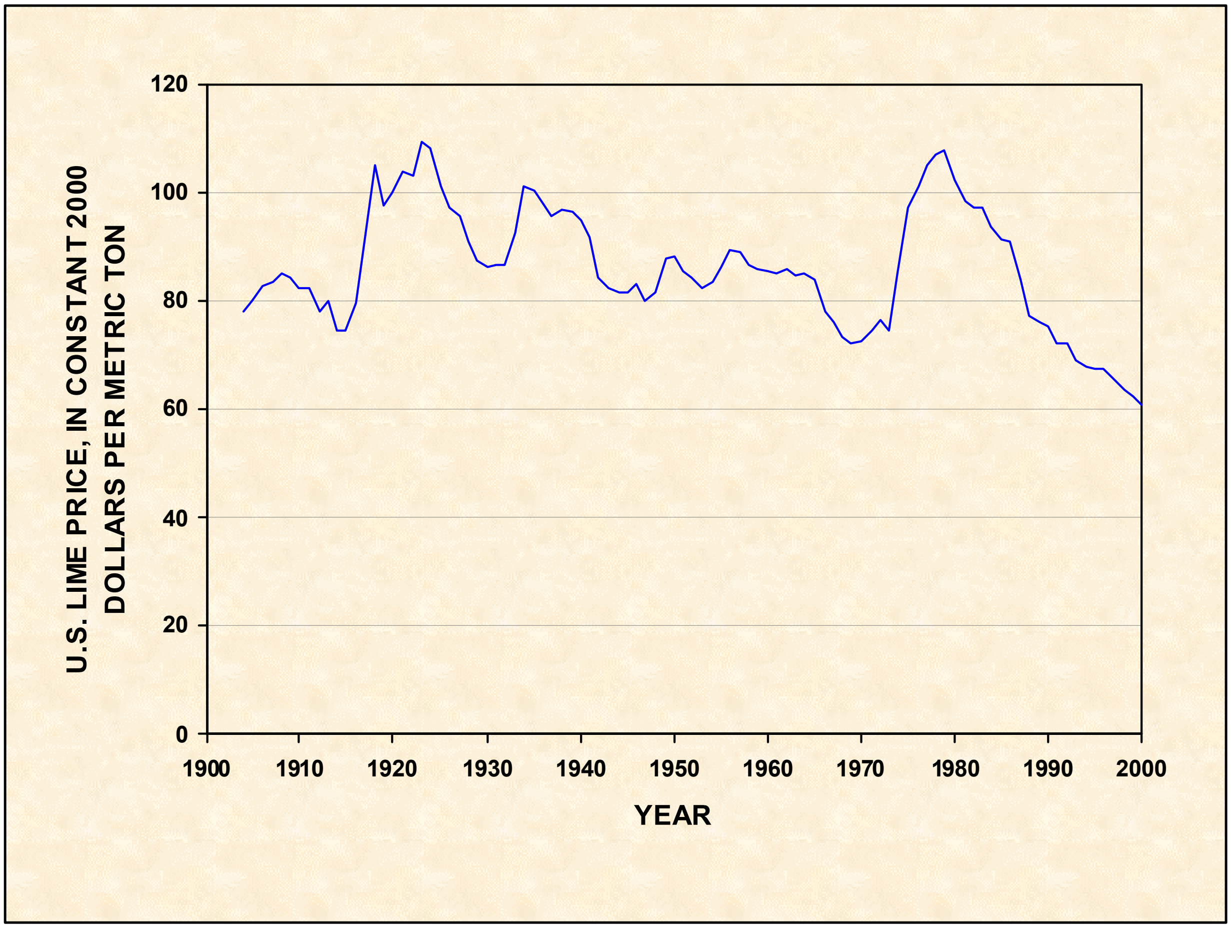

Figure B5. U.S. lime price, in constant 2000 dollars, 1904-2000 (data from Goonan and Miller, 2001).

The price of phosphate rock exhibits a declining trend over the last century in constant dollar terms as shown in figure B6. The price peaked during the first decade of the 20th century when the industry was in its early development. The price reached a low in 1918 during World War I but rebounded to a price in real dollars above $40 per ton that was not sustainable and caused a decline in consumption. In the early 1970s, price controls kept the price low but the real price reached almost $65 during the energy crisis. Subsequently the price has continued its long term declining trend.

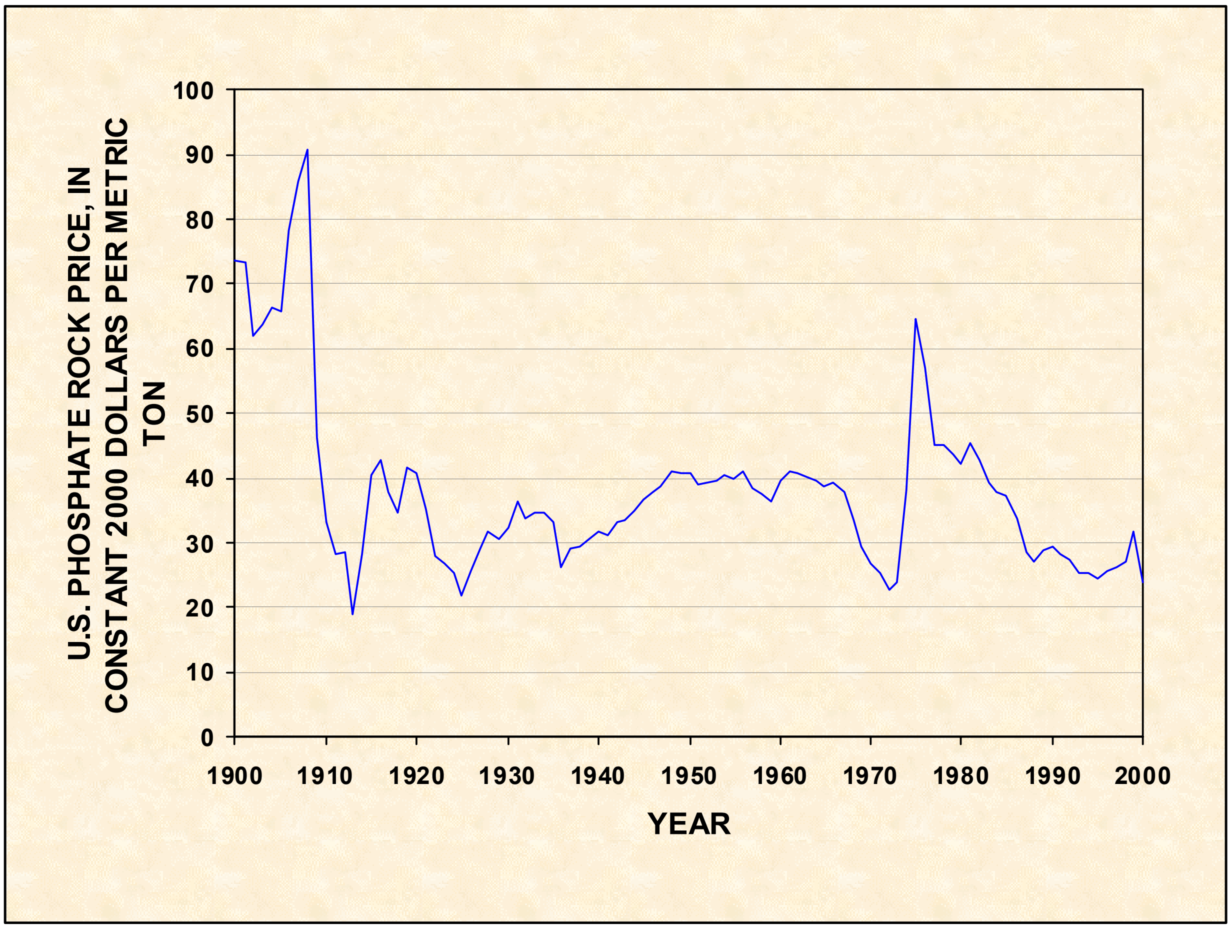

Figure B6. U.S. phosphate rock price, in constant 2000 dollars, 1900-2000 (data from Buckingham and Jasinski, 2001).

Salt is a common mineral that has many uses, including human consumption. Salt is found in most regions of the world. Salt prices, in 2000 constant dollars, are shown in figure B7. In real terms the price of salt remained generally between $25 and $50 per ton, with a declining average trend. The declining trend line for the price of salt during the 20th century illustrates that scarcity has not been a problem.

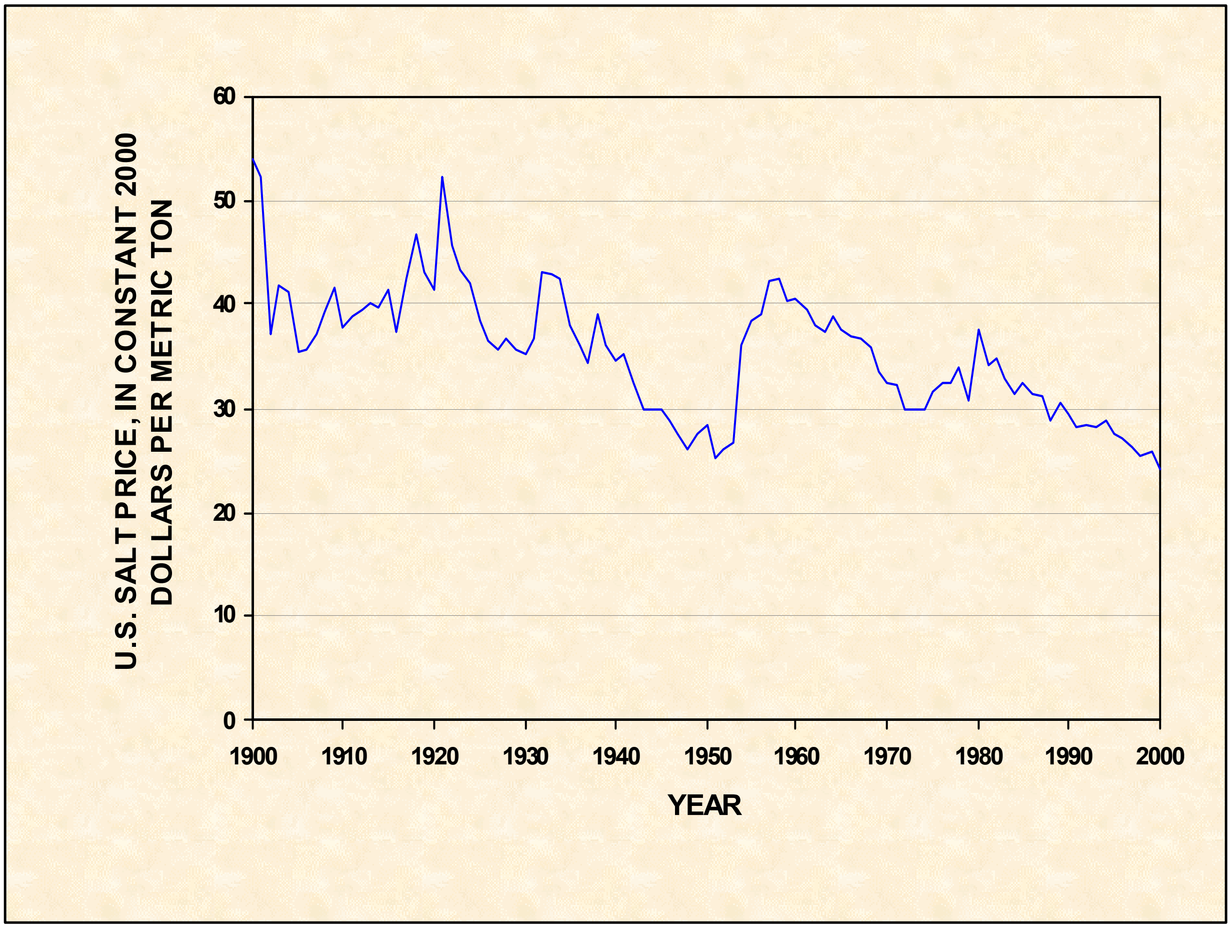

Figure B7. U.S. salt price, in constant 2000 dollars, 1900-2000 (data from Porter and Kostick, 2001).

Sand and gravel is a significant material in the construction industry. Sand and gravel prices, in 2000 constant dollars, are shown in figure B8. The prices shown in the figure are the weighted average price of both construction sand and gravel and industrial sand and gravel. Since the quantity of construction sand and gravel is so large (more than 97 percent in the year 2000) it dominates average price. The price trend line reveals a slight decline. The high prices in the first century's first decade may reflect the consumption of a higher proportion of more valuable materials such as glass sand.

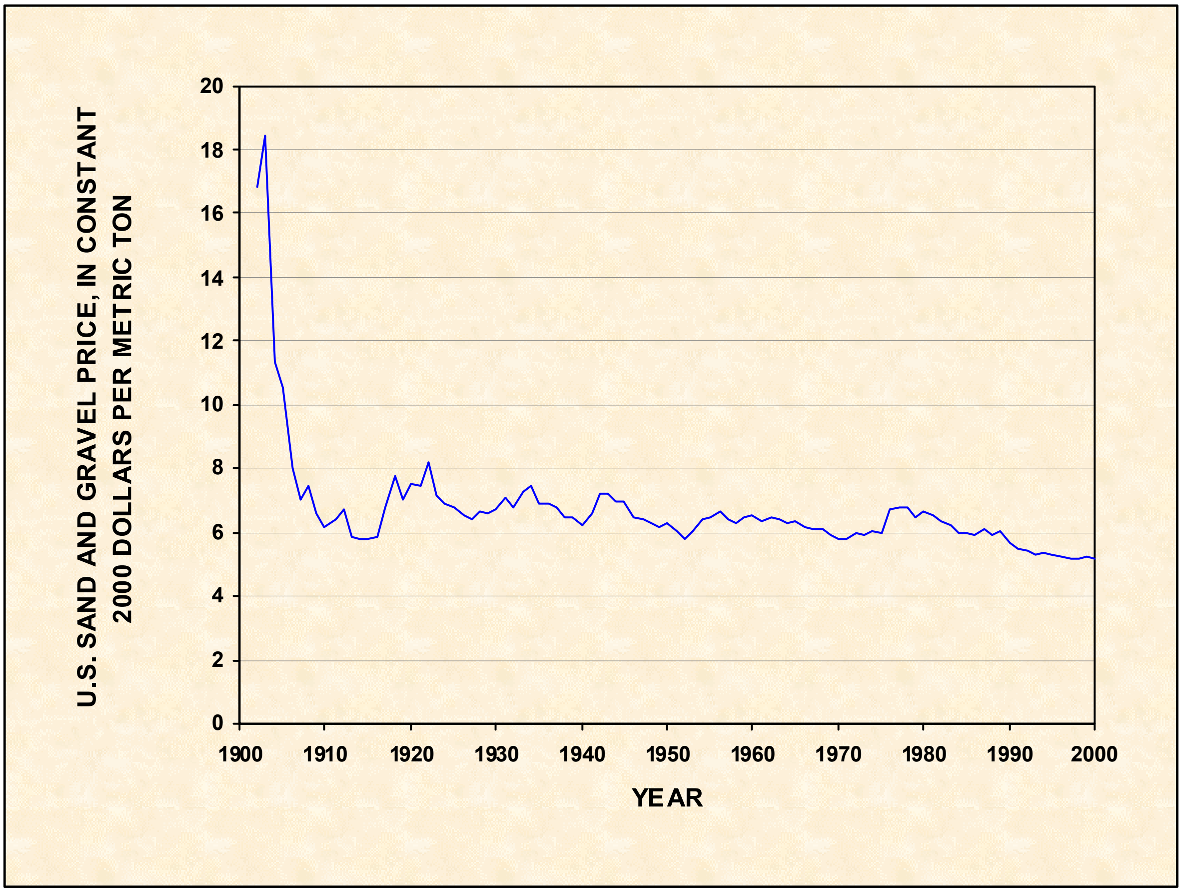

Figure B8. U.S. sand and gravel price, in constant 2000 dollars, 1902-2000 (data calculated from Porter and Bolen, 2001a and 2001b).

Crushed stone accounts for 29 percent of the value of production of industrial minerals included in the composite index and in 2000 was the industrial mineral with the largest value of nonfuel mineral production in the United States ($8,886 million). Most crushed stone was used in the construction of bridges, buildings, highways, and other infrastructure. The price history of crushed stone is shown in figure B9. The figure shows a declining trend in real price of crushed stone. During the century many technological advances allowed producers to reduce costs in real terms resulting in a general reduction in real prices. Technological advances included mechanization of the operations, more efficient machines, and increased economies of scale.

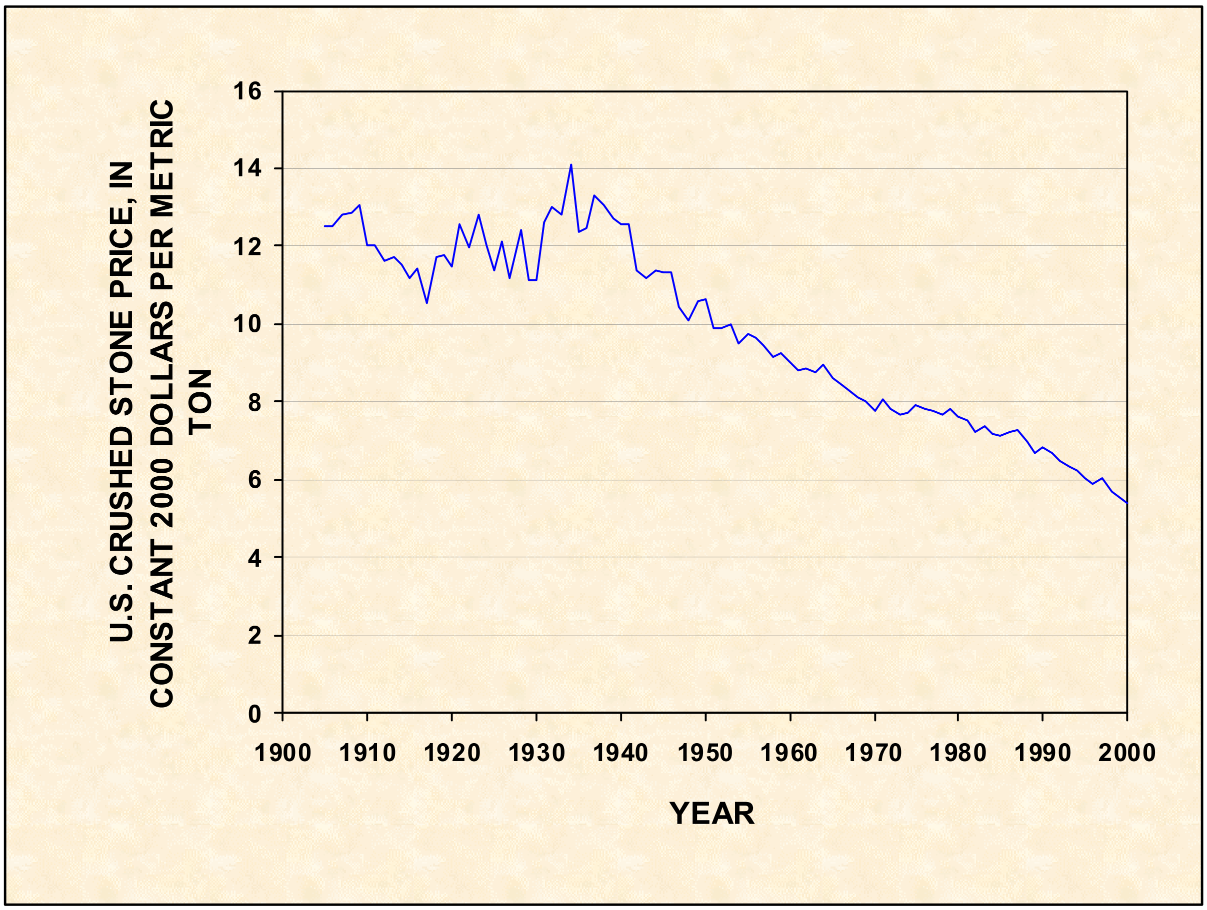

Figure B9. U.S. crushed stone price, in constant 2000 dollars, 1905-2000 (data from DiFrancesco and Tepordei, 2001).

The metals price index has shown more volatility than the industrial minerals price index throughout the century (figure B10). This may be because the metals markets are made up of a smaller number of large producers and consumers and the industrial minerals markets generally have a larger number of smaller producers and consumers. Copper, lead, and zinc, which comprise 45 percent of the index, have downward trends. However, the trends for gold and iron ore prices, which comprise the remainder of the index, were up slightly[15]. When data for the five metals are combined into the metal price index, it has a slight downward trend. The index has a large peak in 1916, which is probably related to high demand during World War I. Another significant peak in 1980 can be attributed to speculation in gold. Data in current and constant dollar terms for the individual metal commodities can be found in Tables B2 and B3. A discussion of the price trends for each of the commodities included in the metals price index, and aluminum, follows.

[15] Even though the long-term trends for gold and iron ore were up slightly, the year 2000 constant dollar price for both metals was less than their respective constant dollar prices in the year 1900.

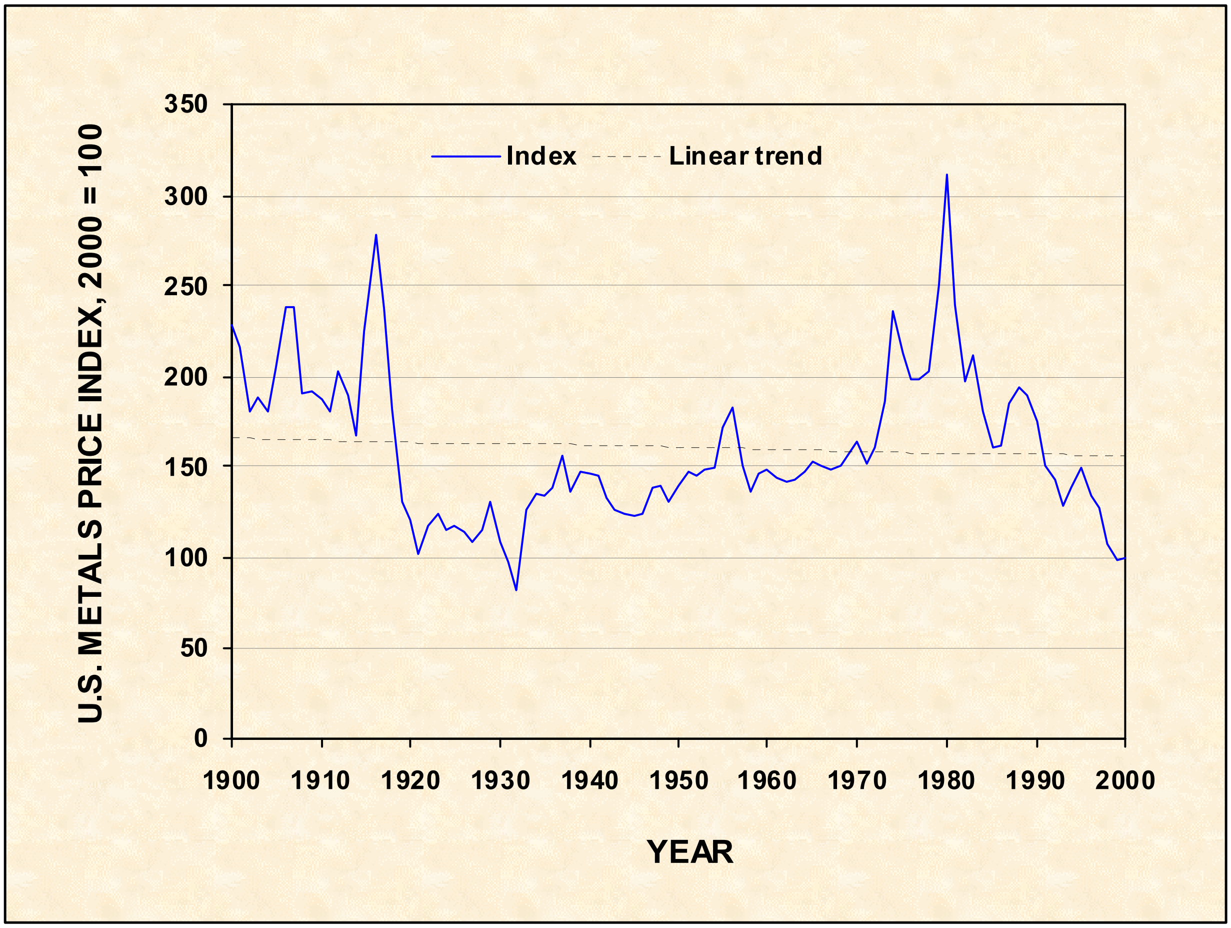

Figure B10. U.S. metal price index, in constant 2000 dollars, 1900-2000.

Copper was the metal with the largest value of mine production ($3,156 million) in the United States in the year 2000 (see table B1). It is a major material used in electronic applications, plumbing, and the transmission of electricity. As with most of the other mineral commodities, the price of copper is sensitive to economic cycles and world events, but the price trend in constant dollar terms is declining (figure B11). The price of copper experienced a significant rise during World War I, a drop during the Great Depression and steady prices during World War II because of price controls. Price controls occur when the government freezes the price of a commodity. Price controls can also occur when the government sets price ceilings and floors, which permit the price of a commodity to rise and fall as long as it does not exceed or fall below a certain level. Prices increased as a result of high demand after World War II. They continued to increase until the 1970s. Since the mid-1970s the trend in the price of copper has been generally declining.

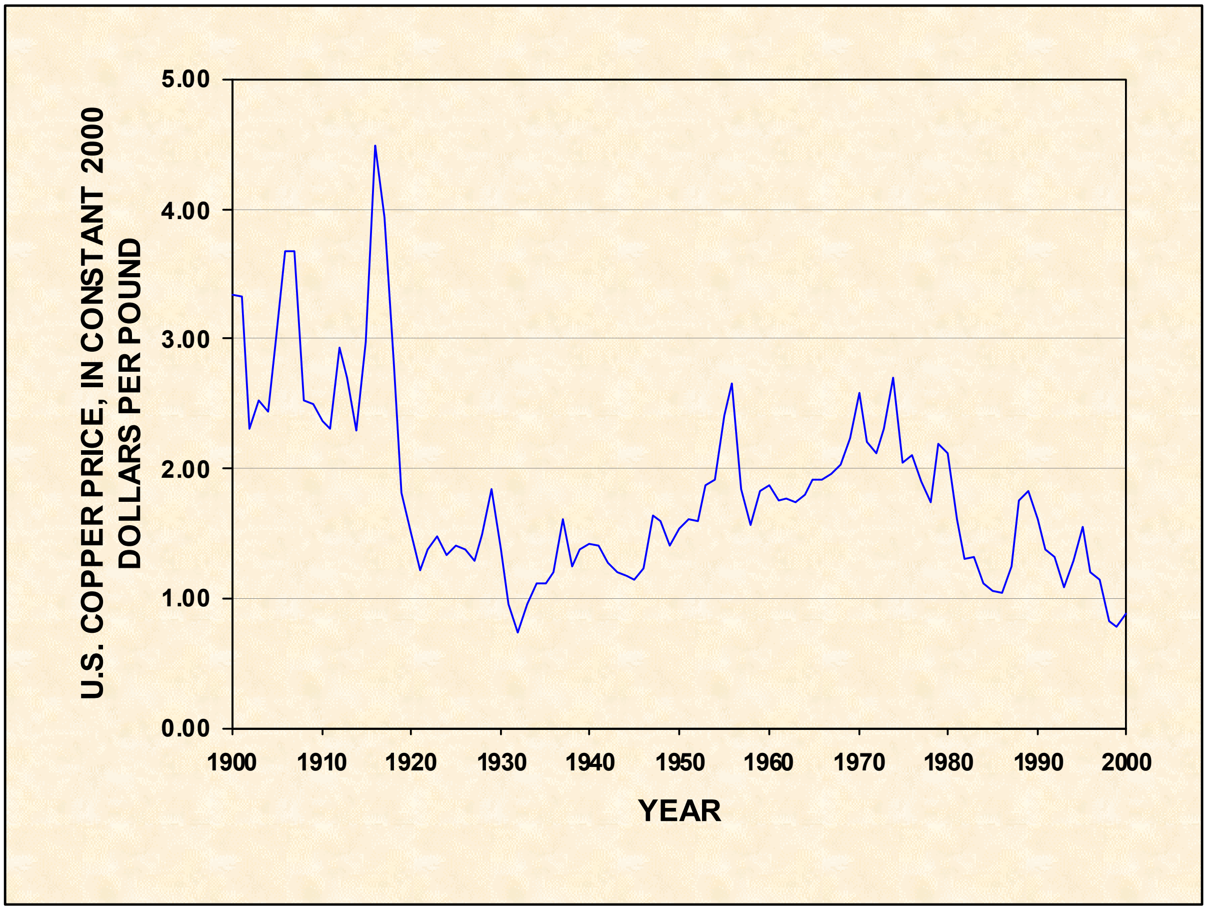

Figure B11. U.S. copper price, in constant 2000 dollars, 1900-2000 (data from Porter and Edelstein, 2001).

Gold is unlike other commodities. Private individuals have used gold as an insurance against inflation and adversity, and monetary systems have used gold as a standard of value for centuries. Implementing a gold standard, the United States government fixed the price of gold at

$20.67 per troy ounce from 1837 to 1934 and at $35 from 1934 to 1968. Since 1968, the United States has been off the gold standard and the market has set the price of gold. Gold, the metal with the second largest value of domestic mine production in the year 2000 ($2,970 million), shows an increasing trend in constant dollar price (figure B12). But the upward trend could be viewed as misleading because the price was fixed by the United States prior to 1968. Note that the prices of gold shown in figure B12 are adjusted to 2000 constant dollars and, therefore, do not match the fixed (current dollar) prices previously mentioned. Economic conditions and political uncertainty brought about by events in Afghanistan, Iran, and elsewhere contributed to the historic high gold price in 1980 (Amey, 1999). Since that time, the trend of the price of gold, in both current and constant dollars, has been downward.

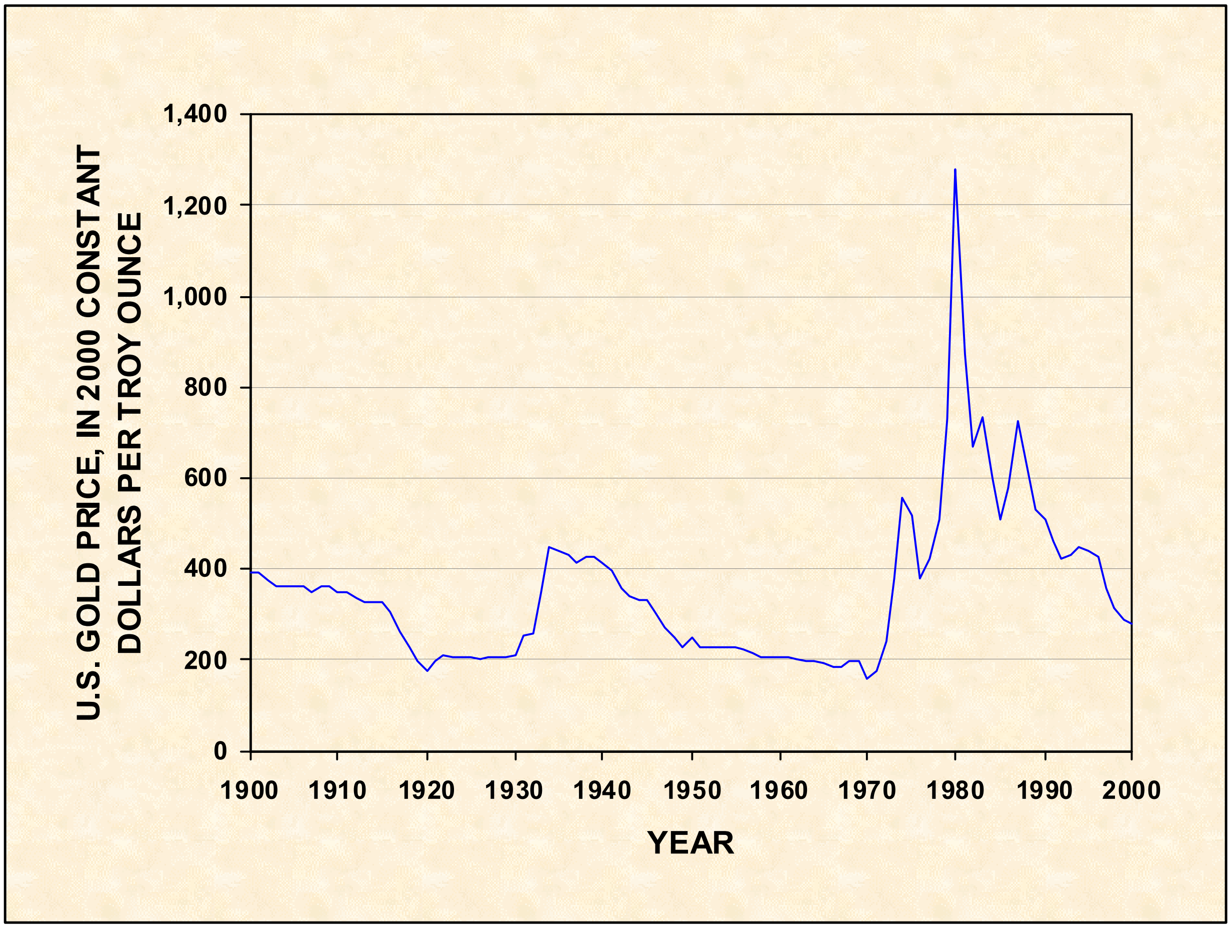

Figure B12. U.S. gold price, in constant 2000 dollars, 1900-2000 (data from Porter and Amey, 2001).

Because the gold market is unique, as described above, the composite index was constructed two ways, by including and excluding gold. The composite price index excluding gold is shown in figure B13. It is similar to the composite price including gold (figure B1) except that it does not have the peak in 1980 that was caused by the high gold price.

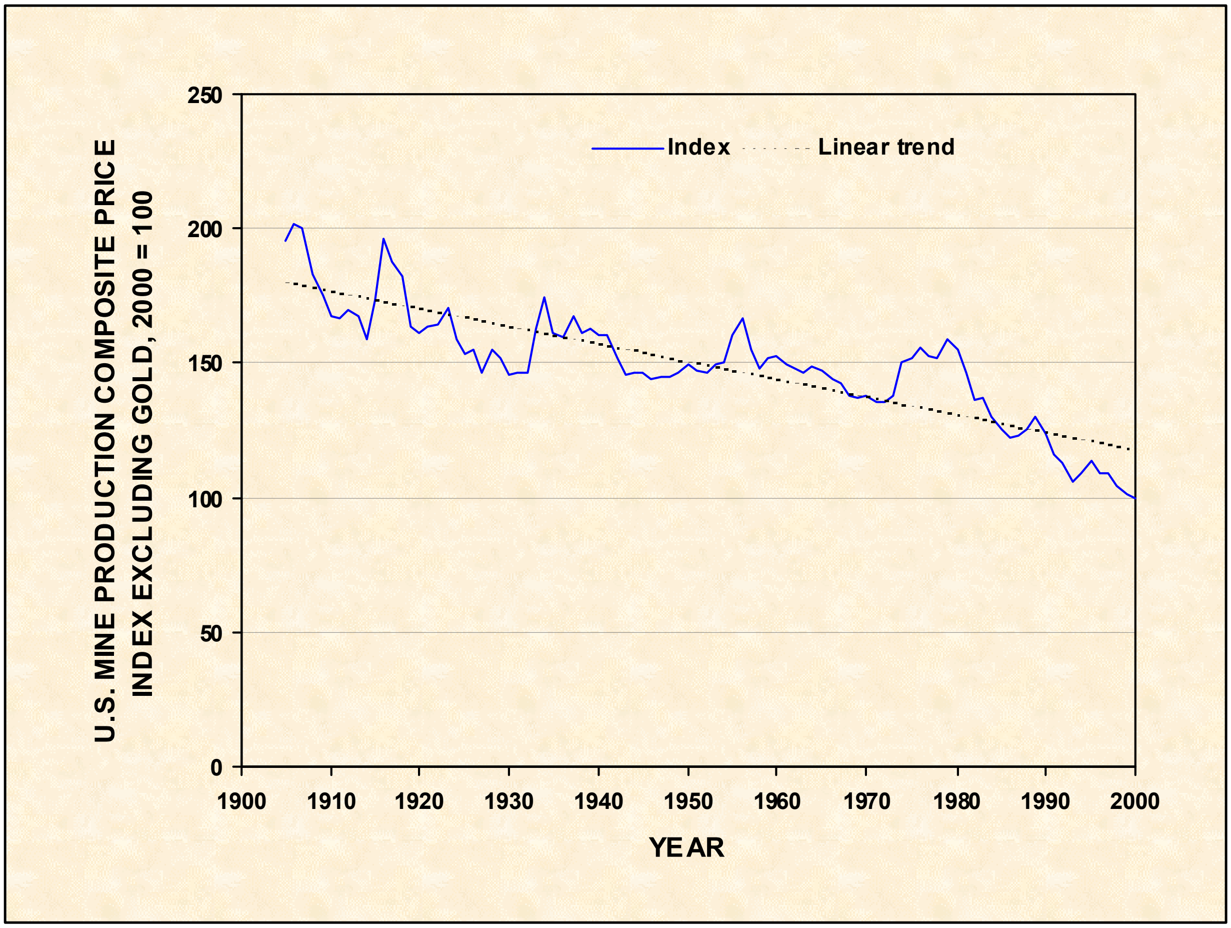

Figure B13. U.S. mine production composite price index excluding gold, in constant 2000 dollars, 1905-2000.

Iron ore prices, in constant dollars, have an increasing trend line for the 20th century (figure B14). Prices increased during the mid-1970s as a result of the oil crisis. Prior to 1982, only annual sales, multiyear contracts, or equity ownership transactions existed in North America. More than three-quarters of iron ore capacity was owned directly by consumers. The increasing trend in prices reached a peak in 1981. In 1982, the market changed as a U.S. spot market for pellets developed, which led to price competition. Costs were cut allowing prices to make domestic ore competitive with imported material. There was a drop in production and constant dollar prices declined. By the mid-1980s, iron ore prices declined to pre-World War II levels in terms of constant dollars (Kirk, 1999).

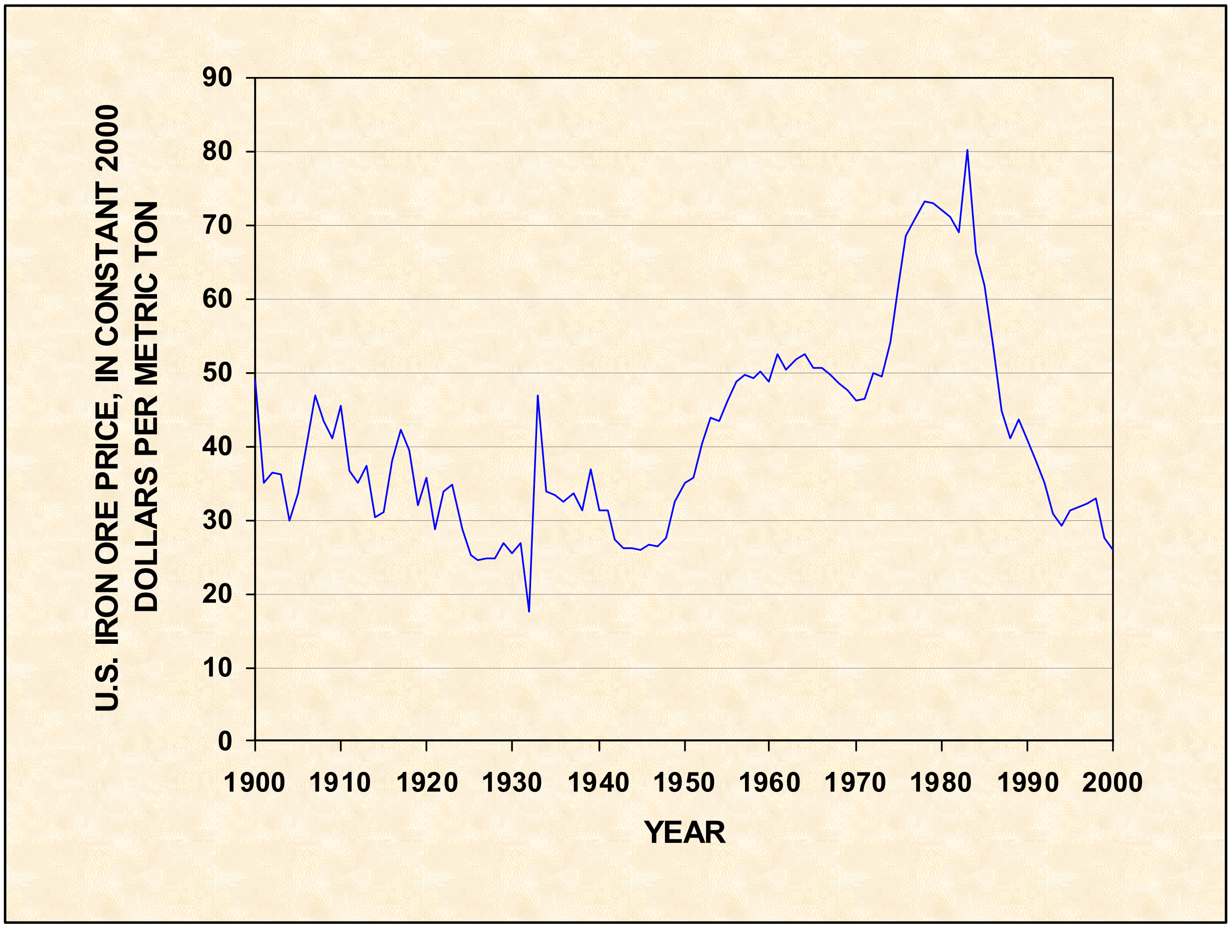

Figure B14. U.S. iron ore price, in constant 2000 dollars, 1900-2000 (data from Kelly and Kirk, 2001).

The price of lead has a declining trend for the century in spite of many peaks and valleys through the period (figure B15). Increased demand for the war effort produced a peak during World War I. Demand generated by the booming of the economy produced another one in the 1920s. Lack of demand resulting from the collapse in the economy resulted in a price drop during the Great Depression. Prices were controlled during World War II, but the increased demand during the post World War II period and the Korean conflict induced a strong rise in the lead price. The price of lead was restrained by anti-inflation price controls imposed in 1971. Price controls were lifted in 1973 and the price reached an historic high in 1979 in the post-Vietnam War economic boom. The price declined in the early 1980s after lead was phased out of gasoline, paints, solders, and water delivery systems for environmental reasons. Lead in these uses dissipated into the environment and was available to be picked up by plants, animals and people. Lead was still in great demand for lead-acid storage batteries in the late 1980s and 1990s and as a result the price generally leveled off (Smith, 1999).

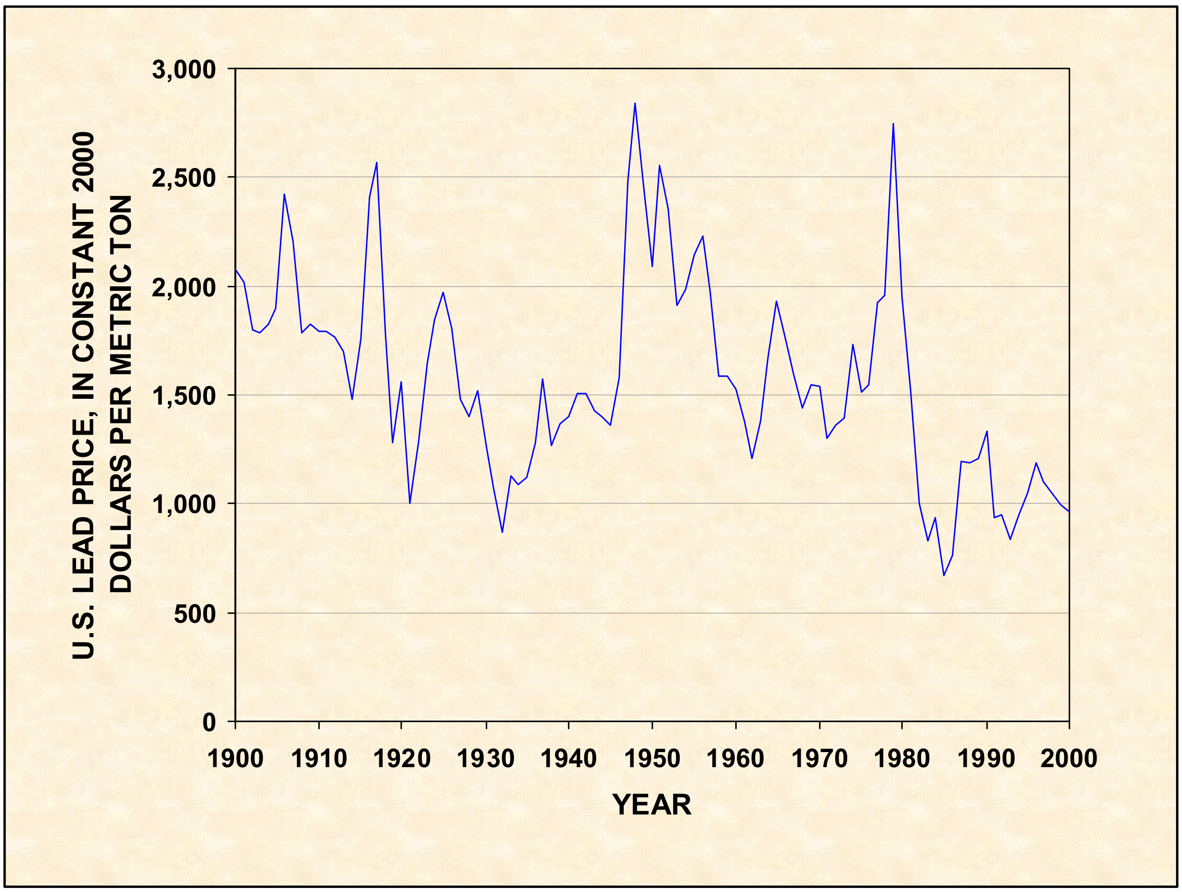

Figure B15. U.S. lead price, in constant 2000 dollars, 1900-2000 (data from DiFrancesco and Smith, 2001).

Zinc prices (figure 16) rose during World War I due to increased demand for war related zinc materials. Prices were at an all-time low in the Great Depression, recovering during World War II. In the 1960s, zinc prices were stable partially because of Government policies relating to the Federal stockpile and import quotas and tariffs. Prices remained stable while price controls were in effect from 1971 through 1973. When price controls were abolished, zinc prices escalated, reaching a peak in 1989. The reason for this increase was strong demand at a time when supply was tight because of strikes, technical problems at some smelters, and hurricane-related delays of zinc shipments from Mexico (Plachy, 1999). Since then the constant dollar price has leveled off.

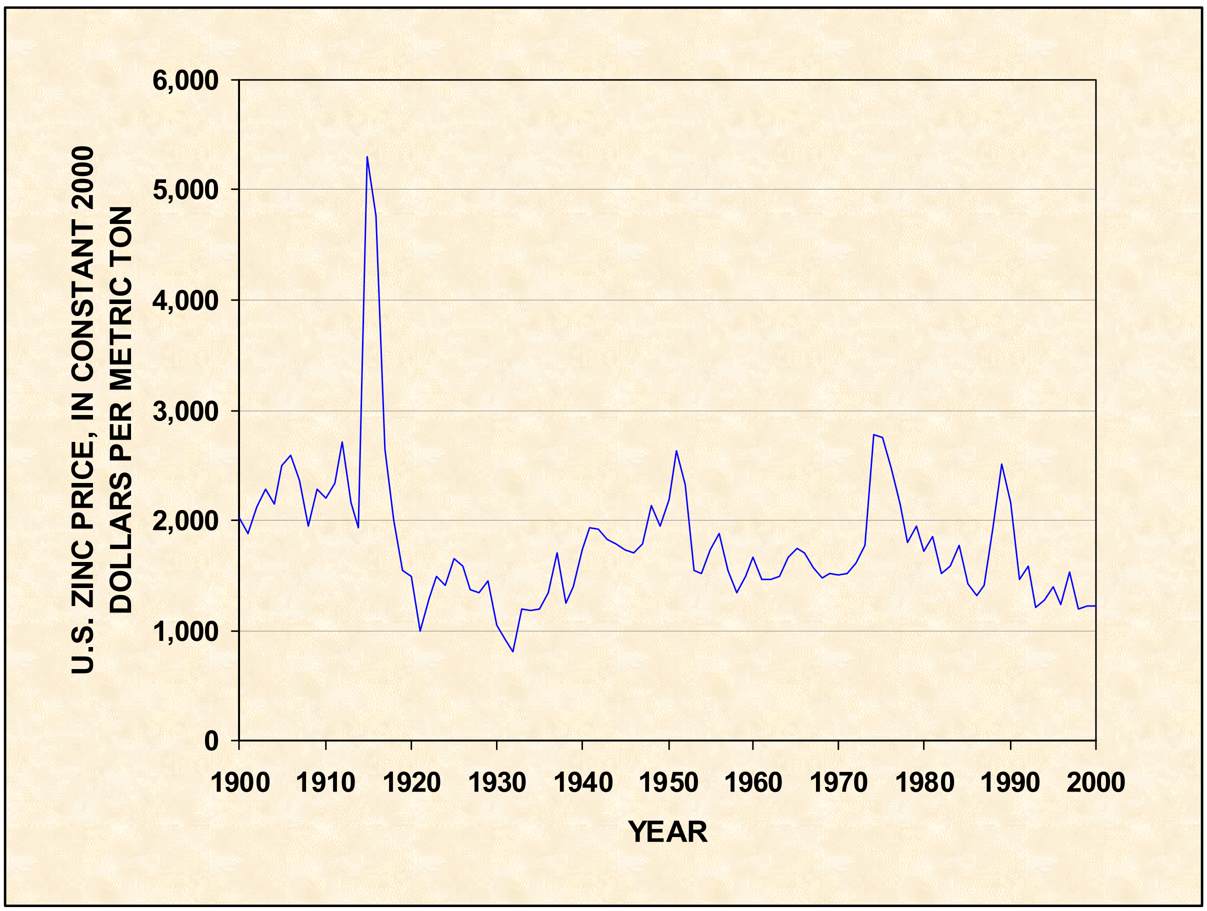

Figure B16. U.S. zinc price, in constant 2000 dollars, 1900-2000 (data from DiFrancesco and Plachy, 2001).

Aluminum is not a component of the U.S. price indexes because U.S. production of bauxite provides less than 1 percent of the U.S. requirement. The small amount of bauxite produced domestically is not used to produce aluminum metal, but is used for abrasives, chemicals, and refractories. The aluminum industry is however a major industry in the United States, as it imports bauxite ore, or alumina, and processes it into aluminum. In the year 2000, production was valued at over $6 billion (Buckingham and Plunkert, 2001). Therefore, it is important to briefly discuss the trend of aluminum prices as shown in figure B17.

Before World War I, the price of aluminum was elevated because the production process was in its infancy and supply was limited. A historic high was reached in World War I because of high demand for use in military aircraft. With the advent of new and improved technology that reduced production costs and the development of a global market, the price of aluminum declined similarly to other mineral commodities.

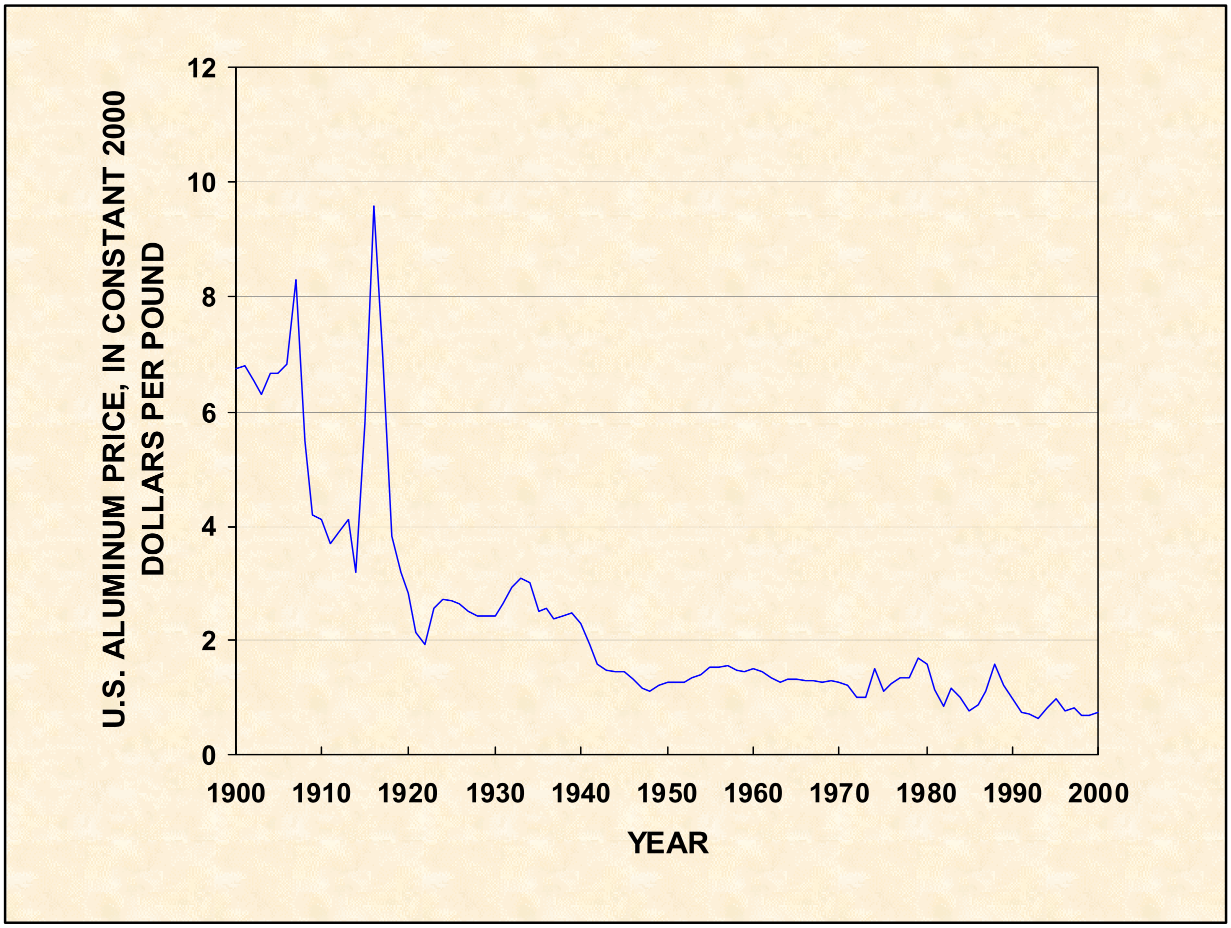

Figure B17. U.S. aluminum price, in constant 2000 dollars, 1900-2000 (data from Buckingham and Plunkert, 2001).

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APPENDIX C: PRODUCTION

Comparing price trends to production trends can shed light on the historical availability of minerals. Increasing levels of production over time, especially in conjunction with a declining price trend, can indicate the lack of scarcity of a material. Calculated production indexes for raw mineral materials, shown below, incorporate the same mineral commodities that were used to develop the price indexes[16]. The production indexes are based on the quantity of mineral commodities produced using their relative 2000 price as a base. The Laspeyres quantity index methodology, similar to the price index methodology, was used in the construction of the production index. The mathematical formula for the Laspeyres quantity index (Mansfield, 1987) is as follows:

$$\textbf{Laspeyres Quantity Index} = \frac{\sum_{i=1}^{m} Q_{1i} P_{0i}}{\sum_{i=1}^{m} Q_{0i} P_{0i}} * 100$$

where,

Q_{1i} = quantity of mineral commodity i produced (mined) for a given year (1)
Q_{0i} = quantity of mineral commodity i produced (mined) in the base year (0)
P_{0i} = price of mineral commodity i for the base year (0)

and,

i = $1 \mid m$, where m is a mineral commodity

Multiplying the price of each commodity in the base year (table B2) by the quantity of that commodity produced in a given year (table C1) and then summing over all commodities derives

[16] Includes the industrial mineral commodities: cement, clays, lime, phosphate rock, salt, sand and gravel, stone-crushed, and the metals: copper, gold, iron ore, lead, and zinc.

the value in the given year using base year prices. This sum is the numerator of the equation. Multiplying the price of each commodity in the base year by the quantity produced in the base year and then summing over all commodities derives the value of mineral production for these commodities in the base year. This sum is the denominator of the equation. The result of the division of the numerator by the denominator is an index that reflects relative changes in the quantity produced for all of the included commodities with the weight of each commodity determined by its price in the base year (table C2).

Table C1. Production of selected mineral commodities, in thousand tons, unless otherwise noted.

[Data from U.S. Geological Survey, 2001; NA, not available. Aluminum is not a component of the production index.]

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold, in tons	Iron ore	Lead	Zinc
1900	2,680	1,108	NA	1,520	2,651	NA	38,400	2	275	120.0	27,995	NA	151
1901	3,202	1,253	NA	1,510	2,612	NA	43,400	3	273	120.0	29,351	NA	168
1902	4,148	1,331	NA	1,510	3,029	1,672	49,000	3	299	122.0	36,125	NA	193
1903	4,898	1,508	NA	1,610	2,409	1,917	44,100	3	317	114.0	35,581	NA	180
1904	5,283	1,405	2,500	1,910	2,798	9,690	49,800	4	369	122.0	28,088	NA	202
1905	6,750	1,661	2,700	1,980	3,298	16,970	56,200	5	403	133.0	43,209	NA	213
1906	8,644	1,868	2,900	2,110	3,578	29,830	63,500	6	416	146.0	48,516	333	210
1907	8,898	2,011	2,800	2,300	3,773	37,990	69,800	7	384	132.0	52,551	340	236
1908	9,059	1,591	2,500	2,420	3,661	33,730	63,500	5	434	138.0	36,561	305	213
1909	11,437	1,990	3,200	2,380	3,824	54,020	74,400	13	511	150.0	51,976	361	277
1910	13,366	2,197	3,200	2,700	3,849	62,930	84,400	16	494	143.0	57,803	359	297
1911	13,678	2,017	3,100	3,100	3,961	60,650	84,400	17	506	146.0	44,581	400	303
1912	14,337	2,325	3,200	3,020	4,232	61,990	87,100	19	567	140.0	56,056	415	350
1913	15,994	2,436	3,300	3,160	4,369	72,220	94,300	21	560	135.0	62,975	454	375
1914	15,322	2,042	3,100	2,780	4,420	71,880	82,500	26	521	139.0	42,105	474	377
1915	14,919	2,200	3,300	1,970	4,856	69,540	87,100	41	675	150.0	56,418	510	533
1916	15,890	2,722	3,700	2,200	5,772	80,810	79,300	52	910	140.0	76,374	565	638
1917	16,085	2,925	3,400	2,900	6,330	69,340	72,600	59	860	123.0	76,497	591	647
1918	12,311	2,777	2,900	2,320	6,567	56,110	60,600	57	866	102.0	70,776	528	577
1919	13,995	2,160	3,000	1,880	6,244	64,000	57,300	58	550	85.6	61,944	403	498
1920	17,163	3,091	3,200	4,040	6,205	74,480	69,000	63	555	74.1	68,690	466	533

Table C1. Production of selected mineral commodities, in thousand tons, unless otherwise noted-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold, in tons	Iron ore	Lead	Zinc
1921	16,950	1,680	2,300	2,470	4,519	72,480	55,400	25	211	72.9	29,964	376	233
1922	19,729	2,528	3,300	2,370	6,162	45,070	70,000	33	438	71.3	47,885	406	428
1923	23,661	3,251	3,700	2,990	6,469	127,400	83,700	58	670	74.8	70,465	496	554
1924	25,715	3,510	3,700	2,890	6,172	141,680	90,300	68	729	76.0	55,138	541	579
1925	27,866	3,844	4,200	3,310	6,711	155,800	101,000	64	761	71.8	62,902	621	645
1926	28,420	3,811	4,100	3,650	6,687	166,600	110,000	67	783	69.4	68,708	620	703
1927	29,903	3,732	4,000	3,070	6,866	179,100	120,000	74	748	65.5	60,158	604	652
1928	30,445	3,913	4,000	3,580	7,325	108,100	103,000	96	821	66.8	63,195	569	631
1929	29,481	4,230	3,900	3,880	7,751	201,700	124,000	103	905	64.0	74,200	588	657
1930	27,798	3,900	3,100	4,020	7,307	178,630	112,000	104	640	66.5	59,346	507	540
1931	21,604	2,547	2,500	2,710	6,675	139,550	83,100	80	480	69.2	31,631	367	372
1932	13,166	1,470	1,800	1,730	5,813	108,720	59,600	48	218	72.5	9,639	266	259
1933	10,913	1,873	2,100	2,400	6,899	97,740	62,700	39	173	71.7	17,835	247	349
1934	13,375	2,184	2,200	2,950	6,906	105,480	82,800	34	215	86.4	24,982	260	398
1935	13,260	2,859	2,700	3,210	7,191	112,840	74,300	54	345	101.0	31,030	300	470
1936	19,523	3,641	3,400	3,520	8,009	161,500	118,000	102	557	118.0	49,572	338	522
1937	20,138	4,049	3,700	4,330	8,384	171,960	119,000	133	764	128.0	73,251	422	568
1938	18,279	2,632	3,000	3,920	7,281	164,910	112,000	130	506	161.0	28,904	335	469
1939	21,212	3,563	3,900	4,050	8,417	204,870	132,000	149	661	145.0	52,562	376	530
1940	22,575	4,398	4,400	4,130	9,398	216,660	138,000	187	797	151.0	74,879	415	603

Table C1. Production of selected mineral commodities, in thousand tons, unless otherwise noted-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold, in tons	Iron ore	Lead	Zinc
1941	28,387	6,555	5,500	5,000	11,540	262,000	165,000	280	869	148.0	93,893	419	680
1942	31,496	6,847	5,500	4,900	12,422	276,300	177,000	473	980	108.0	107,220	450	697
1943	22,901	18,886	5,900	5,460	13,802	212,600	155,000	835	990	42.4	102,870	411	675
1944	15,542	15,690	5,900	5,280	14,258	177,000	141,000	704	882	31.1	95,628	378	652
1945	17,537	17,168	5,400	5,490	13,965	177,200	139,000	449	701	29.7	89,795	355	557
1946	28,102	27,727	5,400	7,280	13,728	230,500	162,000	372	552	49.0	71,980	304	521
1947	31,995	30,481	6,200	9,260	14,564	261,300	188,000	519	769	65.6	94,586	349	578
1948	35,210	34,226	6,600	9,540	14,881	289,300	204,000	565	757	62.7	102,620	354	572
1949	35,939	31,888	5,700	9,020	14,127	289,600	202,000	547	683	62.0	86,301	372	538
1950	38,724	35,726	6,800	10,900	15,086	335,600	228,000	199	825	74.5	99,619	391	566
1951	41,825	39,386	7,500	12,200	18,331	363,200	258,000	759	842	61.6	118,370	353	618
1952	42,394	37,801	7,300	12,300	17,731	394,700	272,000	850	839	58.9	99,490	354	604
1953	45,021	38,488	8,800	12,700	18,859	399,500	277,000	1,136	840	60.9	119,890	311	497
1954	46,434	38,560	7,800	14,000	18,743	505,100	380,000	1,325	758	57.1	79,383	295	430
1955	52,994	43,640	9,500	12,500	20,587	537,000	426,000	1,421	906	58.5	104,660	307	467
1956	56,153	46,061	9,600	16,000	21,959	567,200	458,000	1,523	1,002	56.8	99,448	320	492
1957	52,574	41,388	9,300	14,200	21,631	573,400	482,000	1,495	986	55.8	107,850	307	482
1958	54,831	39,689	8,400	15,100	19,876	621,100	484,000	1,421	888	54.1	68,796	243	374
1959	59,764	44,800	11,300	16,100	22,825	661,600	528,000	1,773	748	49.9	61,243	232	386
1960	56,063	44,515	11,700	17,800	23,114	643,600	557,000	1,827	980	51.8	90,209	224	395

Table C1. Production of selected mineral commodities, in thousand tons, unless otherwise noted-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold, in tons	Iron ore	Lead	Zinc
1961	56,718	42,991	12,000	18,900	23,321	682,400	502,000	1,727	1,057	48.2	72,474	238	421
1962	58,908	43,361	12,500	19,700	26,133	704,200	521,000	1,921	1,114	48.0	72,982	215	459
1963	61,733	45,482	13,200	19,700	27,797	745,100	622,000	2,097	1,101	45.2	74,780	230	480
1964	64,379	48,033	14,600	23,300	28,688	788,100	656,000	2,316	1,131	45.3	86,198	259	522
1965	65,078	50,009	15,200	26,900	31,468	824,000	706,000	2,498	1,226	53.0	88,842	273	554
1966	67,146	51,449	16,400	35,400	33,079	847,900	736,000	2,693	1,297	56.1	91,594	297	519
1967	64,449	49,590	16,300	36,100	35,331	823,000	711,000	2,966	866	49.3	85,530	288	498
1968	68,791	52,025	16,900	37,400	37,443	832,500	742,000	2,953	1,093	46.0	87,243	326	480
1969	71,086	53,246	18,300	34,200	40,138	850,300	781,000	3,441	1,401	53.9	89,746	462	502
1970	67,427	49,762	17,900	35,100	41,636	856,400	787,000	3,607	1,560	54.2	91,201	519	485
1971	71,054	51,407	17,800	35,200	39,986	834,700	793,000	3,561	1,381	46.5	82,058	525	456
1972	74,931	53,938	18,400	37,000	40,843	829,800	834,000	3,739	1,510	45.1	76,645	561	434
1973	77,576	58,378	19,200	38,200	39,834	892,300	960,000	4,109	1,558	36.6	89,076	547	434
1974	73,688	55,153	19,600	41,400	42,217	820,400	945,000	4,448	1,449	35.1	85,709	602	453
1975	61,815	44,495	17,400	44,300	37,222	715,800	816,000	3,519	1,282	32.7	80,132	564	426
1976	66,179	47,527	18,400	44,700	40,089	803,100	817,000	3,857	1,457	32.6	81,277	553	440
1977	70,939	48,259	18,100	47,300	39,383	843,400	865,000	4,118	1,364	34.2	56,645	537	408
1978	76,190	51,548	18,500	50,000	38,890	903,800	952,000	4,358	1,358	31.1	82,892	530	303
1979	76,649	49,613	19,000	51,600	41,543	888,400	995,000	4,557	1,447	30.0	87,092	526	267
1980	68,242	44,262	17,200	54,400	36,607	718,900	892,000	4,654	1,181	30.2	70,730	550	317

Table C1. Production of selected mineral commodities, in thousand tons, unless otherwise noted-*Continued*.

	Industrial Minerals							Metals					
Year	Cement	Clays	Lime	Phosphate rock	Salt	Sand and gravel	Stone, crushed	Aluminum	Copper	Gold, in tons	Iron ore	Lead	Zinc
1981	65,054	40,260	17,100	53,600	35,296	653,200	792,000	4,489	1,538	42.9	74,348	446	312
1982	57,475	32,064	12,800	37,400	34,377	563,900	717,000	3,274	1,147	45.6	36,002	513	303
1983	63,884	37,066	13,500	42,600	31,364	618,100	782,000	3,353	1,038	62.3	38,165	449	275
1984	70,488	39,646	14,400	49,200	35,584	728,700	867,000	4,099	1,103	64.9	52,092	323	253
1985	70,665	40,908	14,200	50,800	36,348	752,700	908,000	3,500	1,105	75.5	49,533	414	227
1986	71,473	40,580	13,100	38,700	33,260	825,900	928,000	3,037	1,144	116.0	39,486	340	203
1987	70,940	43,234	14,300	41,000	33,106	838,400	1,090,000	3,343	1,244	154.0	47,648	311	216
1988	69,733	44,515	15,500	45,400	35,326	863,800	1,130,000	3,944	1,417	201.0	57,515	385	244
1989	70,025	42,254	15,600	49,800	35,250	840,500	1,100,000	4,030	1,498	266.0	59,032	411	276
1990	69,954	42,900	15,800	46,300	36,916	854,800	1,110,000	4,048	1,588	294.0	56,408	484	515
1991	66,755	41,000	15,700	48,100	35,902	731,200	997,000	4,121	1,631	294.0	56,761	466	518
1992	69,585	40,200	16,200	47,000	34,800	859,200	1,050,000	4,042	1,761	330.0	55,593	397	552
1993	73,807	40,700	16,700	35,500	38,200	895,200	1,120,000	3,695	1,801	331.0	55,661	355	513
1994	77,948	42,000	17,400	41,100	39,700	918,300	1,230,000	3,299	1,848	327.0	58,382	363	598
1995	76,906	43,000	18,500	43,500	40,800	935,200	1,260,000	3,375	1,849	317.0	62,489	386	644
1996	79,266	43,100	19,200	45,400	42,900	941,800	1,330,000	3,577	1,920	326.0	62,083	426	628
1997	82,582	41,800	19,700	45,900	40,600	980,500	1,410,000	3,603	1,940	362.0	62,971	448	632
1998	83,931	41,600	20,100	44,200	40,700	1,098,200	1,510,000	3,713	1,860	366.0	62,931	481	755
1999	85,952	42,200	19,700	40,600	44,400	1,138,900	1,530,000	3,779	1,600	341.0	57,749	503	813
2000	87,846	40,800	19,600	38,600	43,300	1,148,400	1,560,000	3,700	1,440	353.0	63,089	457	829

Table C2. Production indexes, 2000 =100.

Year	Composite	Metals	Industrial minerals	Year	Composite	Metals	Industrial minerals
1900	NA	NA	NA	1950	40.1	65.3	31.1
1901	NA	NA	NA	1951	43.7	70.0	34.2
1902	NA	NA	NA	1952	42.7	64.1	35.0
1903	NA	NA	NA	1953	45.0	68.2	36.6
1904	NA	NA	4.3	1954	44.3	53.5	41.0
1905	NA	NA	5.2	1955	50.7	64.6	45.7
1906	16.2	43.6	6.3	1956	53.1	65.5	48.7
1907	16.4	43.1	6.7	1957	52.7	67.2	47.4
1908	15.1	39.6	6.4	1958	49.3	51.7	48.5
1909	18.7	48.3	8.0	1959	51.4	46.1	53.3
1910	19.7	49.1	9.1	1960	54.5	59.6	52.7
1911	19.1	46.4	9.2	1961	53.6	56.3	52.6
1912	20.6	51.2	9.6	1962	55.5	57.9	54.7
1913	21.8	53.3	10.5	1963	58.9	58.4	59.0
1914	19.7	47.1	9.9	1964	62.7	63.1	62.5
1915	22.7	58.1	9.9	1965	66.0	67.3	65.5
1916	26.3	69.8	10.6	1966	68.9	69.7	68.6
1917	25.5	67.5	10.3	1967	64.4	57.6	66.9
1918	22.7	62.3	8.5	1968	67.9	62.8	69.8
1919	19.5	49.0	8.9	1969	72.3	72.7	72.2
1920	21.4	51.0	10.8	1970	72.7	76.9	71.1
1921	14.3	27.4	9.5	1971	71.1	69.4	71.8
1922	18.6	40.2	10.8	1972	73.5	70.5	74.5
1923	25.5	54.6	15.0	1973	78.3	74.1	79.8
1924	25.1	52.5	15.2	1974	75.7	71.5	77.3
1925	27.3	56.7	16.7	1975	66.7	65.3	67.2
1926	28.5	59.4	17.3	1976	70.7	69.5	71.1
1927	27.8	54.9	18.1	1977	70.8	60.0	74.7
1928	27.3	56.8	16.7	1978	76.2	65.6	80.0
1929	30.2	62.0	18.8	1979	77.7	68.0	81.2
1930	25.8	49.9	17.1	1980	68.3	58.6	71.8
1931	19.0	35.1	13.2	1981	67.1	67.4	66.9
1932	12.1	20.9	8.9	1982	55.5	48.9	57.9
1933	12.4	23.3	8.4	1983	59.0	47.8	63.0
1934	14.8	28.5	9.9	1984	65.6	51.8	70.6
1935	16.9	35.8	10.1	1985	67.1	52.8	72.2
1936	23.4	48.4	14.4	1986	67.5	53.7	72.5
1937	27.6	62.1	15.1	1987	72.8	61.8	76.7
1938	21.9	45.0	13.6	1988	77.5	74.1	78.7
1939	26.4	54.7	16.2	1989	79.5	83.5	78.0
1940	30.2	66.0	17.4	1990	81.8	91.4	78.4
1941	35.4	73.7	21.5	1991	77.7	92.3	72.4
1942	37.3	76.5	23.2	1992	82.4	98.1	76.8
1943	32.8	68.3	20.1	1993	84.6	98.1	79.7
1944	28.7	62.1	16.6	1994	89.0	100.7	84.8
1945	27.1	54.9	17.1	1995	90.3	101.8	86.2
1946	29.4	47.5	22.9	1996	93.1	104.3	89.1
1947	35.4	61.5	26.0	1997	96.8	108.8	92.5
1948	37.5	63.2	28.2	1998	100.5	109.5	97.2
1949	35.4	56.6	27.8	1999	99.6	101.0	99.0
				2000	100.0	100.0	100.0

Therefore, by definition, the Laspeyres quantity index is the ratio, expressed as a percentage, of the total value of raw mineral commodities produced in a given year at base year prices for each raw mineral commodity produced in a given year to the total value of these same mineral commodities in the base year.

The U.S. composite mineral production index is shown in figure C1. This index represents almost 90 percent of the value of domestic production of industrial minerals and metals. The composite mineral production index has an increasing long-term trend while during this same period, the composite price index for these commodities, as shown in figure B1, had a declining trend. Fluctuations in the production index curve reflect major military and economic events. There was a deep trough during the Great Depression of the 1930s when demand “dried up” a peak during World War II to support the military equipment needed, and a low at the end of the war that was followed by the post-war economic boom as consumer demand rose. This generally upward trend continued until the decline caused by the oil crisis of the early 1970s. Mineral production recovered through the rest of the 1970s then declined in the recession of the 1980s. After a lull in 1982, mineral production has increased with the economic prosperity at the end of the 20th century.

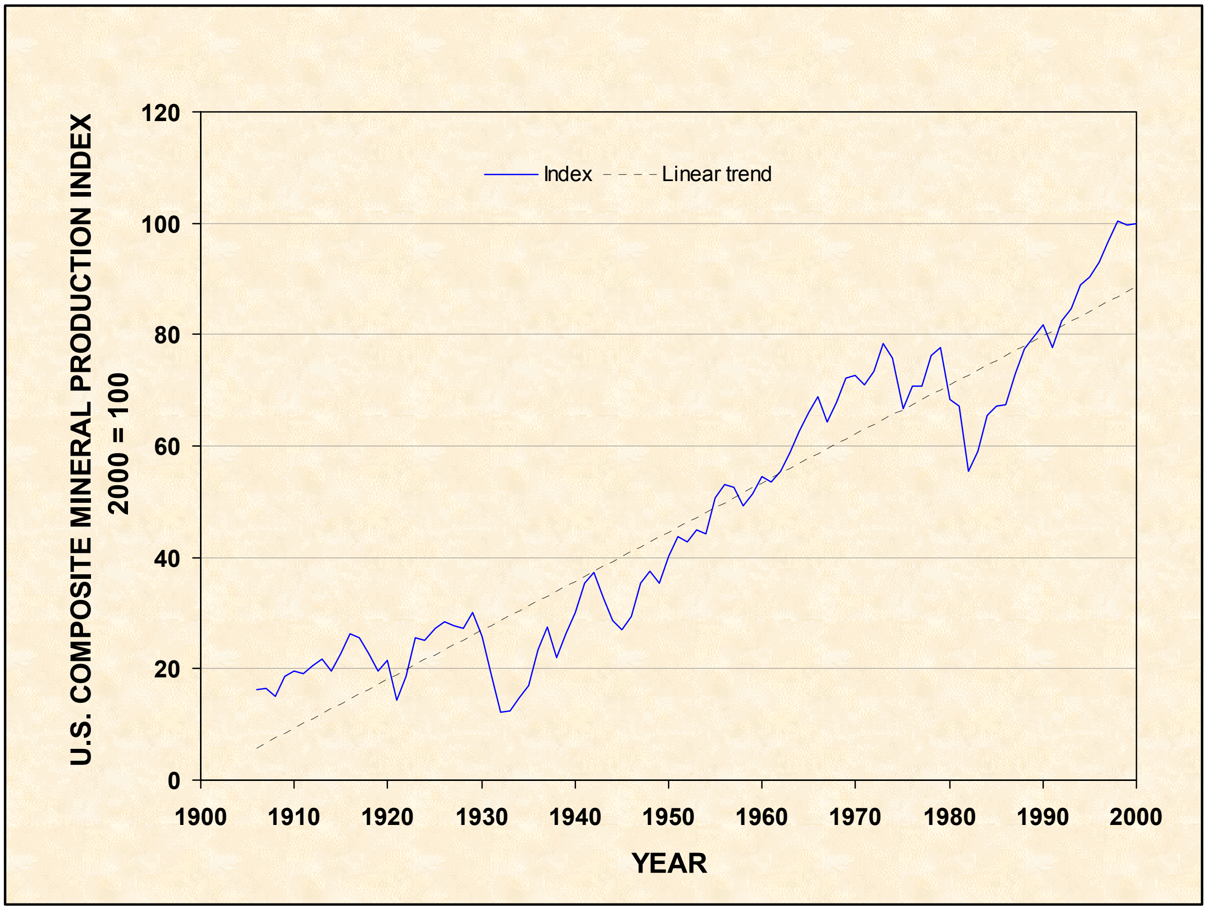

Figure C1. U.S. composite mineral production index, 1906-2000.

The industrial mineral production index (figure C2) has a similar profile, and growth trend, as the composite production index because it comprises two-thirds of the composite index. Production of the industrial minerals is closely tied to in overall economic activity. The 20th century was a time of economic expansion. Industrial minerals grew as a basic part of the economy. A discussion of the trends of the individual commodities comprising the industrial minerals production index follows. It should be noted that the linear trend line in figure C2 is not shown prior to 1910 because it is less than zero. The linear trend is the average trend for the entire series. In this case, the slope of the average trend results in the trend line being below zero prior to 1910. This does not indicate negative production, but demonstrates that the trend line is not applicable to the early part of the data series.

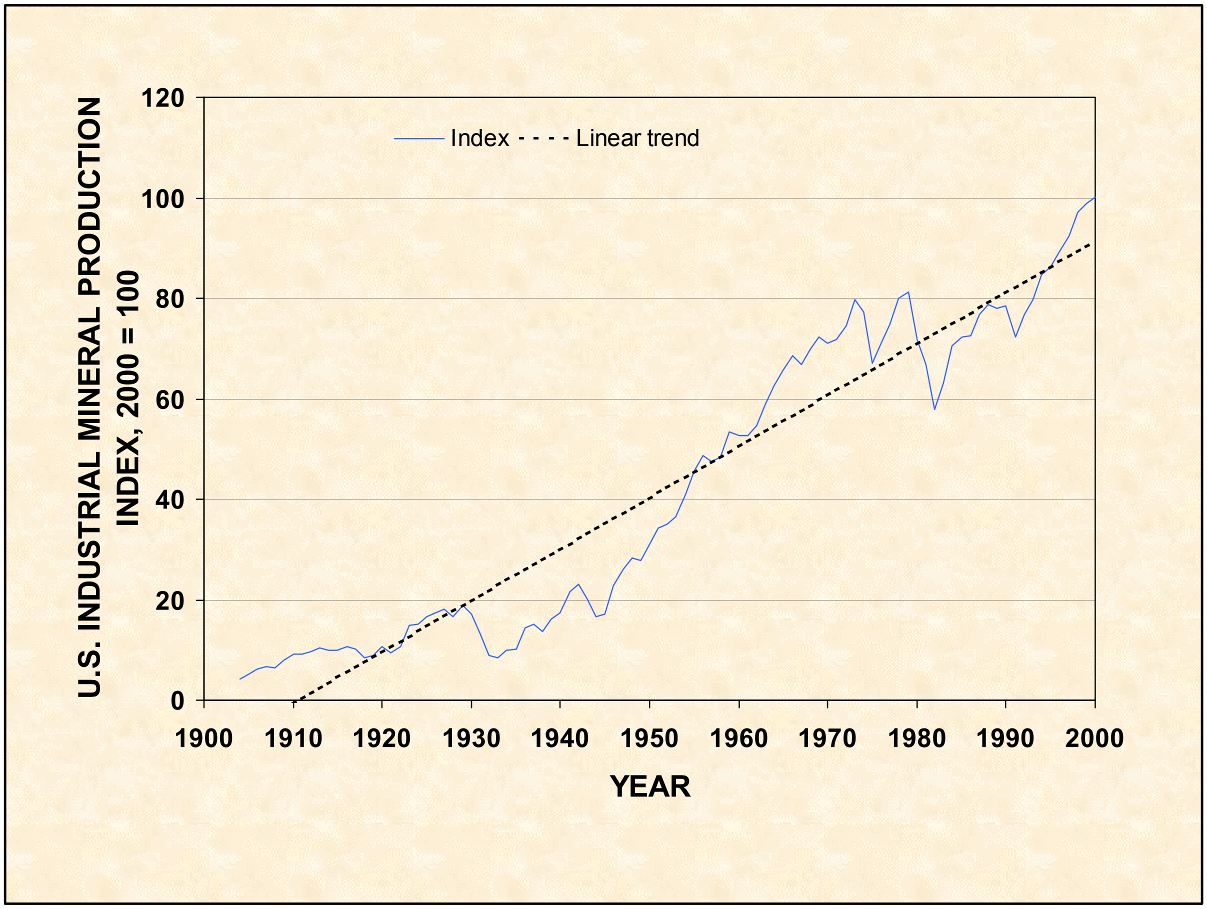

Figure C2. U.S. industrial mineral production index, 1904-2000.

Cement accounts for more than 20 percent of the value of production of industrial minerals included in the composite index and in 2000 was the industrial mineral with the second largest value of mine production in the United States ($6,901 million), see table B1. Most cement was used in the construction of bridges, buildings, highways, and other infrastructure. Cement production expanded during the 20th century along with the construction industry as part of the growing economy. Figure C3 shows the strong increase cement production. Production experienced strong growth during the boom years of the 1920s, then a substantial decline when demand crashed during the Great Depression. There was increased demand at the beginning of World War II, but a decline at the end of the war. There was a very strong growth after World War II until 1972 resulting from a strong economy and the building of infrastructure such as the interstate highway system. From 1972 until the mid-1990s, cement production oscillated around 70 million tons. In the mid-1990s, a new boom began and it reached more than 80 million tons.

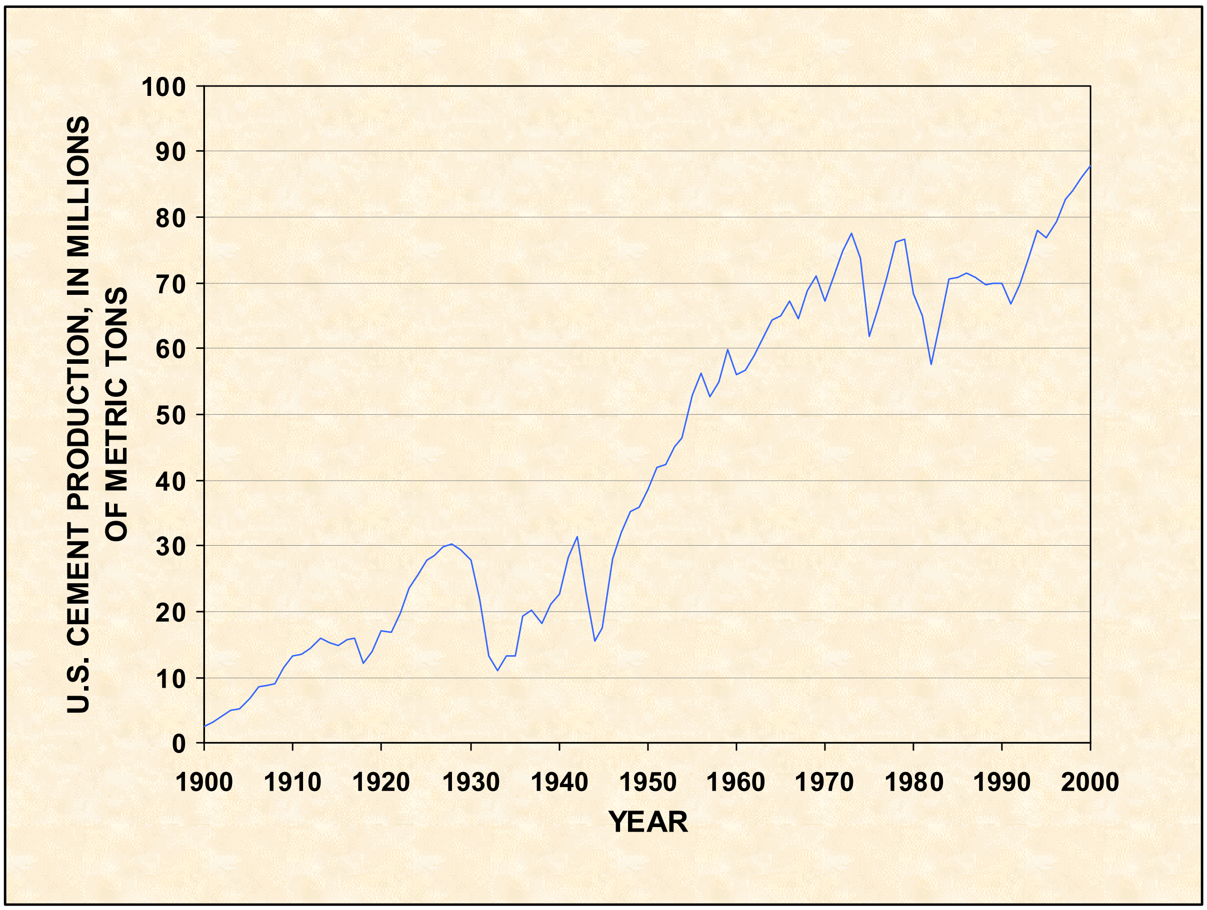

Figure C3. U.S. cement production, 1900-2000 (data from van Oss and Kelly, 2001).

Clay production, shown in figure C4, was less than 5 million tons per year prior to World War II. During and after the war, production began a dramatic increase that continued until 1973 when it reached almost 59 million tons. Production then declined to 32 million tons in 1982. This was the result of lowered demand that occurred as a result of less construction activity (Ampian, 1983, p. 217). In 1985, it recovered to above 40 million tons where it has remained.

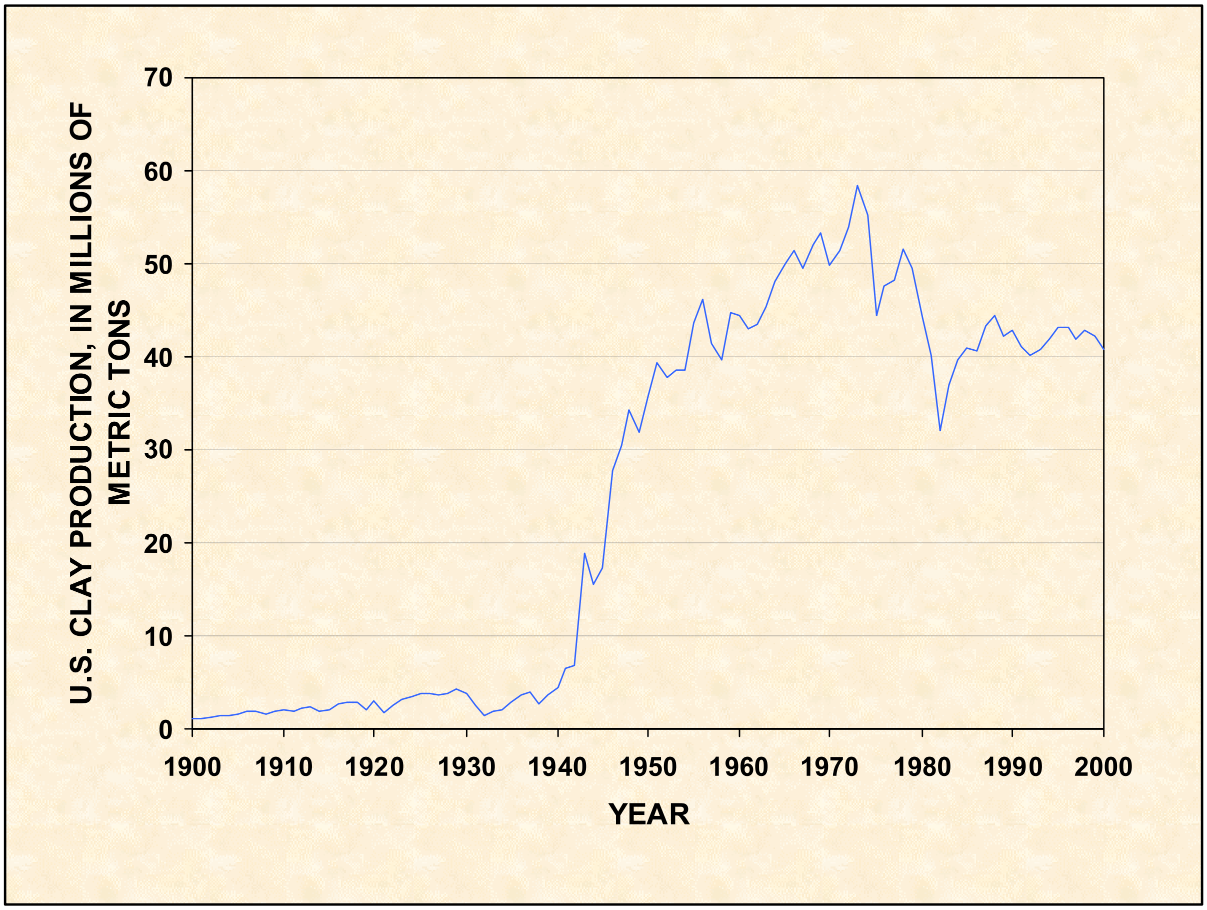

Figure C4. U.S. clay production, 1900-2000 (data from Buckingham and Virta, 2001).

Major markets for lime were steel, flue gas desulfurization, mining, construction, pulp and paper, precipitated calcium carbonate, and water treatment (Miller, 2001, p. 94). Figure C5 shows that the production of lime was relatively level until World War II. Production increased with the economic boom after the War. This growth leveled off in the 1970s when it ranged between 17 and 20 million tons. Production declined during the recession of the 1980s and increased to about 20 million tons in the 1990s.

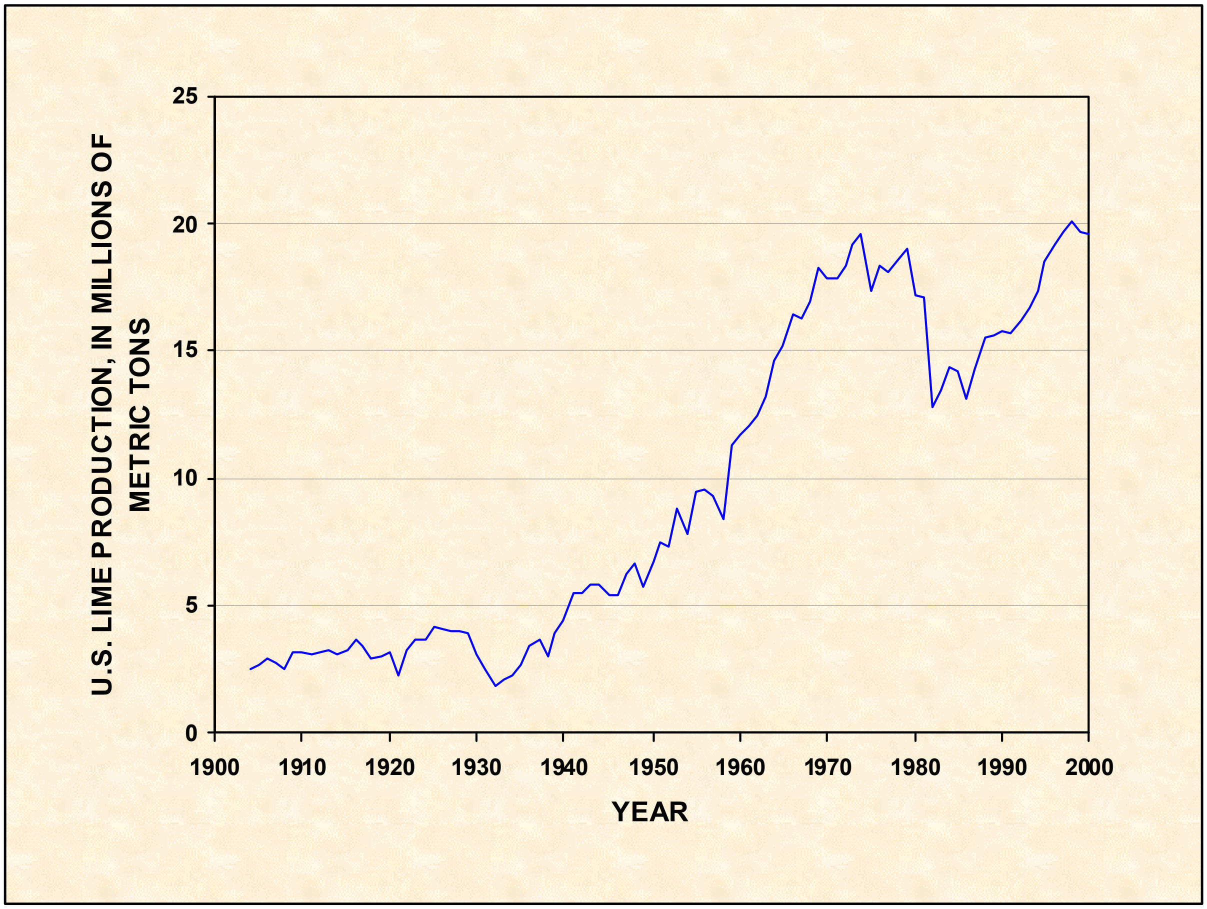

Figure C5. U.S. lime production, 1904-2000 (data from Goonan and Miller, 2001).

Most phosphate rock is used to make fertilizer. Phosphorous is an essential element for plant and animal nutrition. Phosphate rock production expanded greatly after World War II because of a strong increase in the demand for fertilizer (figure C6). It reached over 54 million tons in 1980, almost 10 times the amount produced during World War II. After 1980, demand declined because of a global recession (Stowasser, 1986, p. 579). Since that time, it has oscillated in response to changes in fertilizer markets. It has been between 40 and 50 million tons since 1985.

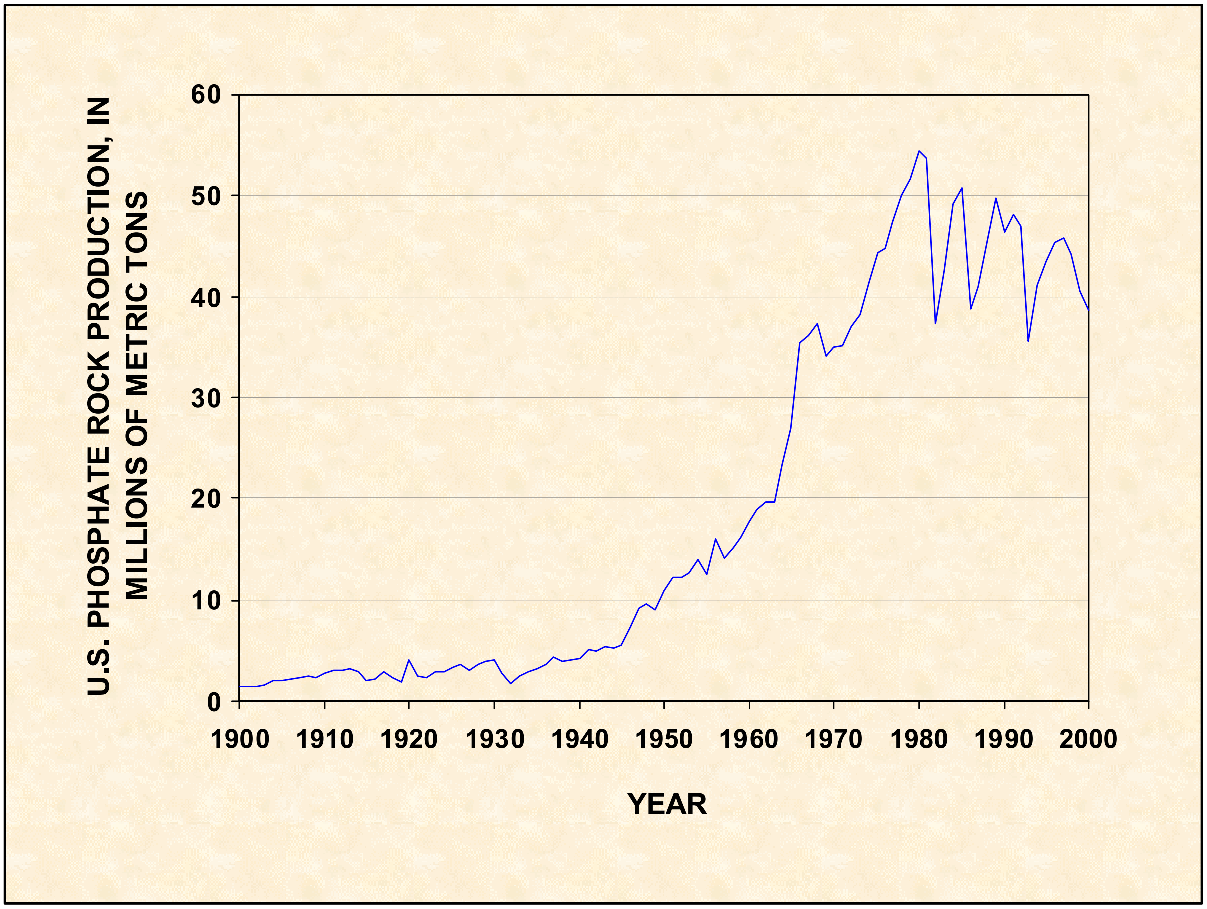

Figure C6. U.S. phosphate rock production, 1900-2000 (data from Buckingham and Jasinski, 2001).

Uses for salt include: highway deicing, industrial processes, agriculture, human consumption, and water treatment. The production of salt is shown in figure C7. In the years after World War II, production rose, influenced by the strong growth in the economy, until 1969 when it reached above 40 million tons. It remained above or near 40 million tons throughout the 1970s. It declined in the recession of the 1980s and did not return to and surpass 40 million tons until the strong economy of the mid-1990s.

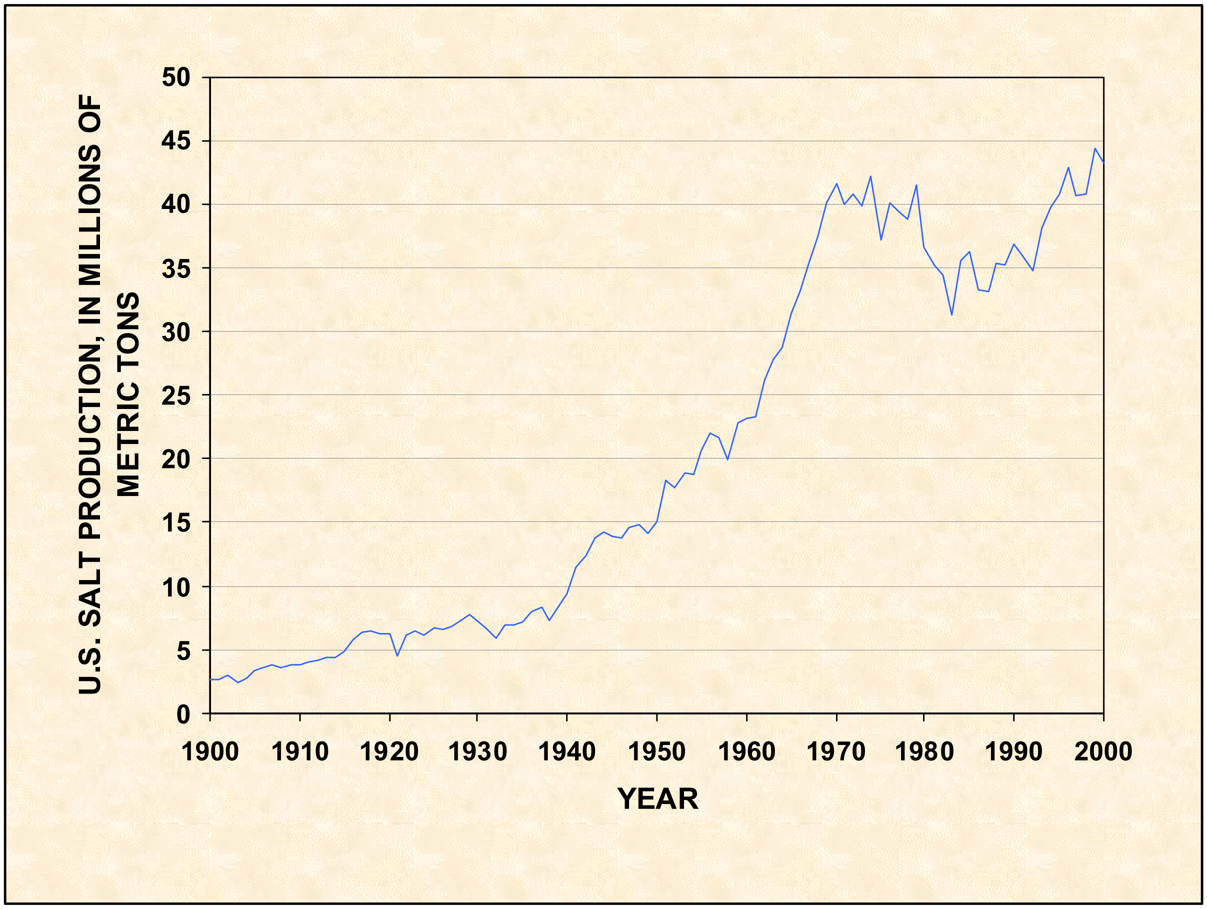

Figure C7. U.S. salt production, 1900-2000 (data from Porter and Kostick, 2001).

Uses of sand and gravel include construction, glassmaking, foundry sand, and abrasives. Because of its broad use, the production of sand and gravel is closely associated with the growth of the economy. Production is shown in figure C8. The figure shows the sum of construction and industrial sand and gravel. It generally grew during the 1920's with the strong economy. The decline in economic activity including construction during the Great Depression is reflected in sand and gravel production. Production of sand and gravel grew during World War II because of the war effort. With the economy, sand and gravel production declined slightly immediately after the war, then recovered strongly during the post war economic boom. Because of the near completion and winding down of the construction of the interstate highway system in the mid-1960s, sand and gravel production leveled off. After 1965, it stayed above 800 million tons except for the recessions in the 1970's and 1980's and a decline in 1991. After 1991, it began a strong increase as part of the strong growth of the economy.

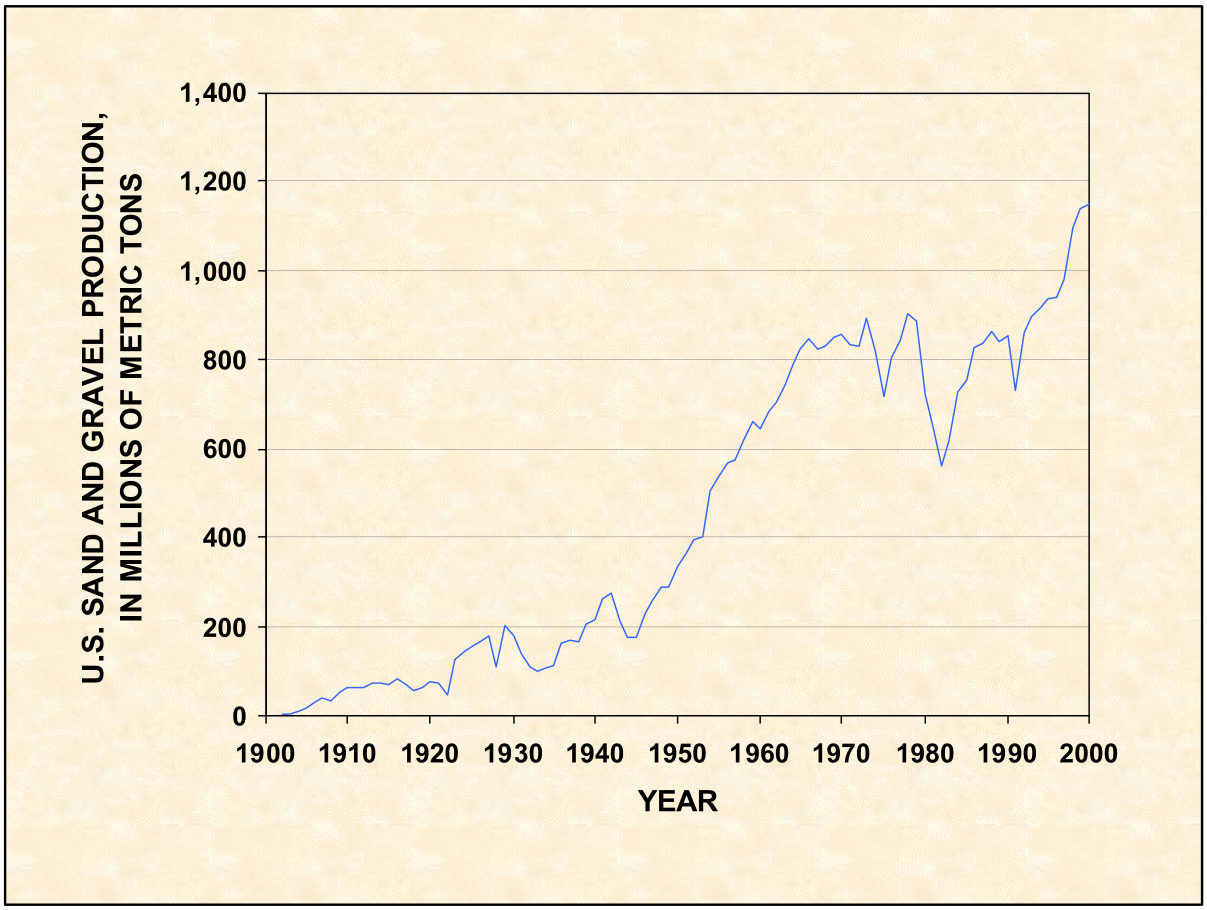

Figure C8. U.S. sand and gravel production, 1902-2000 (data calculated from Porter and Bolen, 2001a and 2001b).

Crushed stone production (figure C9) increased strongly in the United States from the 1950s to the present as the building of U.S. infrastructure accelerated. Recessionary periods in the early 1980s caused decreased crushed stone production, which rebounded after this period.

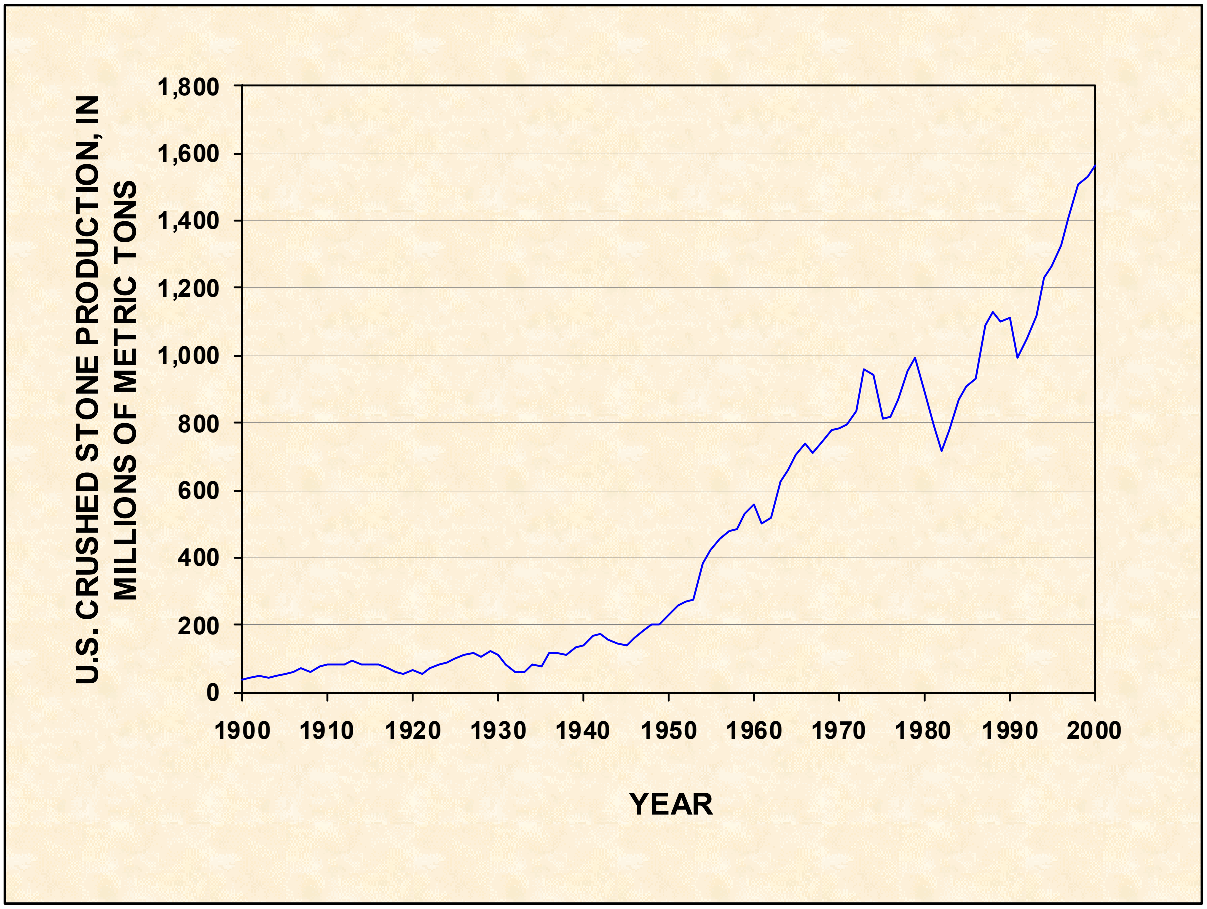

Figure C9. U.S. crushed stone production, 1900-2000 (data from DiFrancesco and Tepordei, 2001).

The metal mine production index (figure C10) has a more moderate increasing trend compared to the industrial minerals index (figure C2). It also has more volatility. This is because, on average, metal production is more concentrated than industrial minerals production. Each facility is large. As a result opening or closing a metal facility has a large impact on metal production. Generally industrial minerals industries are made up of a large number of smaller operations. The opening or closing of a smaller operation does not cause dramatic changes in industrial minerals production. This results in more volatile adjustments in metal production. The metal production index has a large dip during the years of the Great Depression following the sudden drop in demand for goods and services. It then has a relatively level trend from World War II through 1979. After a valley in the 1980s recession, it has risen substantially through 1998 because of strong advances in the economy. The trends of individual metal commodities are discussed below.

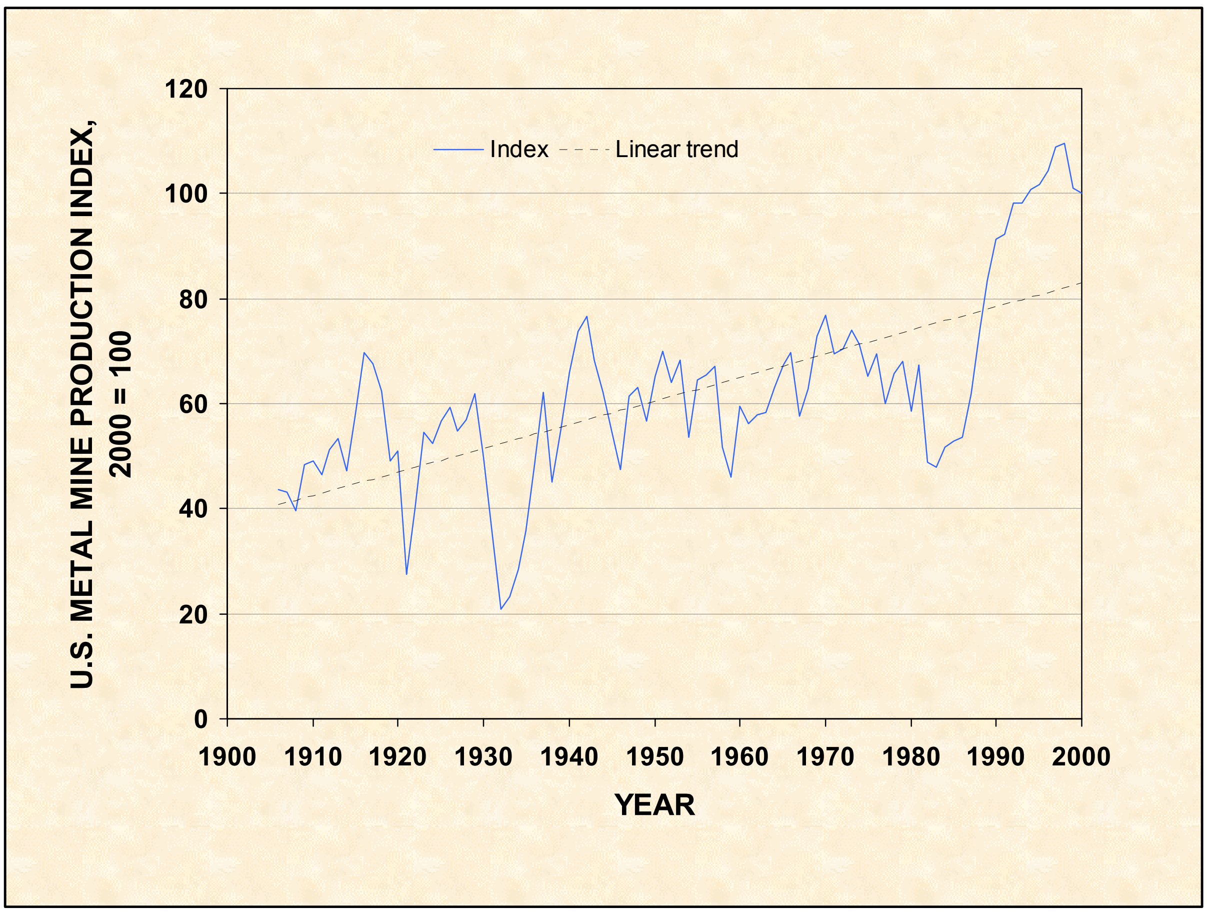

Figure C10. U.S. metal mine production index, 1906-2000.

Because copper represents such a large part of the metal production index, both historical productiond copper mining's historical production pattern (figure C11) is similar to the historical pattern of the metal production index. New developments in mining processes and equipment have made possible the recovery of copper from ore that was not economically feasible using older technologies. These new innovations were responsible for many of the upturns in copper production (Wilburn, Goonan, and Bleiwas, 2001).

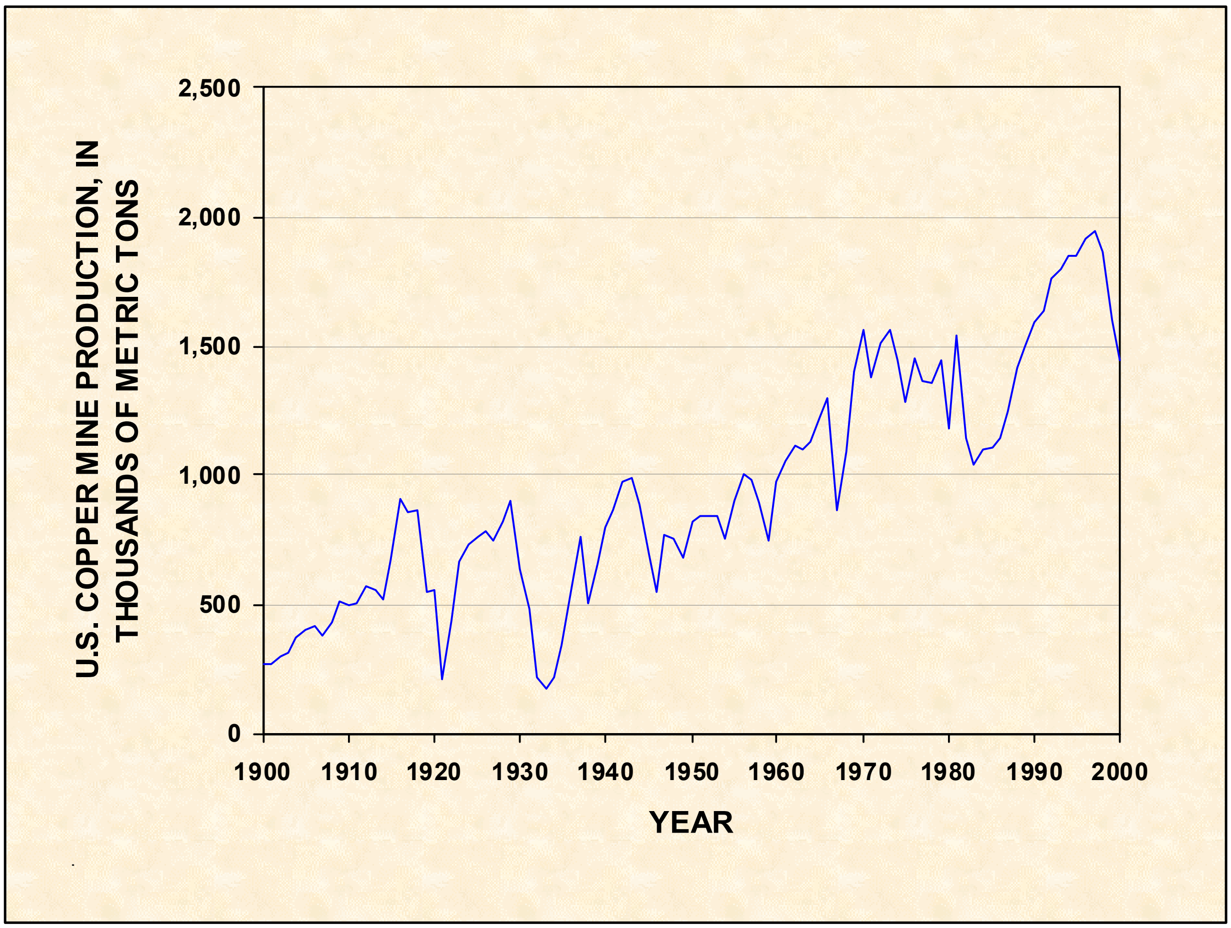

Figure C11. U.S. copper mine production, 1900-2000 (data from Porter and Edelstein, 2001).

Mine production for most of the metals included in the index have increasing long-term trends. Gold mine production (figure C12) has been level to declining, except for a peak that occurred when the government increased the price of gold in 1934. The period of relatively high prices ended in 1942 because U.S. gold mines were ordered closed during World War II so that equipment supplies and labor could be focused on essential base metals. Production remained at this low level after the war because of increased costs associated with reopening closed mines (Lucas, 1986, p. 323). In the early 1980s, gold production began a sharp rise as inflation worries stirred speculation. In addition, new technologies, such as the heap leach method, played a significant role in this dramatic increase. Disseminated deposits were identified as a source of gold in the 1960s. Most of them have been found in California, Nevada, and Utah, where gold is often recovered by heap leaching (Boyle, 1994). The increase in production continued through the 1990s due to high global demand for more gold.

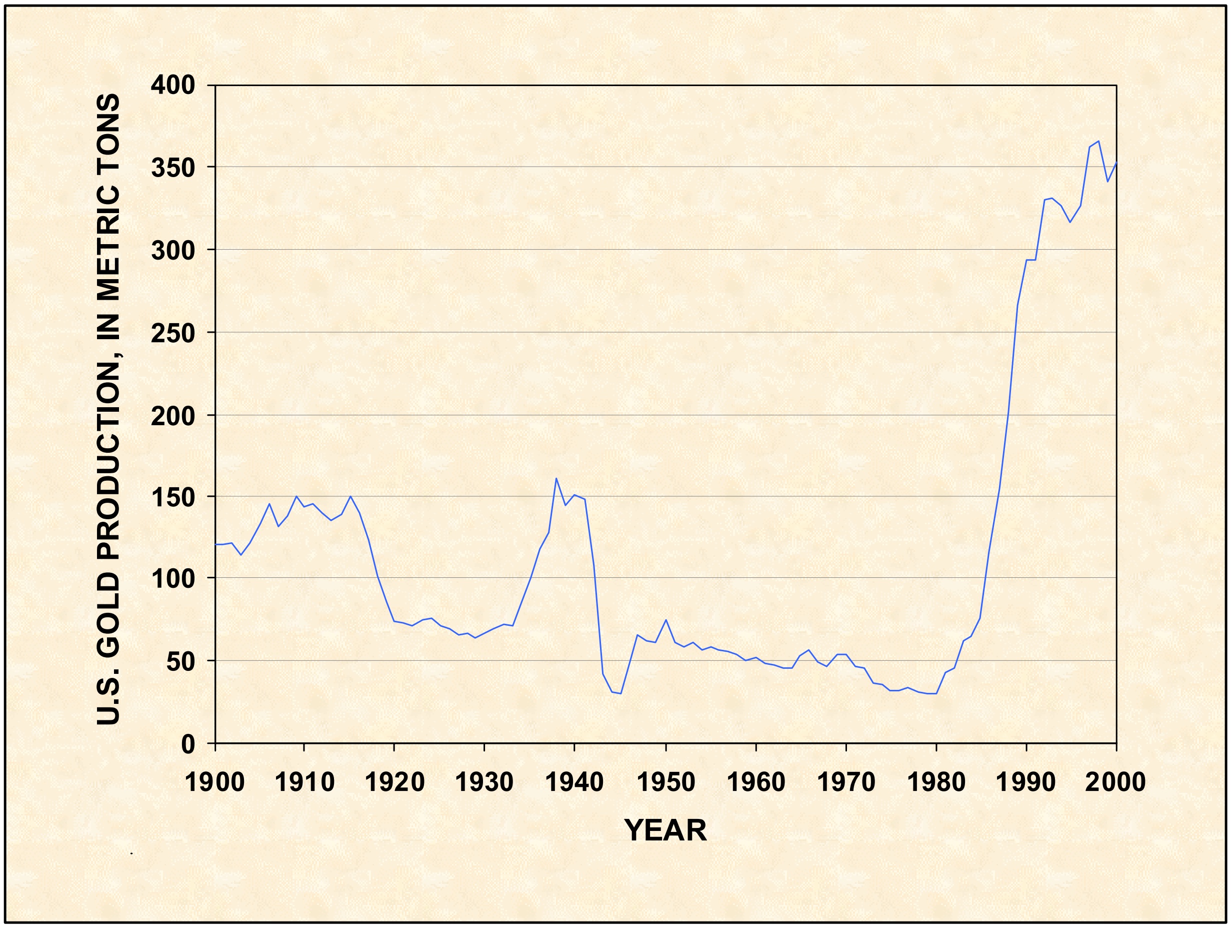

Figure C12. U.S. gold mine production, 1900-2000 (data from Porter and Amey, 2001).

The long run movements in iron ore production followed economic trends until the early 1980s when it decreased because of the decline in the steel industry (figure C13). Iron ore production is volatile because the steel industry is volatile. Steel production plants are typically large facilities and when one closes or starts up it can have a large impact on iron ore demand and the market.

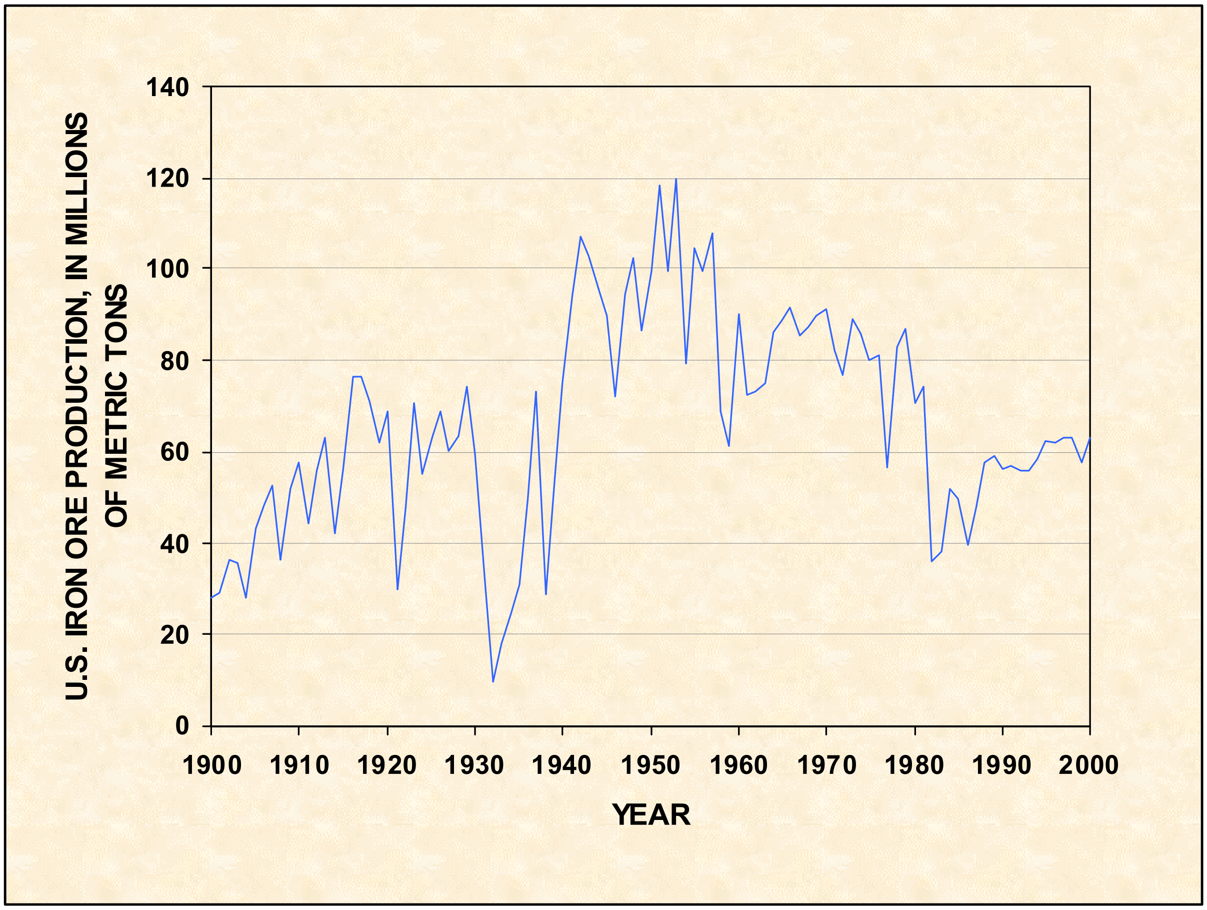

Figure C13. U.S. iron ore production, 1900-2000 (data from Kelly and Kirk, 2001).

Lead production (figure C14) declined during the Great Depression of the 1930s. It recovered during World War II, but turned down after the War due to the depletion of reserves in the "lead belt" in Missouri and Arkansas (Smith, 1999, p. 74). Production increased in 1969 after the first significant production came into the market from the southeast Missouri lead belt in 1969 (Woodbury, 1985, p. 441). Production was effected by a general slowdown in the economy during the 1980s. Since that time, lead production has oscillated around 400 thousand tons per year.

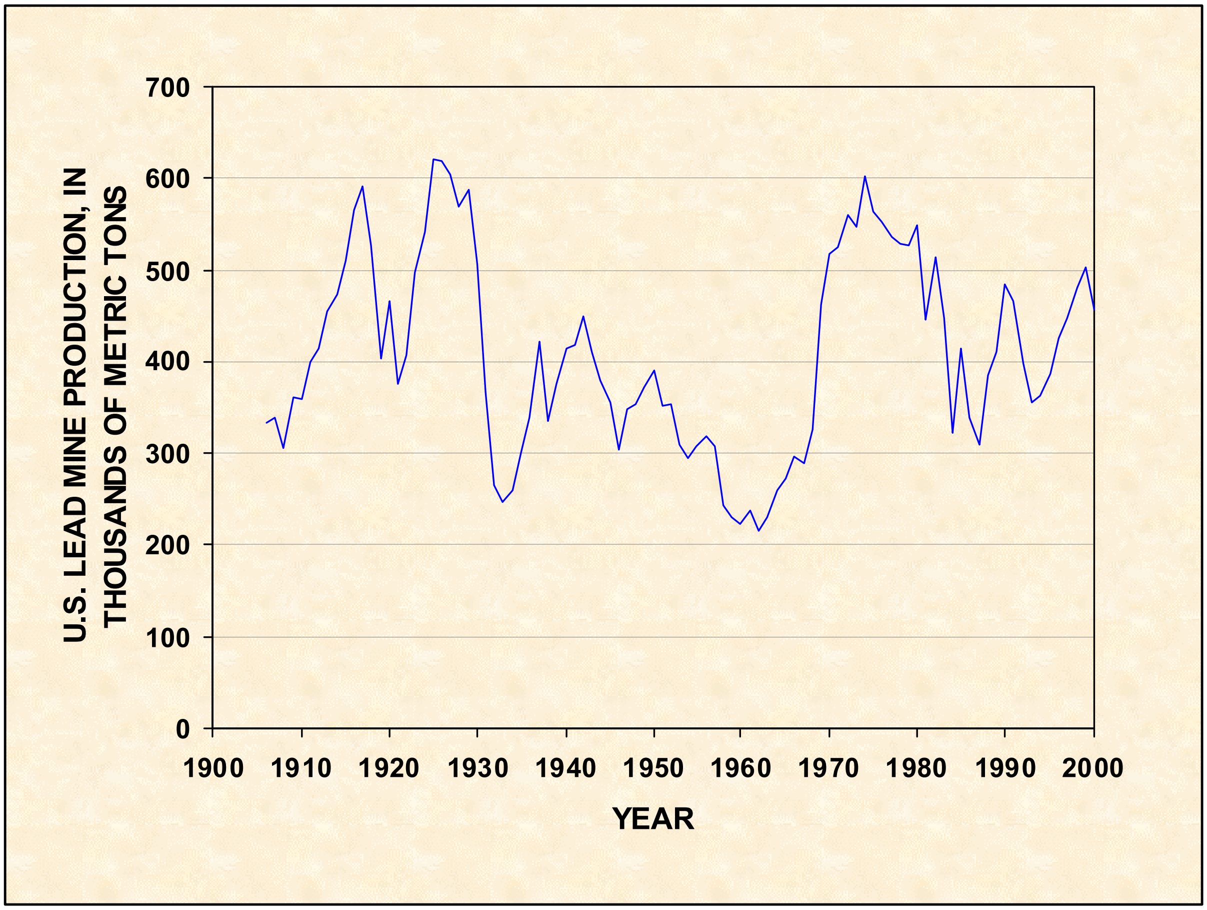

Figure C14. U.S. lead mine production, 1906-2000 (data from DiFrancesco and Smith, 2001).

Zinc production (figure C15) in the first half of the century followed economic trends; increasing during World War I, falling after the War, booming during the 1920s, falling during the Great Depression of the 1930s, and increasing during World War II. Following general economic trends, production declined after the War then increased to a high in 1965. Then it began a long decline to a low in 1986, because of poor market conditions (Jolly, 1987, p.1000). After 1986, recovery in domestic zinc production can be attributed to the development of the Red Dog Mine in Alaska. In the late 1990s, the Red Dog Mine produced more than one-half of U.S. zinc production (Plachy, 1999).

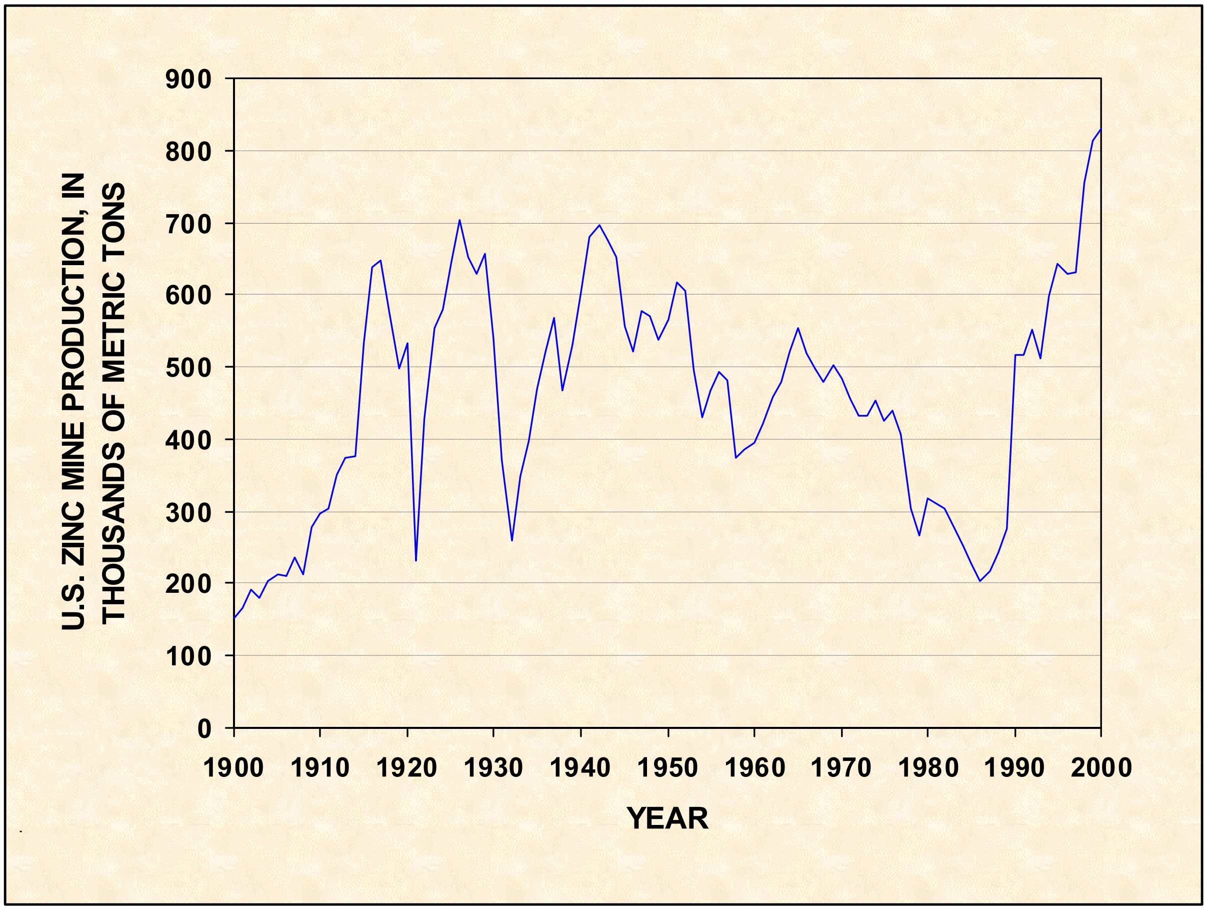

Figure C15. U.S. zinc mine production, 1900-2000 (data from DiFrancesco and Plachy, 2001).

Because there is no domestic mine production of bauxite ore for aluminum, it was not included in the metal mine production index. However, the aluminum industry is important in the United States as large quantities of aluminum are produced from imported bauxite. Aluminum production (figure C16) grew slowly prior to World War II as more and more uses were discovered. Since that time, the trend in aluminum production, both primary and secondary, has been strongly upward through 2000, due to the wide variety of uses for the lightweight properties of aluminum. These uses include packaging (cans and foil), transportation (airplanes and automobiles) and electrical transmissions. From 1970 to 1997, the production of secondary aluminum has increased more than 8.5 times as recycling aluminum became economically viable (Buckingham, and Plunkert, 2001).

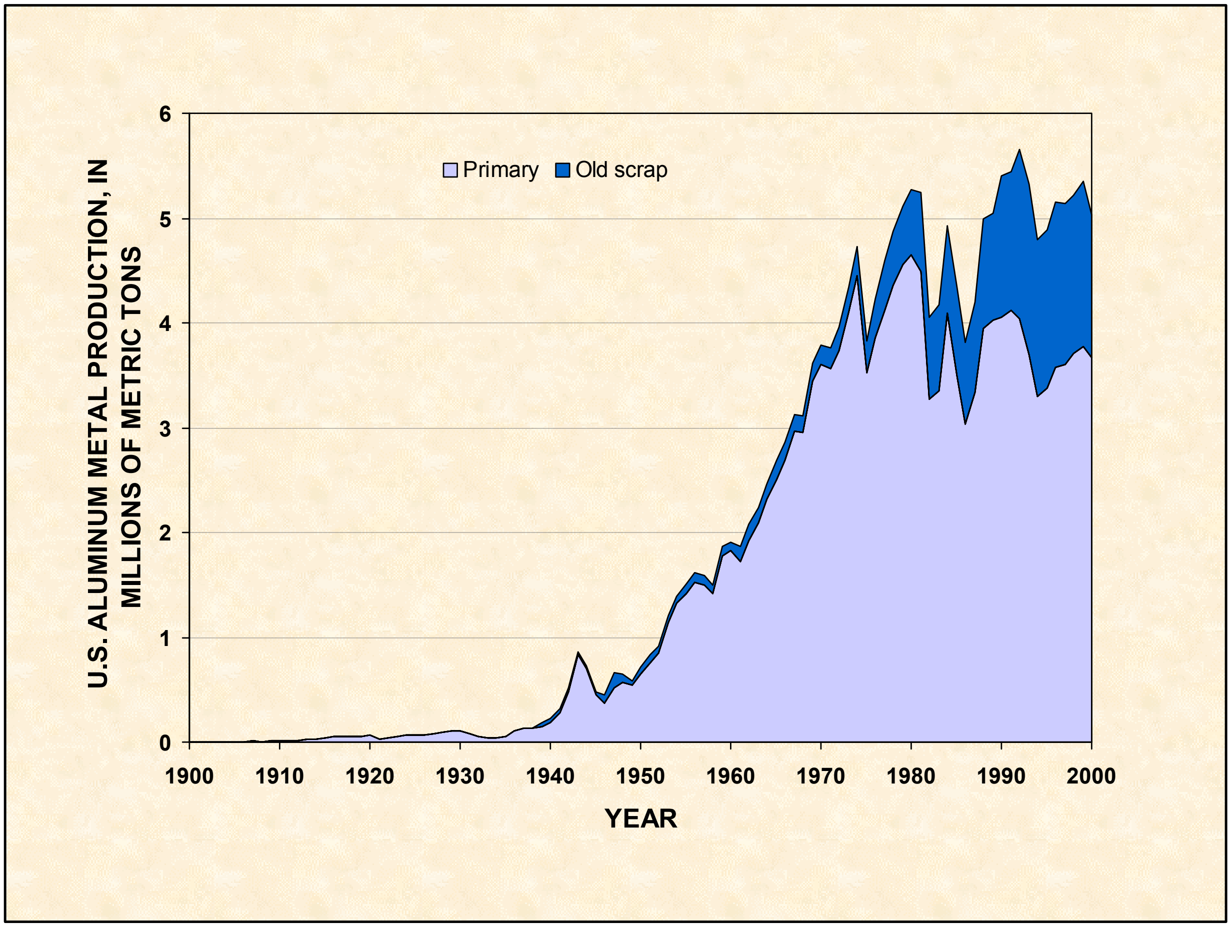

Figure C16. U.S. aluminum metal production. 1900-2000 (data from Buckingham and Plunkert, 2001).

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APPENDIX D: ECONOMIC CASE STUDY – ALUMINUM

Introduction/background

At least one aluminum compound has been in use for centuries. Alum, $KAl(SO_4)_2 \cdot 12H_2O$, was used by the Greeks and Romans as an astringent and as a chemical that fixed dyes in cloth (Banks, 1992). Although aluminum (metal) was isolated in 1827 by Wöhler, it was not until 1886 that an electrolytic process to produce aluminum was discovered independently by Hall in the United States and by Héroult in France. A chemical process to commercially produce alumina (aluminum oxide) from bauxite (Bayer Process) was patented by Karl Bayer (Germany) in 1888.

Aluminum is found in such minerals as alunite, bauxite, kaolinite, and vermiculite. The aluminum compound, bauxite, is the most important commercial source of aluminum metal. It is chemically treated to obtain alumina (Al_2O_3), which is then electrolyzed in a molten salt solution to yield aluminum. Aluminum is commonly alloyed with various other materials including copper, magnesium, or zinc, to provide a wide range of physical properties. The heavy reliance of the transportation industry on aluminum alloys is a testimonial to the efficiency of this material. The combination of high strength, low weight, high corrosion resistance, and workability are features that make aluminum alloys a top choice as structural materials. Some of the more common uses of aluminum are for beverage cans, as packaging materials, and in automobiles. Recyclability, cost, and low weight for improved fuel economies drive automotive demands. Other less common uses for aluminum (alloys) are: bridges, highway signs, kitchen utensils, nails, and many other items.

The modern aluminum industry is composed of two principal producing segments, the primary industry and the recycling industry. Their interrelationships are shown in figure D1. The primary aluminum industry consists of mining to produce bauxite, refining to produce alumina, and smelting to produce aluminum metal. The aluminum recycling industry consists of the scrap industry and secondary smelters and fabricators. Within the recycling industry, are the beverage can recyclers, which is a distinct industry, and those who recycle other products.

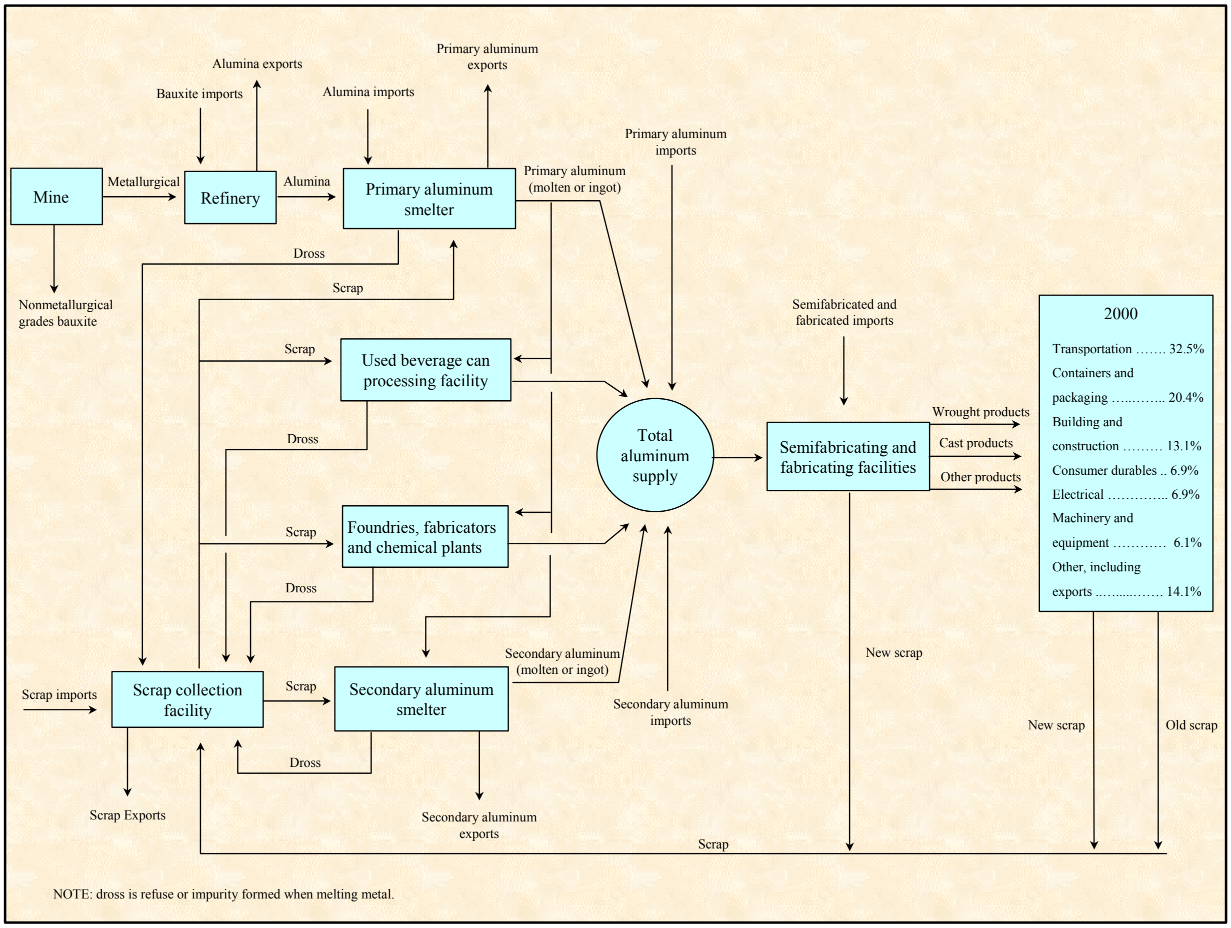

Figure D1. U.S aluminum flow diagram (diagram adapted from Wilburn and Wagner, 1993, consumption data from Plunkert, 2002a).

Historical economic trends

In 1900, the U.S. aluminum industry imported 8,800 tons of bauxite ore (U.S. Geological Survey, 1902) and processed it into primary aluminum metal valued, in constant 2000 dollars, at almost $34 million. These numbers compare to bauxite imports of 9.3 million tons and the production of primary aluminum valued at $6.1 billion (2000 dollars) in 2000 (U.S. Geological Survey, 2001). This is roughly an increase of over 1,000 times for bauxite imports and 180 times the production value of primary aluminum during the twentieth century. Apparent consumption of aluminum in 1900, equal to the primary aluminum production, was recorded as being slightly less than 2,300 tons. Almost 8.0 million tons of aluminum (primary metal production plus recovery from old aluminum scrap plus imports minus exports) were used in 2000 (Plunkert, 2002a), an average annual growth rate of 8.5 percent since 1900.

Prices

Even with these tremendous increases in the use of aluminum, the long-term trend in aluminum prices (constant 2000$/ ton) has surprisingly decreased. During this time period, there were two exceptions that exhibited major upward movements (see figure D2). One price peak in 1907 may be partially explained by the increasing demand for both railroad cars and automobiles due to aluminum's lightweight and high strength properties. A second factor was the increase in both copper and tin prices that encouraged manufacturers to substitute aluminum for these metals where possible, which further increased demand for aluminum. The most pronounced peak in aluminum prices occurred in 1916 when demand for war materials increased dramatically as the United States became more involved in World War I. Since that time, the advent of various new technologies have helped to increase productivity and reduce production costs, which have been major contributors to the decline of aluminum prices.

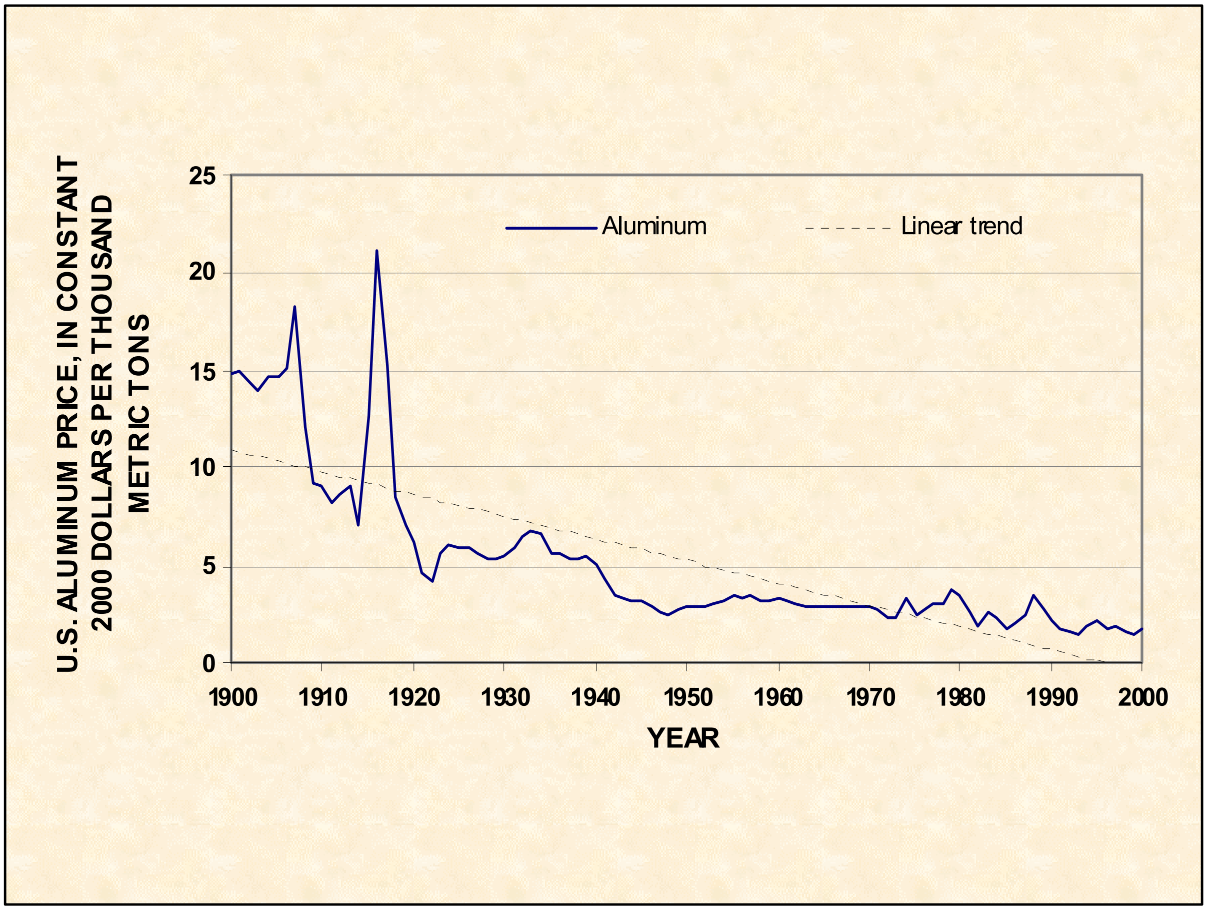

Figure D2. U.S. aluminum price, in constant 2000 dollars, 1900-2000 (data from Buckingham and Plunkert, 2001a).

As the major source for aluminum, bauxite's price trend line exhibits an overall slight decline. Since the mid 1970s, there has been a decidedly downturn in bauxite prices. Between 1900 and 2000, average annual bauxite prices, constant 2000 dollars per ton, ranged from a historic low in 1999 of $22 to a historic high of $106 in 1962. In figure D3, the historic price data[17] for bauxite exhibits several sharp up and down spikes. These peaks and valleys in the bauxite price chart are

[17] Bauxite is usually consumed by its producer (affiliate) and no commercial price is quoted, therefore U.S. import price of bauxite, port of shipment (free alongside ship) was used for this figure.

not particularly associated with any specific economic events and the importance of this data is to evaluate the long-term trend. The overlay of world production on this same chart provides a picture of the magnitude of the production increase during the 20th century. There is no particular graphical correlation between the price and production of bauxite.

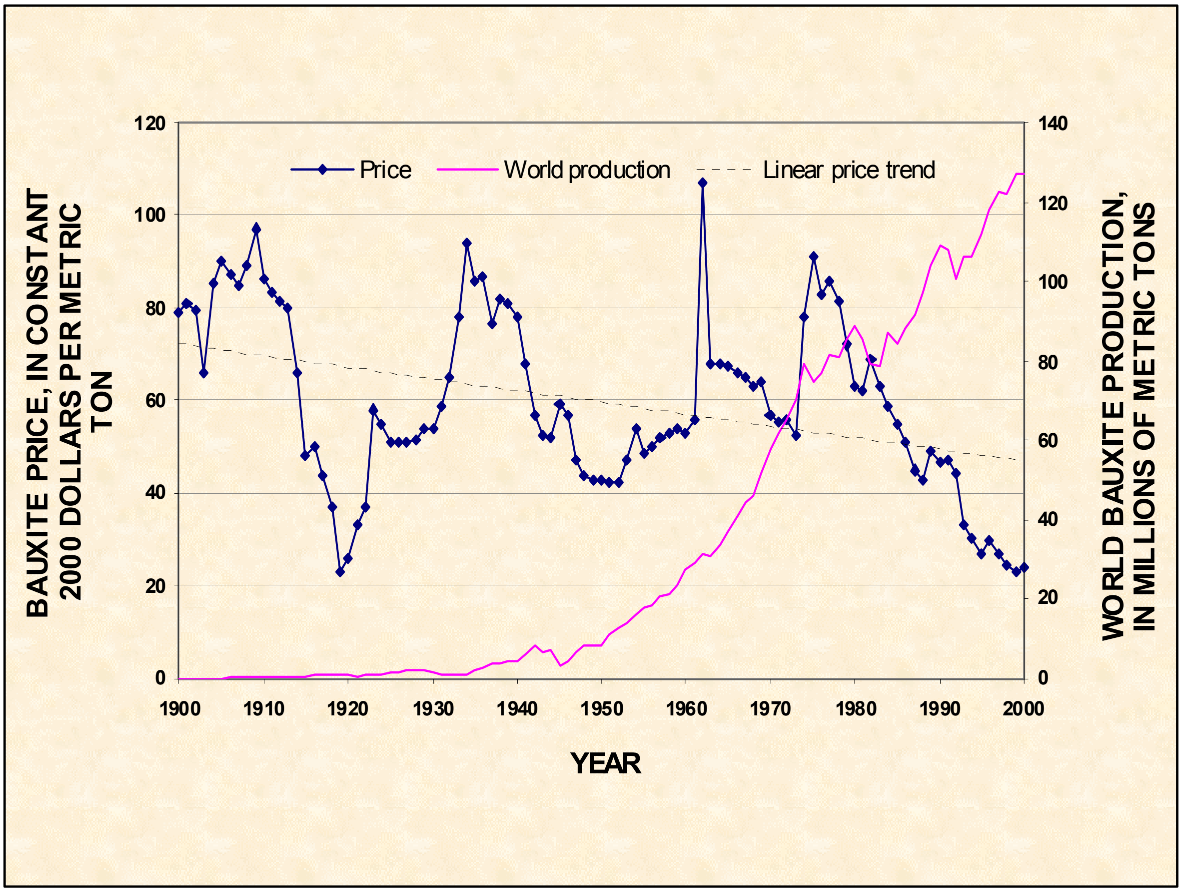

Figure D3. U.S. Bauxite price, in constant 2000 dollars, and world production, 1900-2000 (data from Buckingham and Plunkert, 2001b).

Prices for alumina have only been available since the 1960s when trade of this intermediate material became sufficiently large enough to establish a consistent market. The last several decades have seen alumina prices following the same decreasing trends as both bauxite and aluminum. As a value-added product derived from bauxite, but still requiring processing to become primary aluminum, alumina prices have fallen between the two. One justification for stable and/or falling alumina prices is because more bauxite producers are incorporating their own conversion processes to produce and sell alumina. This is usually accomplished within their organization and at a nearby site rather than shipping the bauxite ore to another location to be processed by the purchasing firm.

Domestic production

Figure D4 shows the U.S. production of bauxite, alumina, and primary aluminum. Typically, for every 4.5 tons of bauxite fed into an alumina refinery, approximately 2 tons of alumina are extracted, from which about 1 ton of primary aluminum is produced (Wilburn and Wagner, 1993). The United States has been mostly dependent on foreign suppliers for metallurgical grade bauxite. Domestic production of bauxite, which is not normally used for metal production, has essentially been flat for the last century with one dramatic exception. This enormous increase in domestic bauxite production occurred during the early 1940s to meet the wartime demand for aluminum, which was especially critical to the military aircraft industry. Also, a continuous supply of bauxite from foreign sources was in jeopardy due to a short supply of transport ships and the possibility of enemy submarine attacks (U.S. Bureau of Mines, 1943). The total domestic production of bauxite in the 3 war years of 1942, 1943, and 1944 was greater than the prior 40-year period, from 1900 through 1941. The production peak was in 1943 when over 6.0 million tons were produced. In 1988, the last year that domestic production data on bauxite was available, 588 thousand tons were produced. This was utilized for refractory and other specialized applications.

Domestic production of alumina reached highs of slightly more than 6.8 million tons in both 1974 and 1980. Since then, alumina production has trended down with approximately 4.8 million tons produced in 2000 (Plunkert, 2002b), a decrease of 16 percent from 1980 levels. Production trends of alumina and primary aluminum in the United States have moved almost parallel since the 1950s[18].

The major growth period for primary aluminum production in the United States was concentrated between the beginning of World War II and the 1970s. Military demands initiated the growth and a recession associated with the oil crisis in the 1970s halted the growth that saw production of primary aluminum go from slightly less than 200 thousand tons in 1940 to almost 4.5 million tons in 1974, an increase of over 2,000 percent. Since that time, primary aluminum production has been around the 4.0 million tons level with the indication of a slightly decreasing trend.

[18] Alumina production data was not recorded in the Minerals Yearbook prior to 1950s.

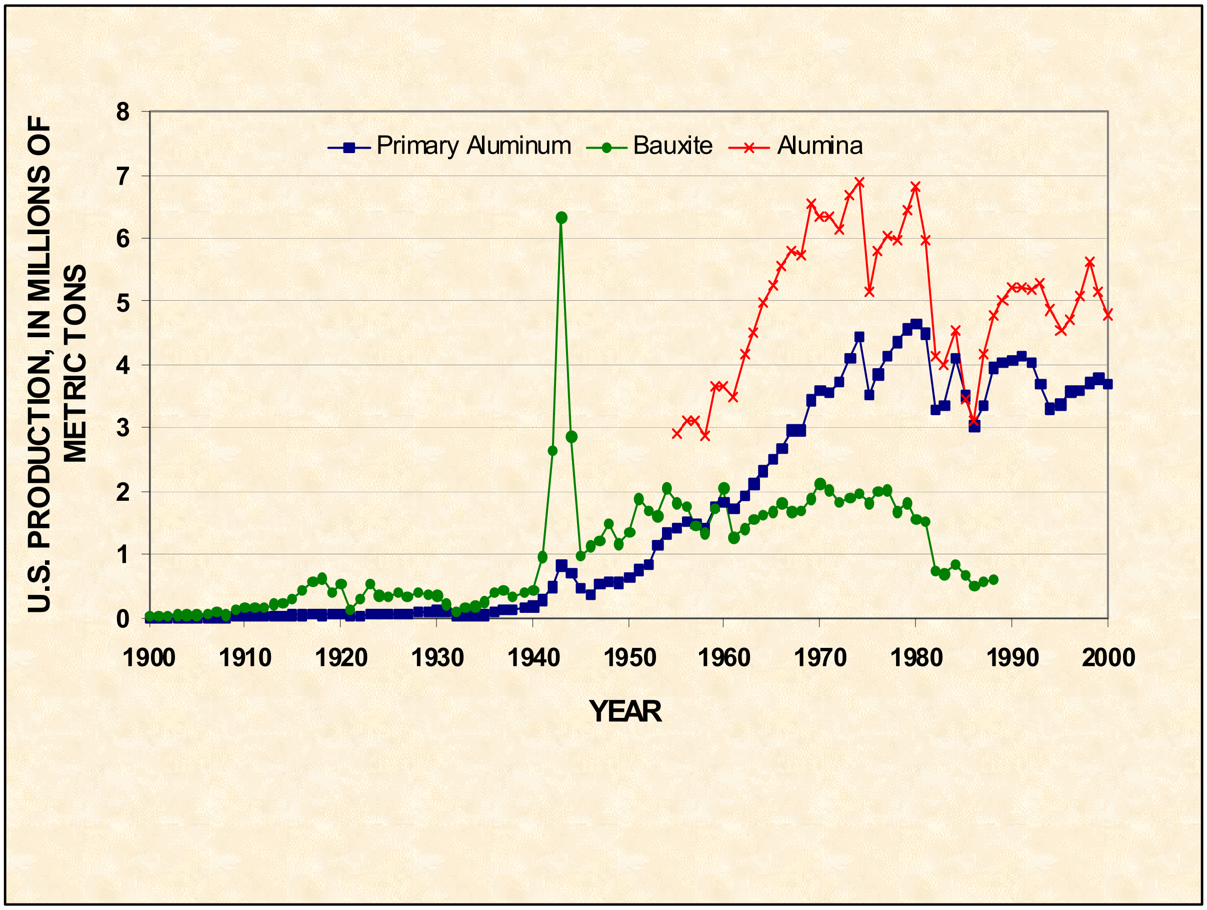

Figure D4. U.S. production of alumina, bauxite, and primary aluminum, 1900-2000 (data from Buckingham and Plunkert, 2001a and 2001b).

Aluminum production from primary and secondary sources[19] has continued to increase over the last century. Secondary scrap has assumed a major portion of the domestic aluminum supply. There are two components of secondary scrap, new and old. New scrap refers to the material that is left over after fabrication of aluminum products. Old scrap is the term used for aluminum products that have reached the end of their economic life and are discarded. In 2000, almost 3.5 million tons of aluminum were recovered from new and old scrap (Plunkert, 2002a).

[19] Metallic recovery from purchased, tolled, or imported new and old scrap.

Viewing the trends of secondary old scrap and primary aluminum production in figure D5, secondary production has been increasing while primary aluminum production has leveled off. A widening gap has occurred over the last several decades. Secondary old scrap aluminum production has become a larger and larger portion of this overall supply and in 2000, represented over 30 percent of total aluminum production in the United States. Based on worldwide statistics from the International Aluminium Institute, aluminum recovered from scrap[20] has averaged approximately 10 percent of total aluminum production (aluminum recovered from scrap plus primary production) from 1996 through 2000 (International Aluminium Institute, 2001§).

[20] Aluminum recovered from scrap is the weight of aluminum recovered from purchased or tolled scrap and excludes in-plant (run-around) scrap.

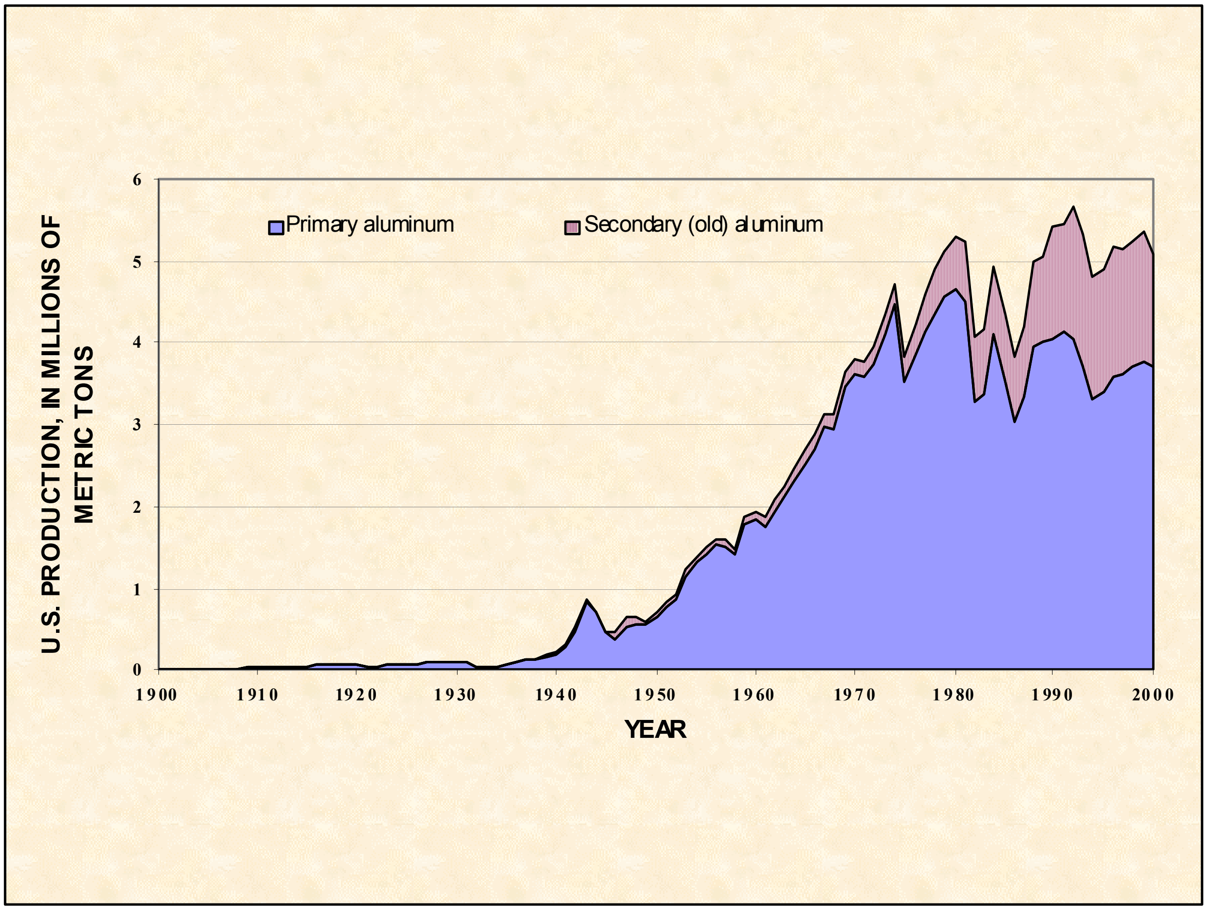

Figure D5. U.S. primary and secondary (old) aluminum production, 1900-2000 (data from Buckingham and Plunkert, 2001a).

World production

In 1988, the last year data was available for domestic production of bauxite; U.S. production of bauxite was 588 thousand tons. This was less than 1 percent of the world production of 97.4 million tons. In 2000, world production of bauxite was 127.0 million tons, an average annual growth of 2.2 percent. The top producer in 2000 was Australia with an estimated reported mine output of more than 49.0 million tons, over one third of the total world's production (Plunkert, 2002a). Reviewing figure D6, the long-term trend of world bauxite production has been increasing since World War II driven by rising global demand for aluminum. Both alumina and aluminum world production trends have also increased, but not at the rate of bauxite. This might be attributed to lower grades of bauxite ores, which would require more ore to yield a comparable amount of aluminum metal.

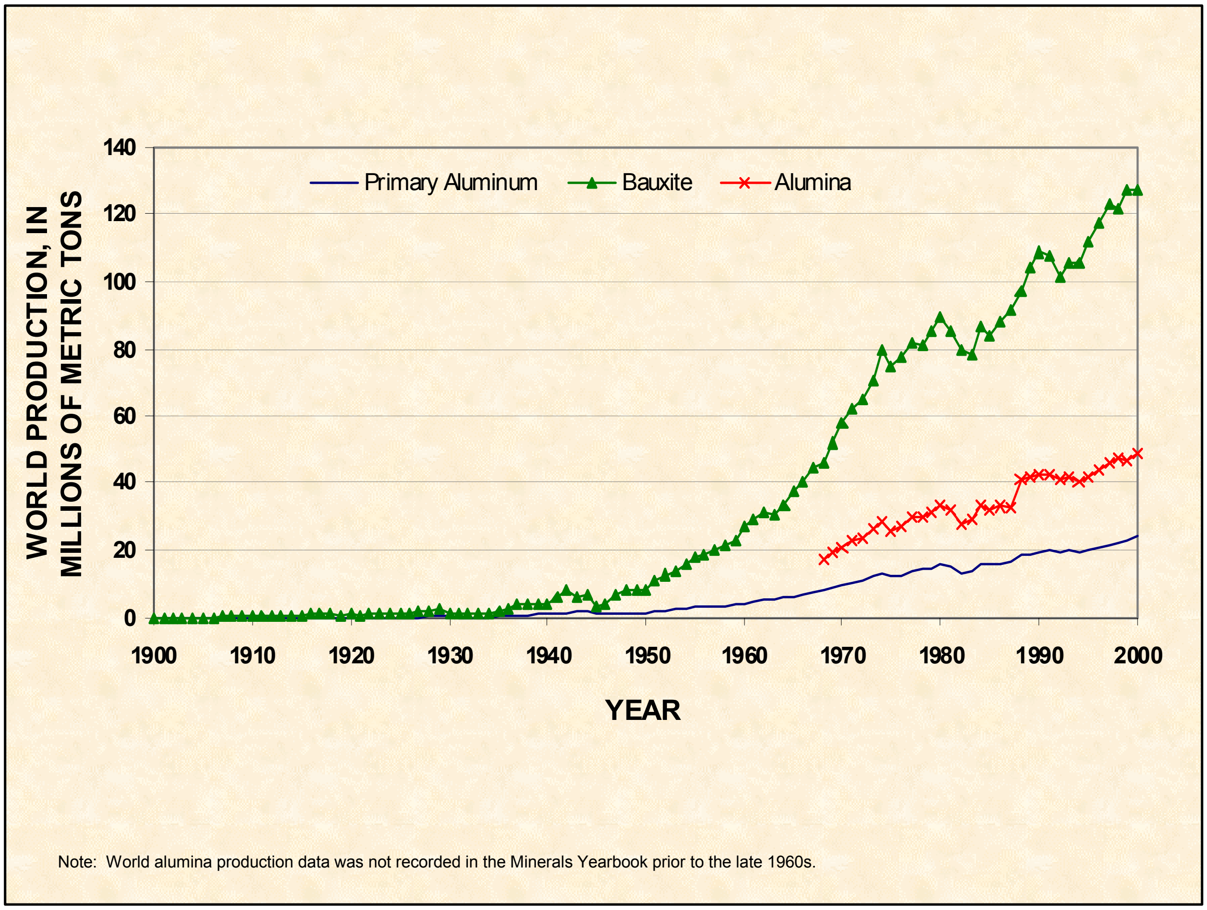

Figure D6. World production of alumina, bauxite, and primary aluminum, 1900-2000 (data from Buckingham and Plunkert, 2001a and 2001b).

Although world production of primary aluminum has continued to increase over the last century, the U.S. share of primary aluminum production (percent of world) has dropped to its lowest level (figure D7). Until the depression years, the U.S. share varied between 30 and 50 percent of world production. From the early 1930s to the early 1940s, the U.S. share of world production fluctuated between 20 and 30 percent. Then, after reaching a peak in 1946 as WW II came to a conclusion, it started a decline that continues today. This decline resulted as primary aluminum production stabilized in the United States (figure D4) while the rest of the world continued to expand its capacity.

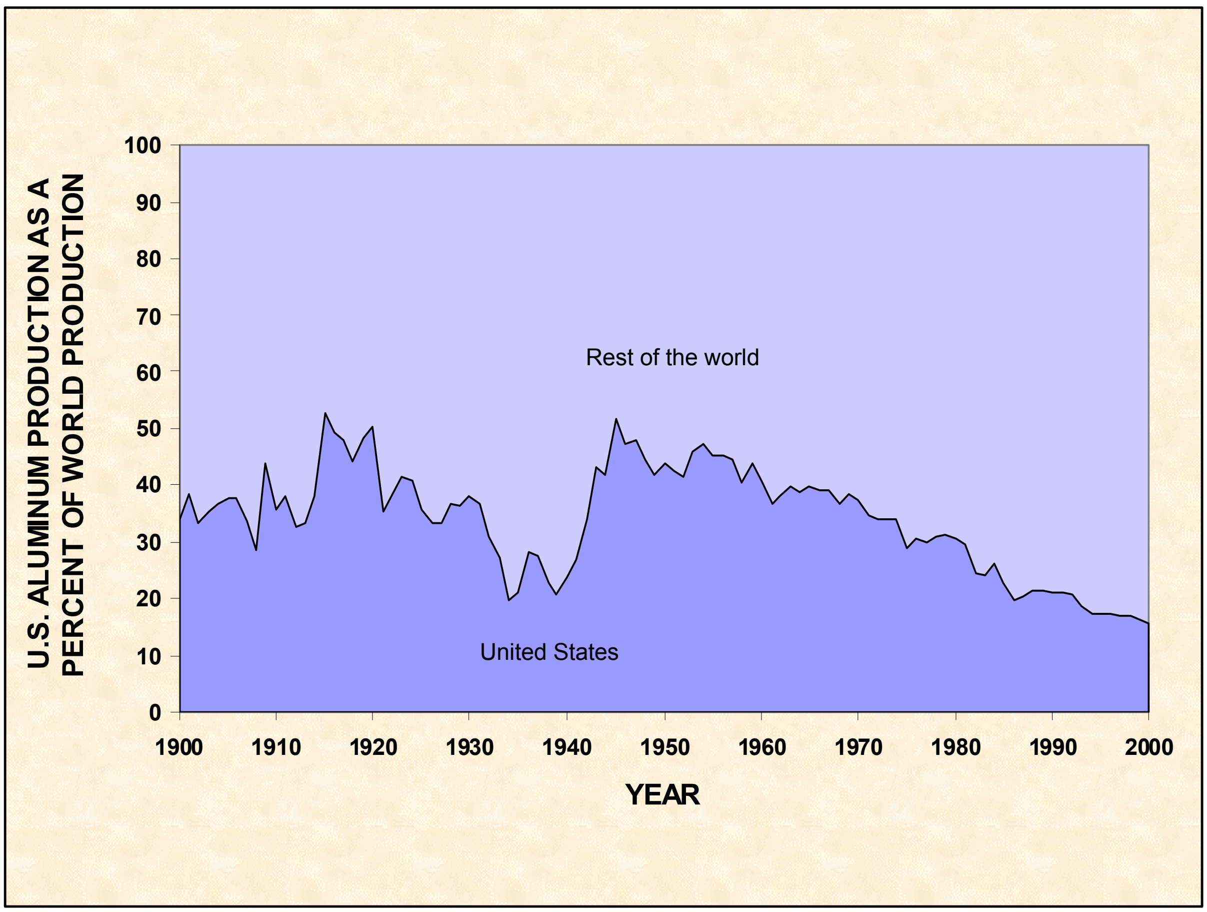

Figure D7. U.S. primary aluminum production as a percent of world production, 1900-2000 (data from Buckingham and Plunkert, 2001a).

Reserves/resources

Worldwide bauxite resources are extensive and the known quantity may increase in the future as a result of exploration activities. Commercially, bauxite ore is the only raw material used to produce domestic metallurgical grade alumina. The three largest import sources of bauxite are Guinea, Australia, and Brazil. Their reported reserve base[21] makes up 60 percent of the world total and is listed in table D1 for 1980, 1990, and 2000.

There is continuing research to develop technology that will economically produce alumina from other sources such as various clays, coal wastes, and oil shales (U.S. Geological Survey, 2001b, pg. 29). To date, however, it has been cheaper to import foreign bauxite than to process domestic nonbauxite resources. Alunite, $KAl_3(SO_4)_2(OH)_6$, is a source for alumina, but no commercial cost-effective process currently exists in the United States to exploit this source.

> Alunite was utilized at alumina refineries in the former Soviet Union, but became uneconomical in the post-Soviet era (Casey, 2000). In 2000, a Dutch firm had won a management contract for Azerbaijan's aluminum holding company and the government expected this new management to restart the Gyandja refinery using alunite ore to produce alumina (Metal Bulletin, 2000).

Alunite deposits are worldwide, with large identified resources in China, Australia, Mexico, and the former Soviet Union (Hall, 1978). Potential domestic nonbauxite aluminum resources are abundant and could meet domestic aluminum demand if an economically profitable technology is developed. It should be noted that the current world reserve base for bauxite is sufficient to

[21]The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated.

meet world demand for aluminum well into the 21st century (Plunkert, 2002b). Another important source of aluminum is aluminum products, which could be considered an "above ground reserve" as they come to the end of their useful life and are recycled.

Table D1. Bauxite reserves and reserve base estimates, in million tons.

[Data from U.S. Bureau of Mines, 1981a and 1991a; and U.S. Geological Survey, 2001]

Countries	1980	1990		2000	
	Reserve base	Reserves	Reserve base	Reserves	Reserve base
Guinea	6,500	5,600	5,900	7,400	8,600
Australia	4,500	4,440	4,600	3,800	7,400
Brazil	2,500	2,800	2,900	3,900	4,900
United States	40	38	40	20	40
Other countries	9,260	8,922	11,060	9,880	14,060
World total	22,800	21,800	24,500	25,000	35,000

Domestic usage (apparent consumption)

Prior to War World II, the trends of apparent consumption[22] for bauxite, alumina, and aluminum (figure D8) were relatively flat with the exception of a spike in bauxite during the early 1940s (see explanation in domestic production section). As the war ended, the built-up aluminum capacity from the war effort became available for consumers. Product after new product was conceived, manufactured, promoted, and distributed. Aluminum consumption suffered a brief downturn in the mid 1970s as a consequence of the 1973 oil embargo, which produced higher energy prices. From that period, a general increase in aluminum usage continued.

[22] Defined as domestic primary metal production plus secondary recovery from old scrap plus imports minus exports plus adjustments for Government and industry stock changes.

After reaching a historic high of over 17.0 million tons in 1974, domestic consumption of bauxite fell to a thirty year low in 1986 at slightly under 7.0 million tons. During the last decade, consumption has held steady between 11.0 million and 12.0 million tons (Plunkert, 2002b). The dramatic downturn in domestic bauxite consumption that started in the late 1970s (see figure D8) resulted from a combination of actions. Domestic plant closures, increasing costs of energy, and the vertical integration of foreign bauxite mining operations with foreign refineries contributed to this decline (U.S. Bureau of Mines, 1985c).

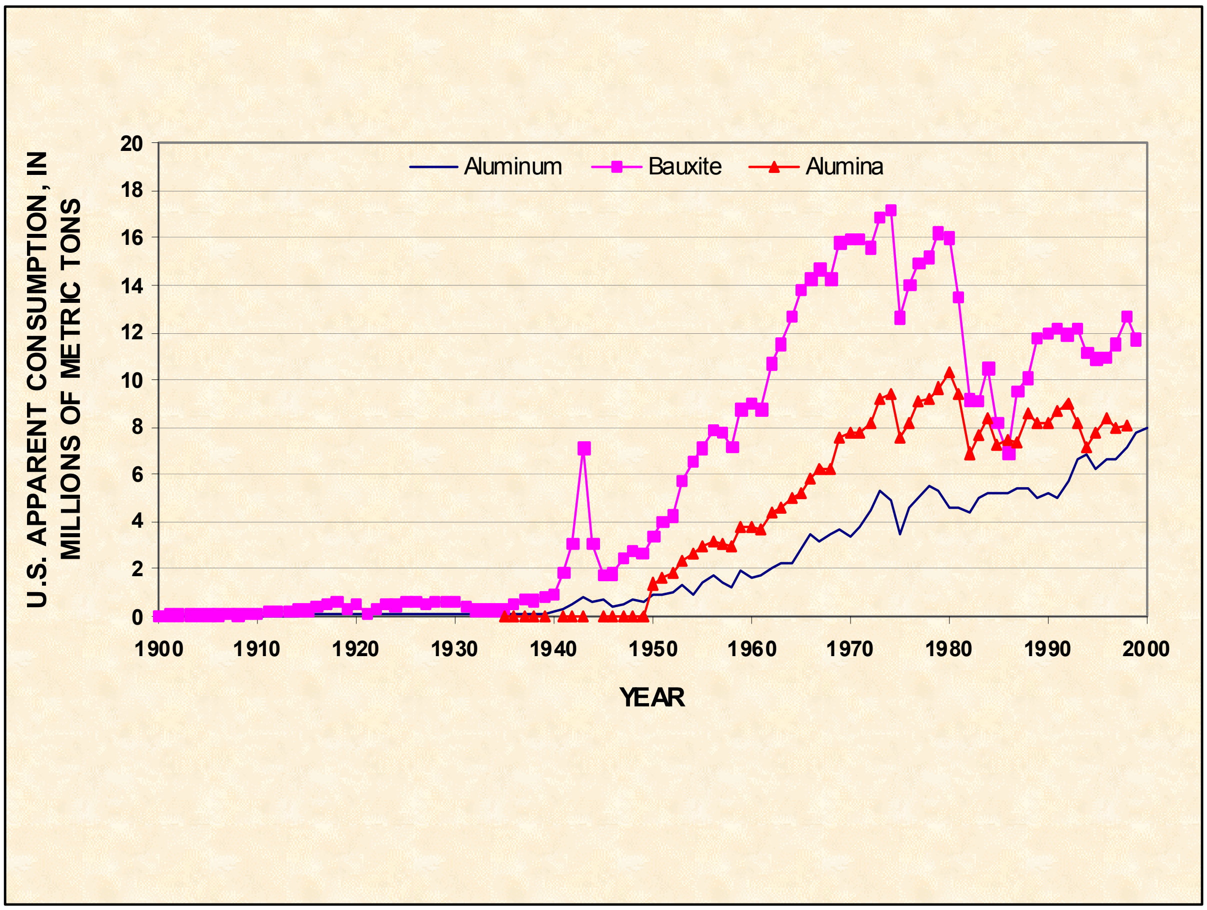

Figure D8. U.S. apparent consumption of alumina, aluminum, and bauxite, 1900-2000 (data from Buckingham and Plunkert, 2001a and 2001b).

Distribution of U.S. aluminum shipments among industrial sectors for the period 1980 through 2000 is shown in figure D9. This illustration demonstrates the distribution of aluminum within market sectors, and shows shifts in the long-term trends of aluminum use. The recession in 1982 resulted in decreased shipments for all of the industrial sectors. Although shipments to the selected sectors received a relatively constant supply, shipments to the transportation industry continued to increase at a greater rate, especially since 1991. One explanation for this sustained growth was the increased production of cars and aircraft, as well as the amount of aluminum used in each unit.

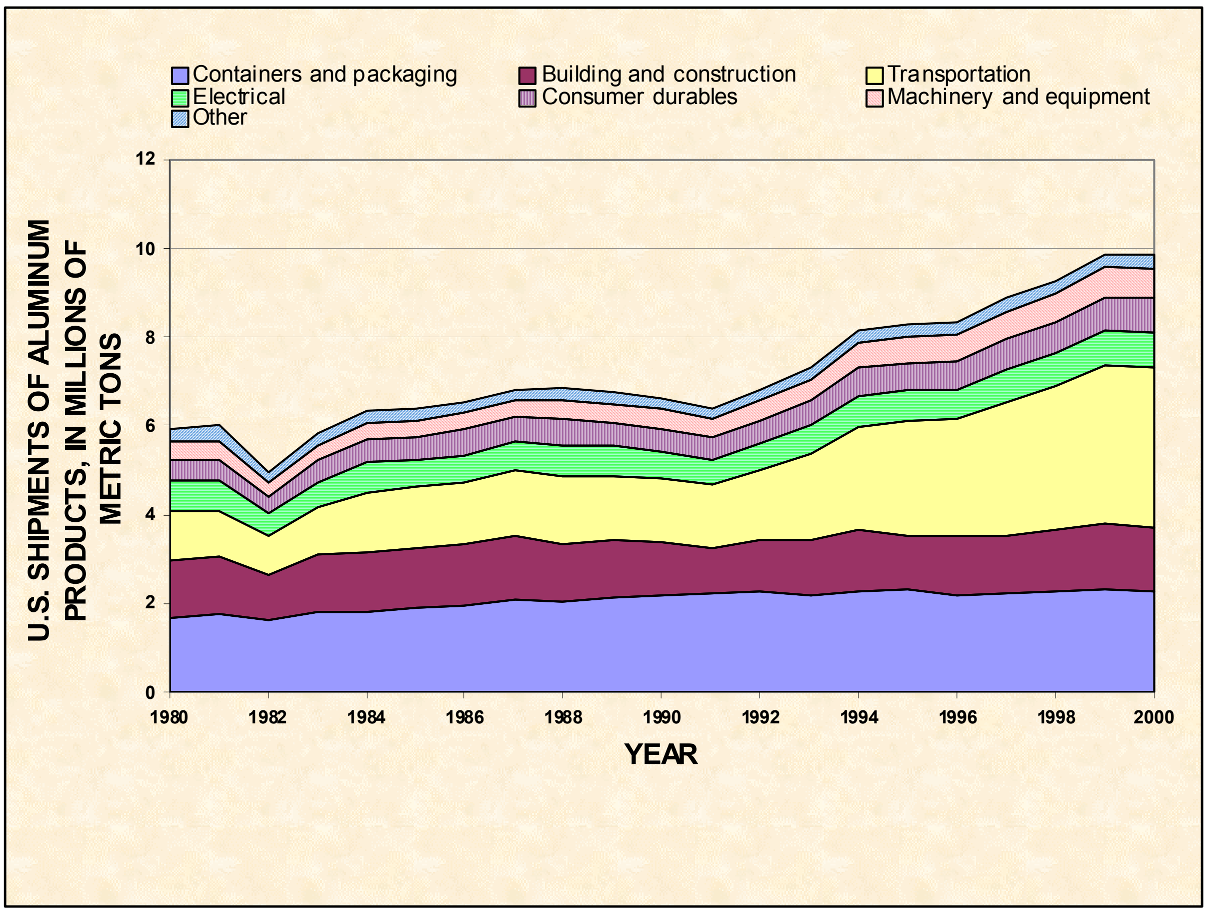

Figure D9. U.S. distribution of end-use shipments of aluminum products, 1980-2000 (data from Plunkert, 1997a–2002a, and U.S. Bureau of Mines, 1982b– 96b).

Globalization

Most of the restructuring of the world aluminum industry began in the late 1970s as the cost of energy soared due to higher oil prices. Bauxite mining operations with access to cheaper forms of power, for example, hydroelectric, built alumina refineries and aluminum smelters. Today, Australia and China have emerged as major primary aluminum producers. Canada continues to provide the bulk of aluminum imports to the United States, which amounted to 55 percent in 2000 (Plunkert, 2002a). Other countries that are key producers of aluminum in order of decreasing production are Russia, Brazil, and Norway.

The primary source for aluminum is the metallurgical-grade of bauxite ore, which is distributed unequally around the globe. Initially, bauxite-producing countries operated their mining operations with no facilities downstream in the production process. If possible, they eventually moved into higher value processing by producing alumina or aluminum metal. As international demand for aluminum and associated products increased, the development of mining and processing operations spread worldwide.

The United States is heavily reliant on imports for metallurgical-grade bauxite that is used for the production of alumina from which the metal aluminum is produced. In the early 1990s, it was estimated that approximately 90 percent of the bauxite mine output in market economy countries was for metallurgical use (Wilburn and Wagner, 1993). Minor amounts of nonmetallugical grade bauxite are exported to be used in products such as abrasives, chemicals, and refractories. Reviewing figure D10, bauxite imports, after peaking in 1974 at 15.5 million tons, turned down in the 1980s. This was attributed to a worldwide overcapacity of alumina refineries. After rebounding in 1990, bauxite imports have moderated as demand has slackened.

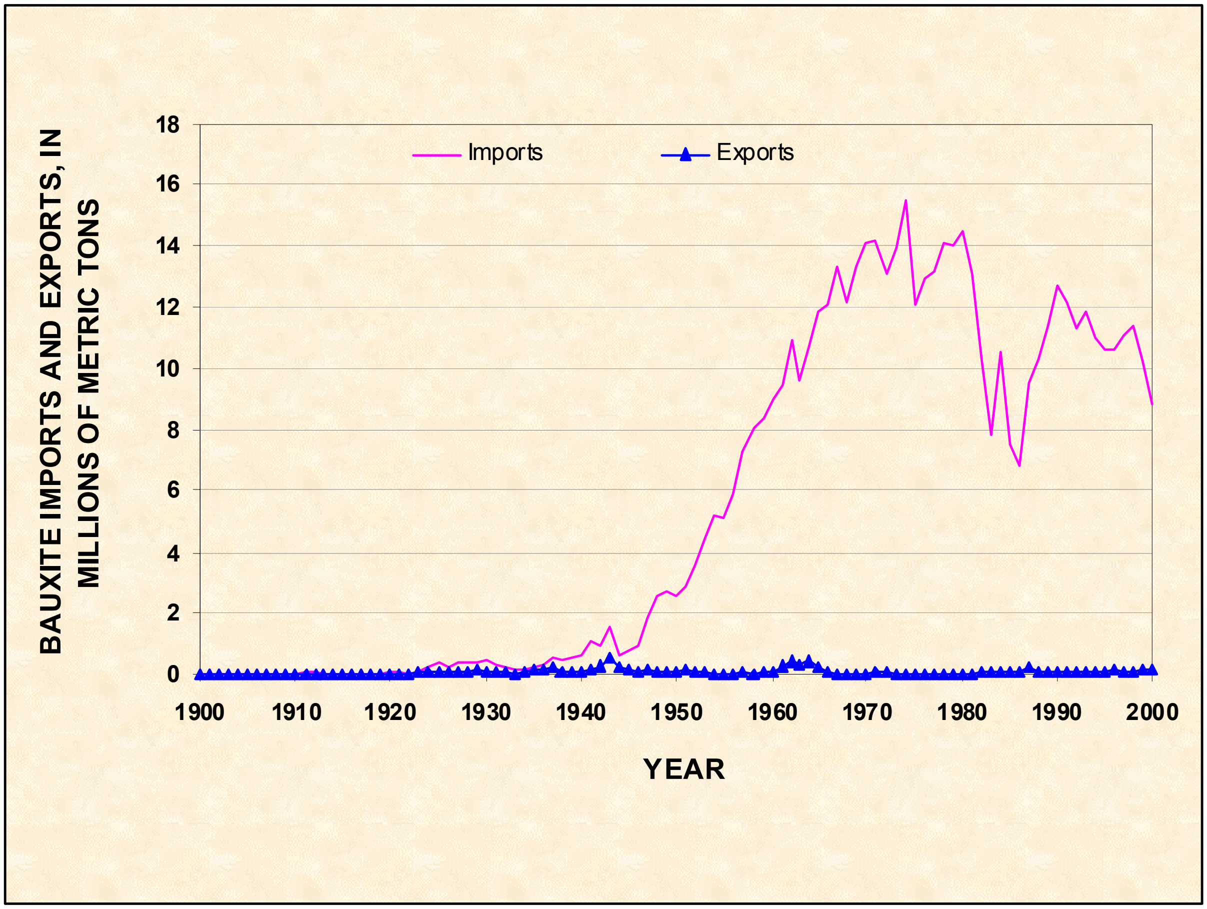

Figure D10. U.S. bauxite imports and exports, 1900-2000 (data from Buckingham and Plunkert, 2001b).

As mentioned previously, mining companies have added refining capacities to produce alumina at or near their mining operations. The impact on domestic alumina producers is that these international sources are replacing U.S. alumina production. This is shown in the shrinking gap between alumina imports and domestic alumina production as imports remained fairly constant while domestic production decreased over the last two decades (figure D11).

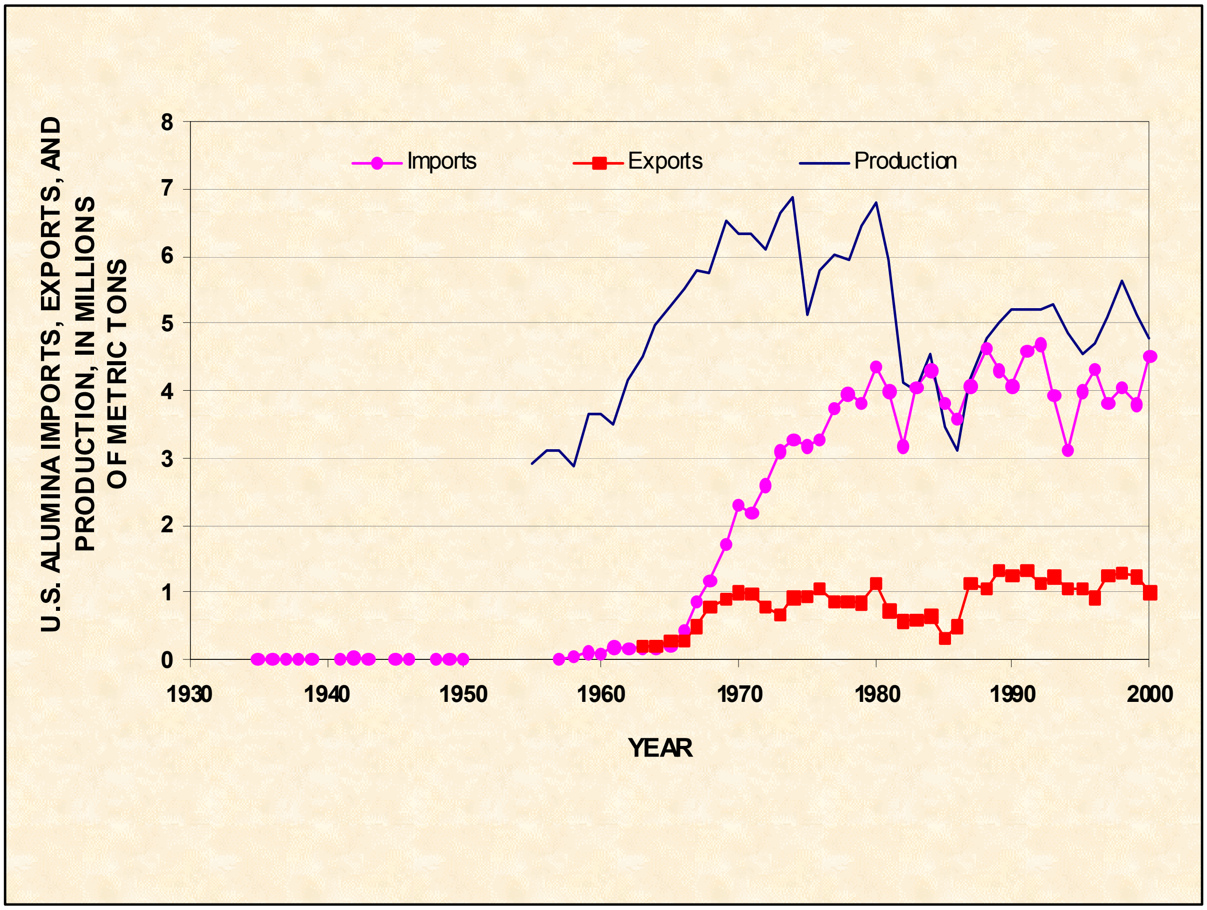

Figure D11. U.S. alumina imports, exports, and production, 1935-2000 (data from Buckingham and Plunkert, 2001b).

Aluminum imports and exports quantities were approximately equal until the early 1990s when they diverged with imports rising sharply (figure D12). This trend will probably continue as the domestic aluminum industry depends more on aluminum imports due in part to higher energy prices and stricter environmental regulations.

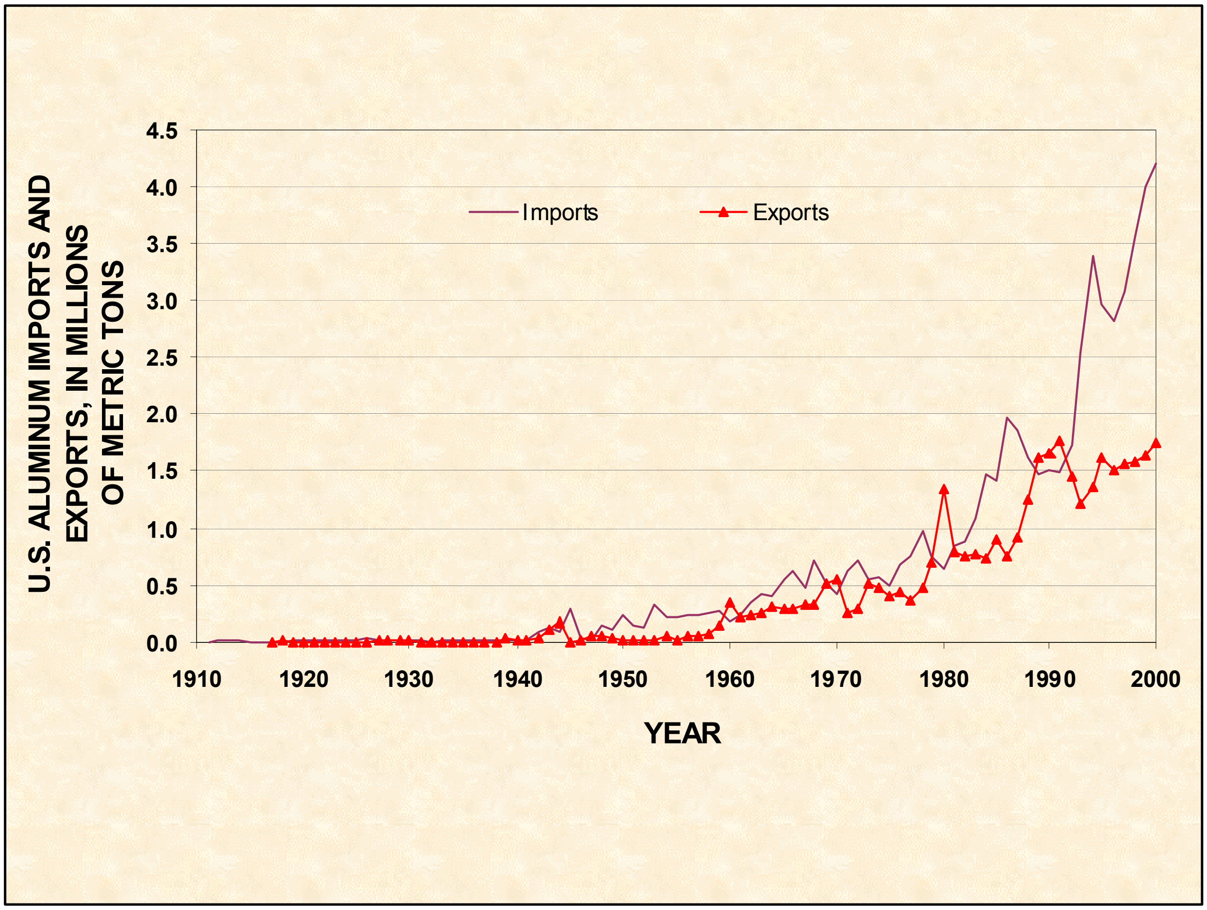

Figure D12. U.S. aluminum imports and exports, 1911-2000 (data from Buckingham and Plunkert, 2001a).

Secondary (recycling) aluminum has been providing a growing share of total aluminum supply. From 1940 to 2000, old aluminum scrap has become an increasingly important component of total import and export quantities. In 1940, old aluminum scrap represented 3.6 percent of crude and semicrude aluminum imports for consumption and 3.4 percent of crude and semicrude[23] aluminum exports (U.S. Bureau of Mines, 1942). In 2000, old aluminum scrap represented 16 percent of crude and semicrude aluminum imports for consumption and almost 33 percent of

[23] Unalloyed aluminum is referred to as "crude", while "semicrude" refers to alloyed aluminum.

crude and semicrude aluminum exports (Plunkert, 2002a). These numbers are an indicator of the growing supply of the “above ground” aluminum reserves.

Labor productivity

With primary aluminum production relatively flat over the last decade and the number of employees in this industry decreasing, it is not surprising that productivity has increased (figure D13). Technological advances have almost certainly increased productivity to some degree, but the main benefits were to reduce costs, primarily associated with high-energy usage.

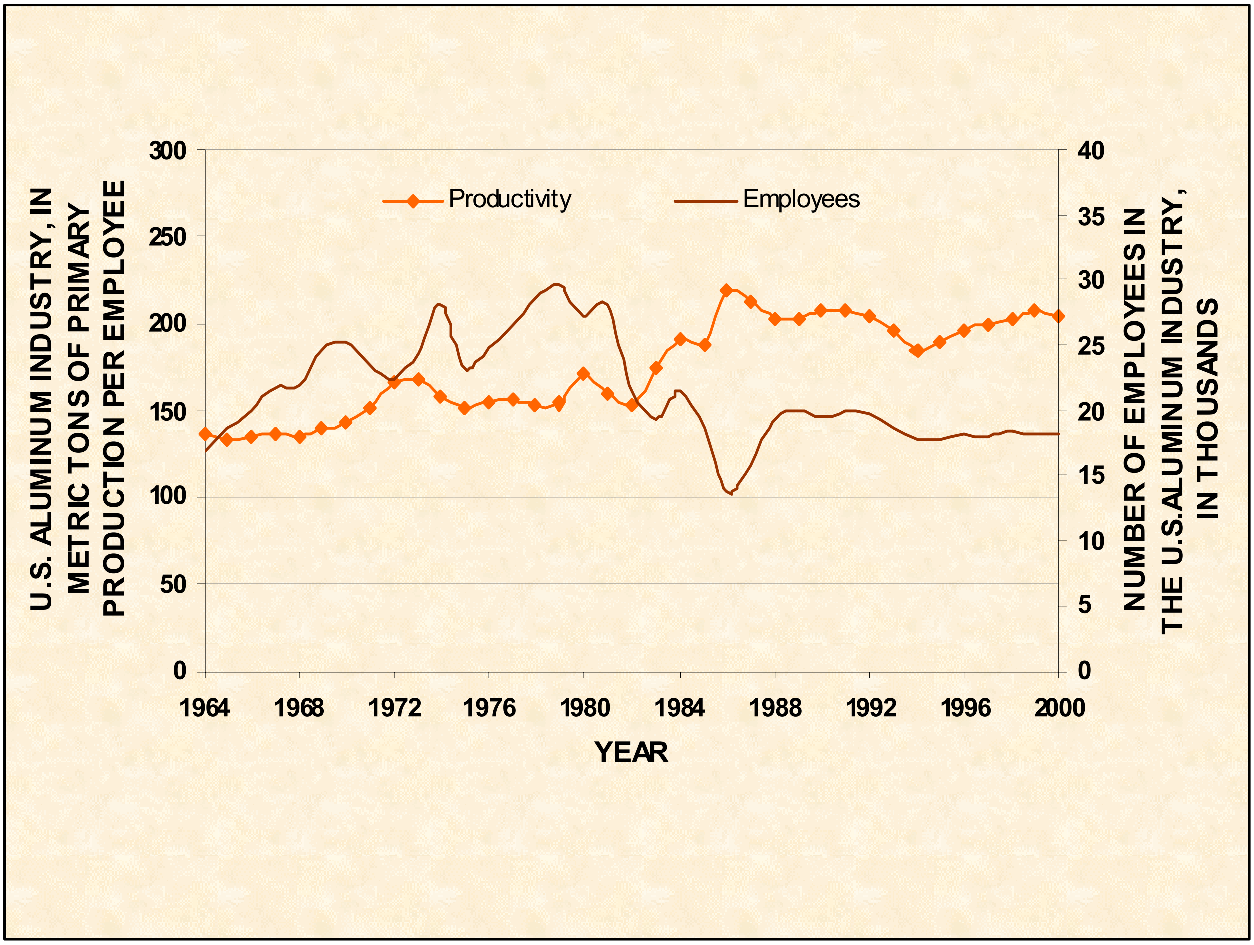

Figure D13. U.S. aluminum productivity and number of aluminum industry employees, 1964-2000 (data from Plunkert, 1997a–2002a; U.S. Bureau of Mines, 1965a–95a and 1982b–96b; U.S. Geological Survey 1997–2001; and U.S. Geological Survey and Bureau of Mines, 1996).

Costs

To remain viable, companies must be capable of operating at a profit or they must be subsidized during periods of non-profitability. Since net profit equals total income minus all expenses, it is essential that all costs be considered. Total production costs are usually comprised of manufacturing costs related to actual production including raw materials, labor, and equipment;

and general expenses such as administrative salaries, product distribution costs, research and development, and taxes. Although individual companies typically report these costs in their annual reports, a broader measure is available through the U.S. Census Bureau's publication, Economic Census – Manufacturing, (1999).

Table D2 contains 1992 and 1997 primary aluminum industry data from the U.S. Census Bureau (1999). The right-hand column in the table lists the percent changes from 1992 to 1997. All the categories in the primary aluminum industry had decreases from 1992 to 1997. In both compensation categories, "all employee payroll" and "production worker wages" decreases of 23 and 26 percent respectively were noted in terms of 2000 dollars. All of these changes were the effects of continuing technological process improvements and consolidation in this industry.

Table D2. Domestic primary aluminum industry data.

[Adapted from Bureau of Census, 1995 and U.S. Census Bureau, 1999; —, not applicable]

Category	1992		1997		Change, in percent
	Quantity	2000 constant dollars	Quantity	2000 constant dollars	
Companies	30	—	13	—	-56.7
Number of employees	20,400	—	15,763	—	-22.7
Wages of employees	—	981,249,000	—	752,956,000	-23.3
Number of production workers	16,200	—	12,624	—	-22.1
Wages of production workers	—	739,924,000	—	545,972,000	-26.2
Cost of materials	—	5,147,596,000	—	3,946,175,000	-23.3
Electricity purchased in kilowatt-hours	60,272,400,000	—	43,426,337,000	—	-28.0
Product shipments – tons	4,689,377	—	4,074,390	—	-13.1

Supply/demand

Aluminum applications continue to expand in areas ranging from automobiles to housing and infrastructure. Technological advancements have also helped to make aluminum products more cost competitive. All of these factors have been driving up aluminum demand.

The domestic demand for aluminum is growing in many industries, with 2000 shipments of 11.1 million tons. The transportation industry was the largest consumer of aluminum, receiving 2000 shipments of 3.61 million tons. As stated in the Ducker Report, the American passenger car contained an average of 241 pounds of aluminum in 1999. This is an increase of 23 kilograms (50 pounds) over 1991 (Ducker Research Company, Inc., 1998§). The second largest consumer of aluminum was the domestic container and packaging industry, which used over 2.26 million tons in 2000. The Can Manufacturers Institute, Inc. (2001§) reported that over 100 billion aluminum beverage cans were shipped in 2000. Based on an average of 73 cans per kilogram (33 cans per pound), this equals approximately 1.4 million tons. The 2000 U.S. apparent supply[24] of aluminum, reported by the U.S. Geological Survey was 9.61 million tons. Primary domestic production was 3.67 million tons with secondary production (recycled) at 3.45 million tons. Recycled aluminum supplied slightly less than half of the total U.S. production in 2000. Imports for consumption were 3.91 million tons and exports were listed as 1.76 million tons (Plunkert, 2002a).

[24] Defined as domestic primary metal production plus secondary recovery plus imports minus exports plus adjustments for Government and industry stocks changes.

Demand for aluminum products is anticipated to grow, as developing nations expand their transportation industry, primarily in the automobile and aircraft sectors. Likewise, world production is expected to continue to rise, meeting this demand as new international facilities associated with bauxite mining companies come into the production stream.

Conclusions

The aluminum industry was born during the Industrial Revolution. In the early 1900s, aluminum was in high demand for both railroad cars and automobiles due to aluminum's desirable properties (lightweight and high strength). Production was stimulated again during World War II to meet the wartime demand for aluminum, which was especially critical to military aircraft. During the 1950s and 1960s, the excess production capacity was used for numerous new aluminum applications. As a growing number of Americans became more conscious of protecting the environment in the 1970s, recycling aluminum cans became a widespread industrial activity in the United States. Also, an economic incentive was provided as recycled centers exchanged money for aluminum cans. Secondary scrap has assumed a major portion of the domestic aluminum supply. In 2000, aluminum recovered from new and old scrap reached 3.45 million tons. Today, almost half the supply of aluminum metal in the United States originates from recycling (all aluminum products).

The international aluminum supply has met the increased demand as worldwide production capacity continues its expansion with the construction of new refineries and smelters. The growth of aluminum consumption reflects the widespread applications of this metal in global industries such as building and construction, containers and packaging, and transportation. Aluminum-based materials are heavily traded internationally, which demonstrate the global nature of the aluminum industry.

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APPENDIX E: ECONOMIC CASE STUDY -- COPPER

Introduction/background

Copper was one of the first metals to be utilized for tools, weapons, and ornaments. Copper has many useful physical properties such as high electrical and thermal conductivity, corrosion resistance, ductility and malleability, and high strength. It is also nonmagnetic. The multitude of electrical-based inventions that followed the discovery of electricity greatly expanded the uses for copper. Copper is used in electrical and telecommunications products, building construction, industrial machinery and equipment, transportation, and consumer products.

Historical economic trends

The price of copper, in constant 2000 dollars, is shown in Figure E1 for the period from 1900 through 2000. The figure shows that the price is highly volatile with an overall downward trend for the period. During World War I, the price reached more than $4 per pound in 2000 dollars because of the increased demand for copper in munitions and other aspects of the war effort. In 1932, in the midst of the Great Depression, the price bottomed out at $0.73 per pound (2000 dollars). During World War II, the price was controlled by the government but rose again during the postwar boom to a high of $2.64 in 1956 (2000 dollars). After declining because of a recession, the price began a gradual increase until 1971 when price controls were used to fight inflation. After controls were ended, the price rose again reaching a peak of $2.67 per pound in 1974 (2000 dollars). Since that time, the price has generally declined with a trough during the recession of the 1980s. Copper prices in the late 1990s (2000 dollars) approached the all time historic low that had occurred during the Great Depression. The volatility, not explained by major economic and political events, resulted from technological innovations and changes in the copper market. Because the copper industry is made up of a small number of large producers, operations opening or closing have a large impact on supply. This results in volatile prices.

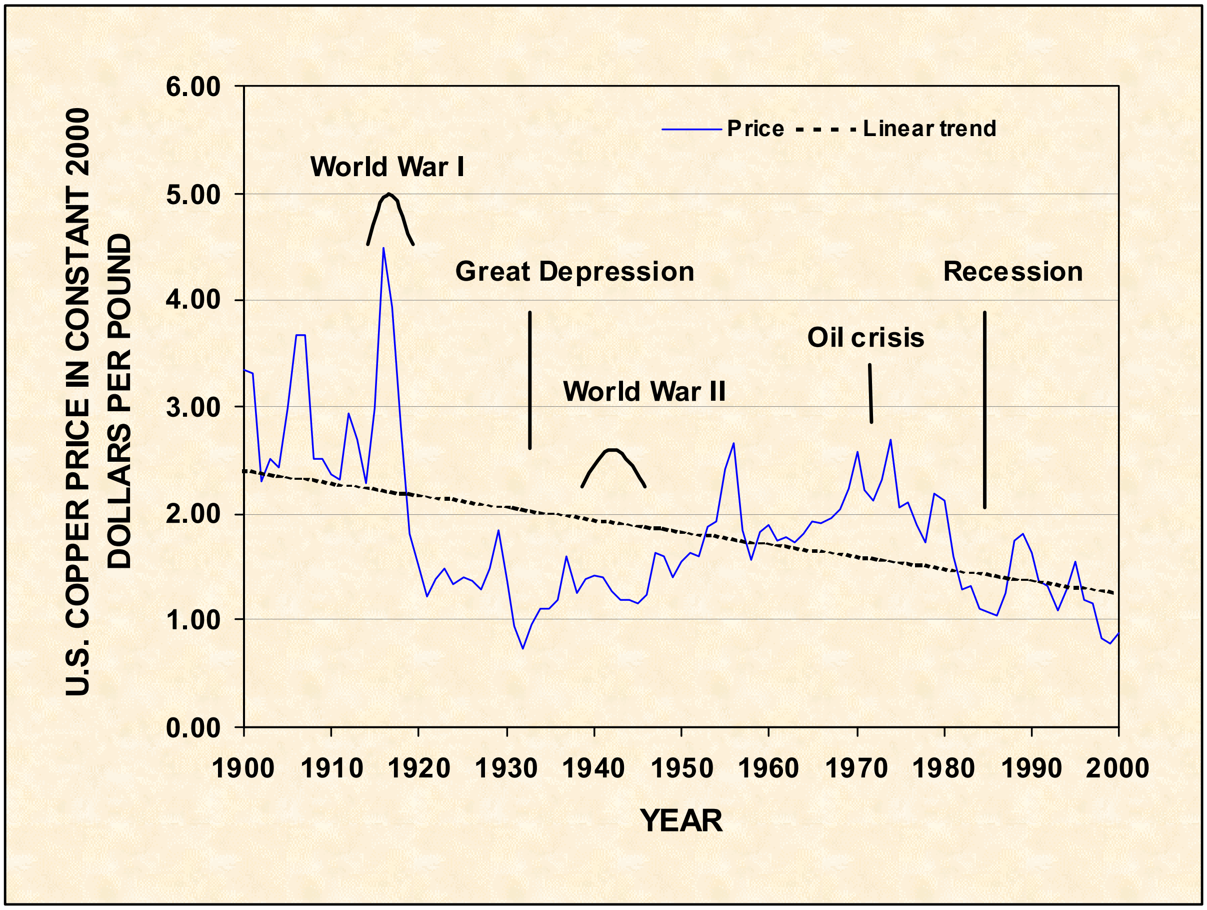

Figure E1. U.S. copper price, in constant 2000 dollars, 1900-2000 (data from Porter and Edelstein, 2001).

U.S. mine production of copper is shown in figure E2. The figure shows that production from year to year was volatile although with an overall increasing trend. Rising production in conjunction with declining prices is not inconsistent with traditional supply and demand theory.

Factors such as productivity, technology, and deposit availability can reduce costs significantly, making more copper available at lower prices.

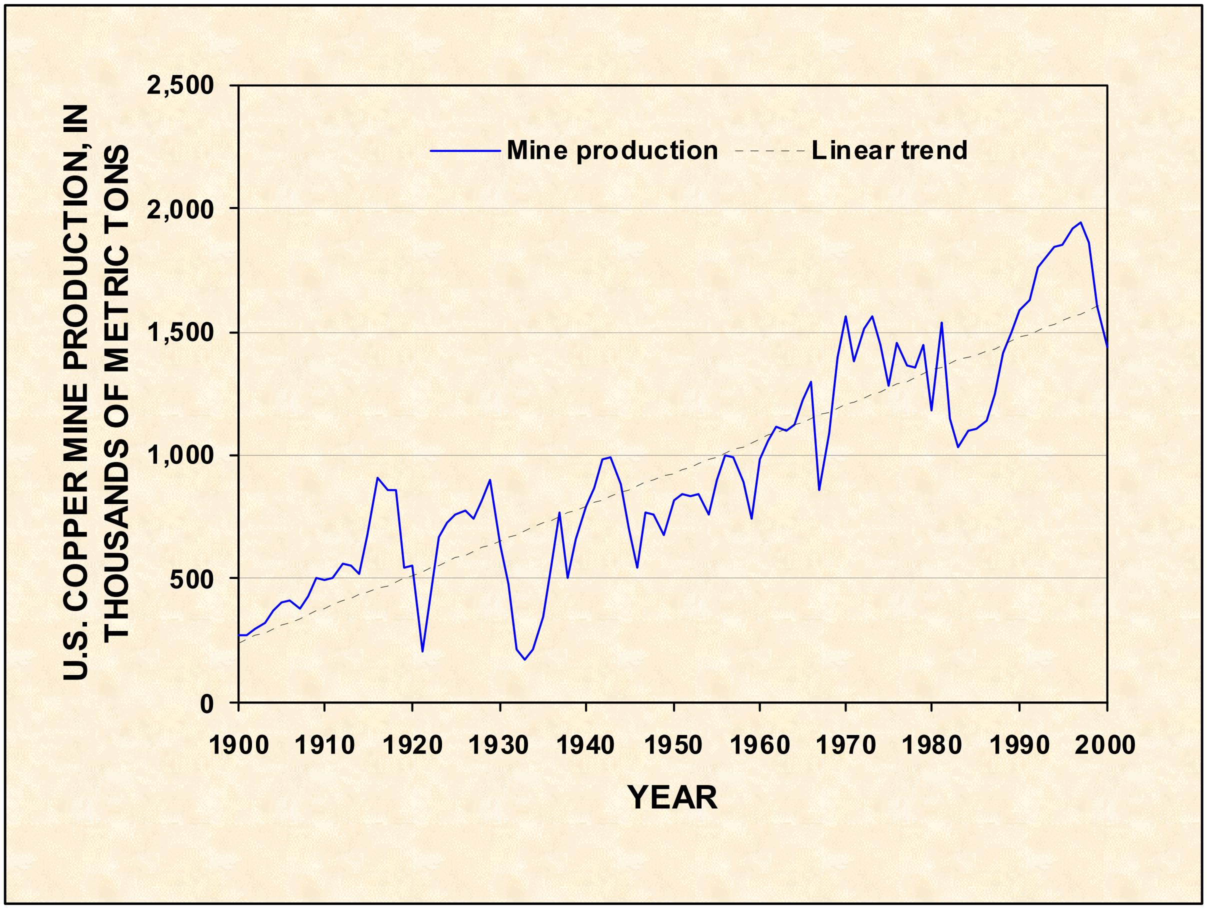

Figure E2. U.S. copper mine production, copper content, 1900-2000 (data from Porter and Edelstein, 2001).

Figure E3 combines price and mine production on the same graph to illustrate some interesting points. Before World War I, domestic production was growing and the price of copper was relatively high. During this war, both production and price jumped because of the demand for copper for munitions and other war related needs. After the war, both fell sharply adjusting to the fact that copper was no longer needed for the war effort. In the 1920s, production increased responding to the demand from the strong economy. When the economy crashed in 1929, the demand for copper also crashed. In 1933, production was at the lowest point of the century. For the remainder of the 1930s, production gradually recovered. With the advent of World War II, the demand for copper for munitions and other war related goods increased strongly resulting in a large increase in production. Immediately after the war, copper was no longer needed for the war effort, resulting in a decline in production. Demand from the post-war economic recovery resulted in a strong increasing trend in production that lasted through the late 1960s. In 1968, a technology to recover copper ores using chemical solutions called solvent extraction and electrowinning was introduced commercially (Jolly, 1985, p. 205). As a result of the development of this cost-effective method, production has trended upward as prices have declined, with the exception of the recession of the 1980s when they both declined.

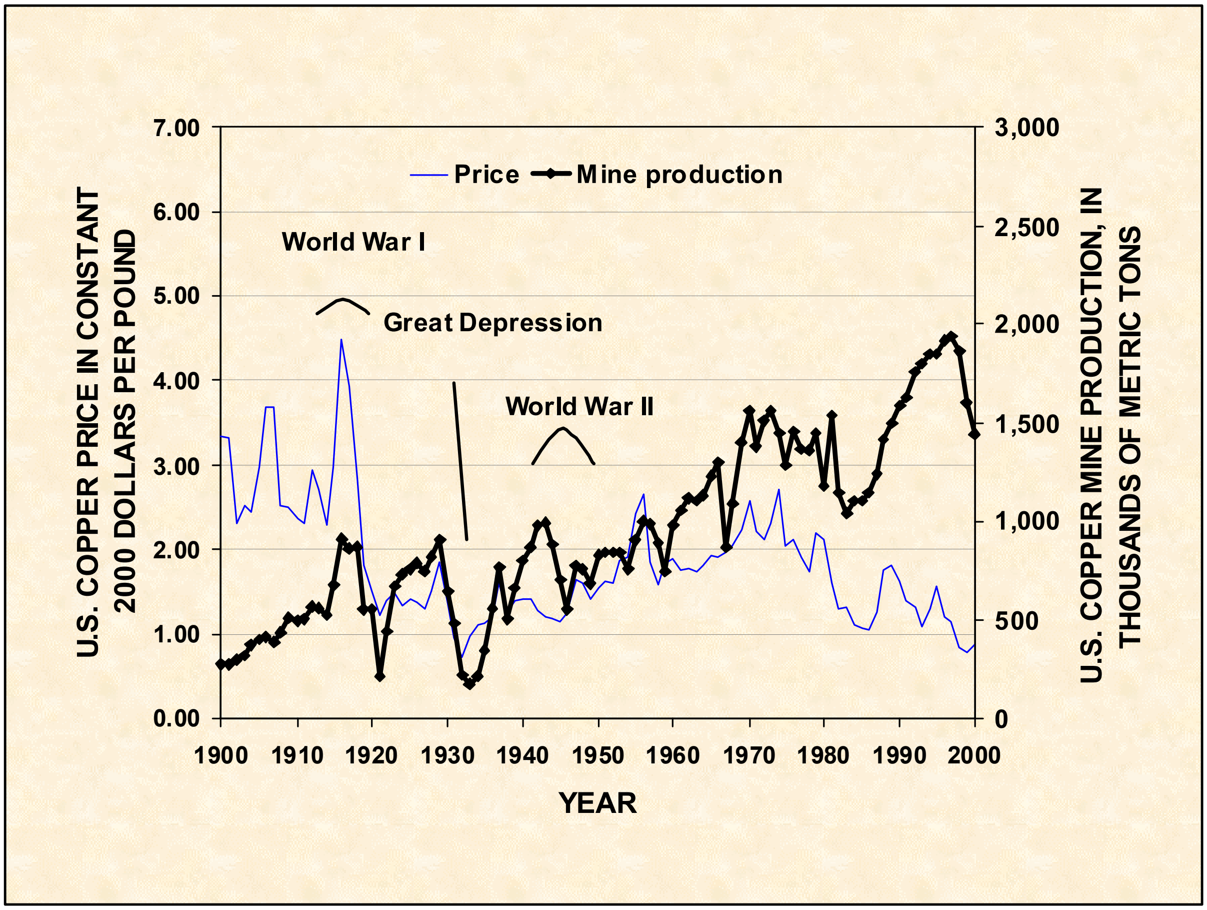

Figure E3. U.S. copper price, in constant 2000 dollars, compared to mine production, 1900-2000 (data from Porter and Edelstein, 2001).

Production of copper metal from ores and from old scrap is shown in figure E4 (old scrap is copper that has been used in a product that is at the end of its lifecycle and available as an input to copper processors). Total copper production has a pattern of peaks and valleys similar to the pattern for mine production. There are notable valleys after World War I, when war demands ceased; during the Great Depression, when all demand declined dramatically; and the decline in demand that took place during the recession of the 1980s. Secondary production of copper has a long history. It was first reported in the early 1900s and has grown parallel to the copper industry.

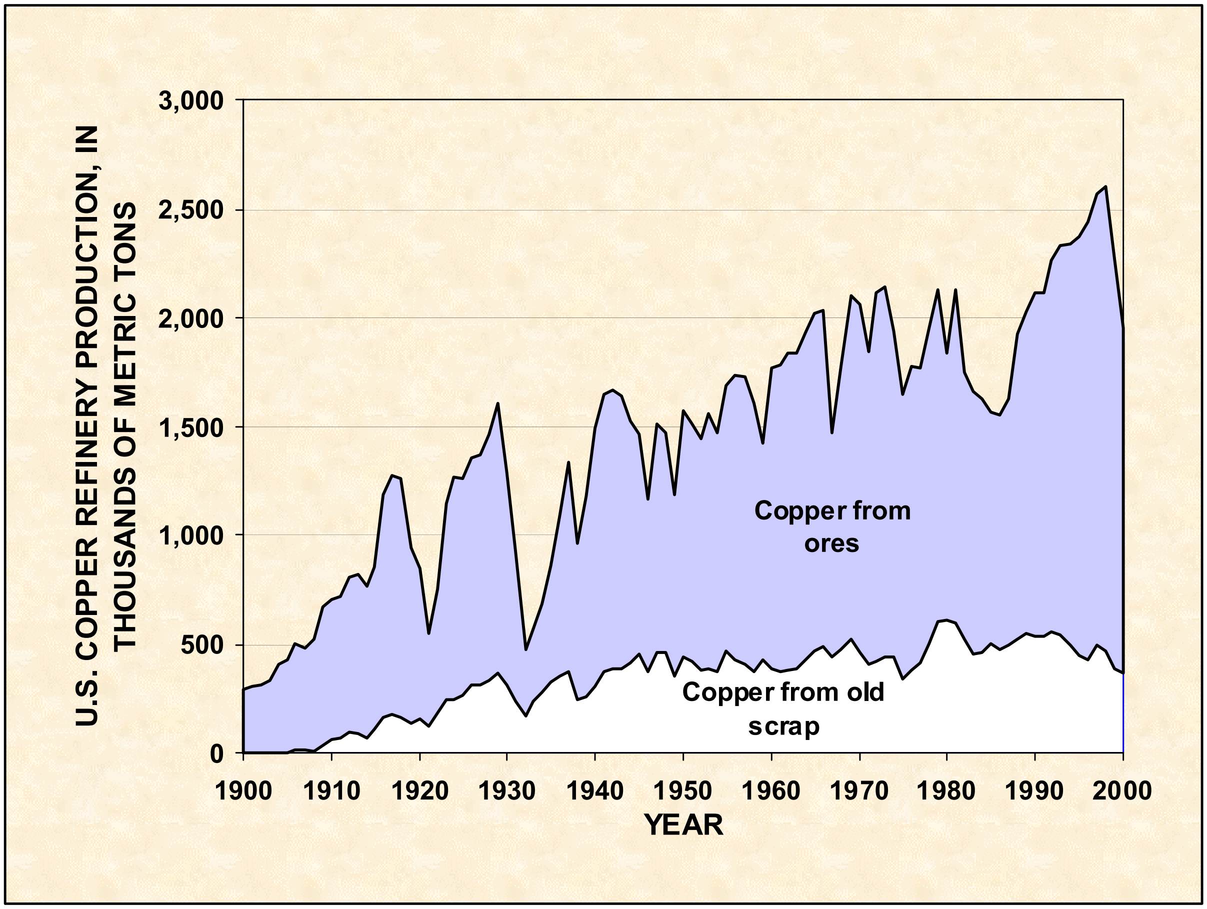

Figure E4. U.S. copper refinery production, copper metal, 1900-2000 (data from Porter and Edelstein, 2001).

Figure E5 shows copper from old scrap as a percent of total copper refinery production. The share of old scrap grew at a fast rate until the 1930s when it leveled off. When recycling began, old scrap that had built up from previous times was available to be recycled, resulting in a strong growth in recycling. As the copper recycling industry matured, the growth in recycling has leveled off because the prior accumulations of old scrap were no longer available. Many copper products used in construction or electrical applications have long lifecycles, which can be more than a hundred years. This results in a time lag between when copper is produced and when it becomes available for recycling.

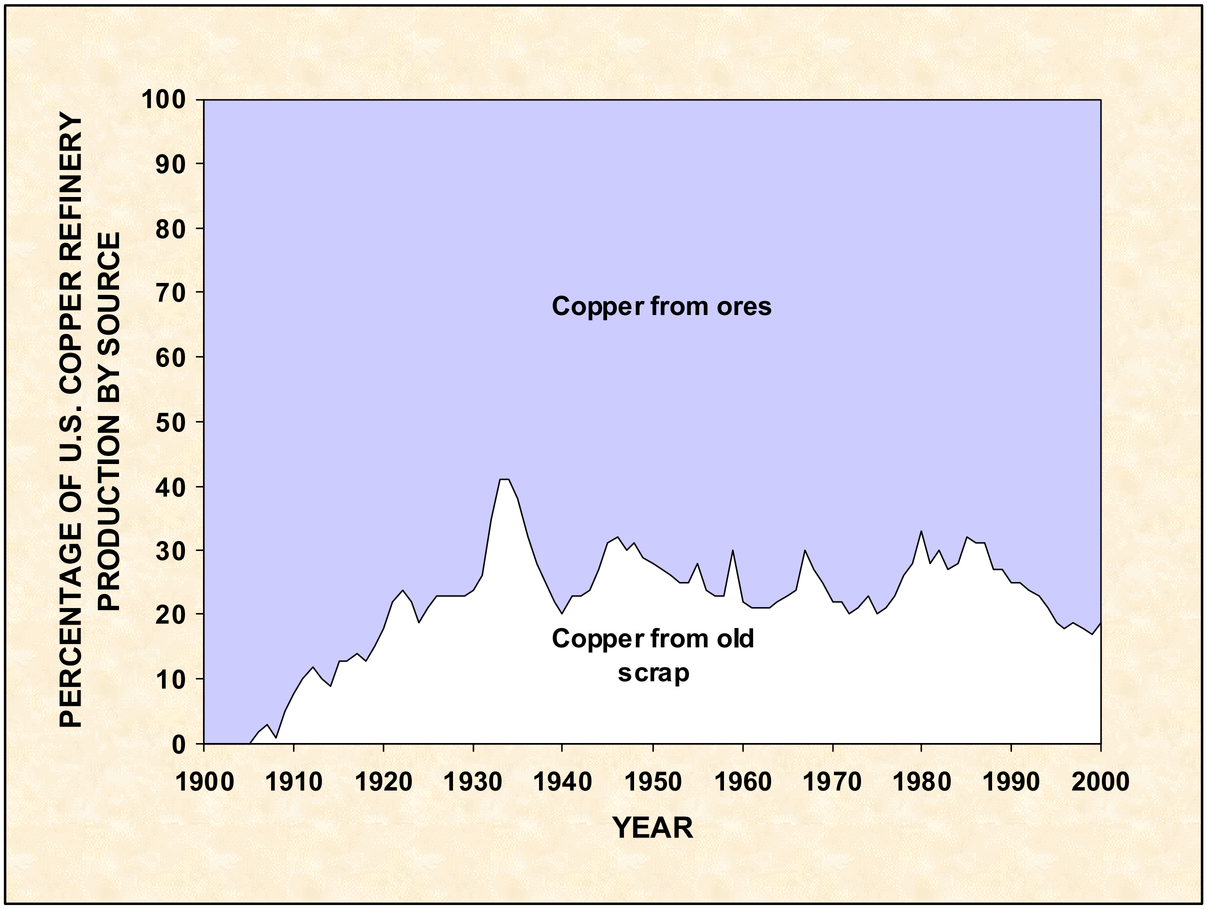

Figure E5. U.S. copper refinery production by source, by percent, 1900-2000 (data from Porter and Edelstein, 2001).

World production

Figure E6 shows the strong growth in world mine production of copper during the 20th century. Like U.S copper mine production, it reacts to worldwide events such as World Wars I and II and the worldwide Great Depression. The curve exhibits the characteristics of a compound growth rate. Comparing 495 thousand tons produced in 1900 to 12.9 million tons produced in 2000, the annual growth rate was 3.3 percent for this 100-year period.

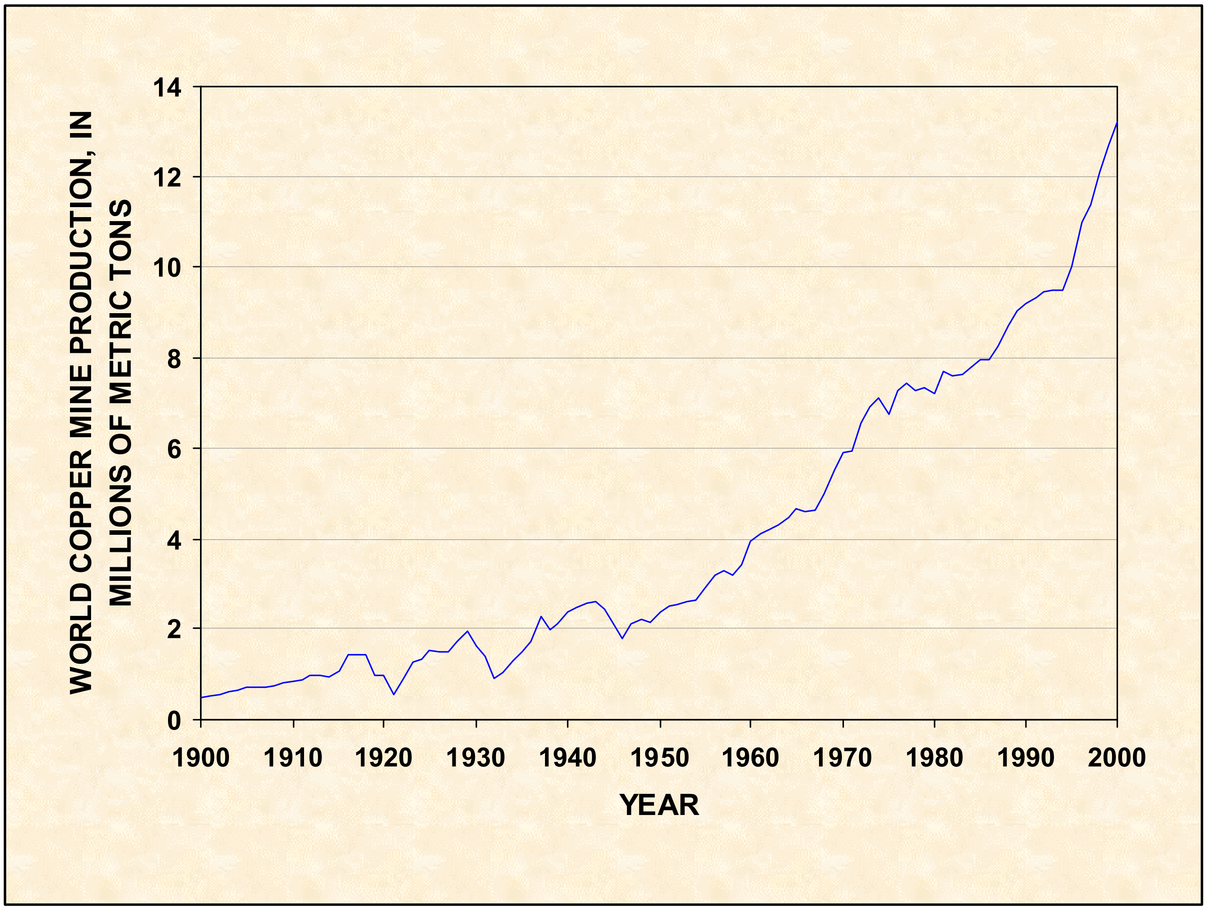

Figure E6. World copper mine production, copper content, 1900-2000 (data from Porter and Edelstein, 2001).

Figure E7 shows U.S. copper mine production as a percent of world mine production. It shows that for most years between 1900 and the Great Depression, U.S. production accounted for more than 50 percent of total world mine production. During the Depression of the 1930s, the U.S. share sank below 17 percent. It rose to a high of almost 39 percent during World War II and has been below 20 percent since the 1970s. The decline in the U.S. share of copper mine production has occurred in spite of increases in the absolute quantity of mine production in the United States. This is a result of the globalization of the copper mining industry. As the industry has grown, deposits all over the world have been discovered and developed, reducing the relative share of the U.S. copper mining industry. Domestic production along with increased net imports has satisfied the economy's growing demand for copper.

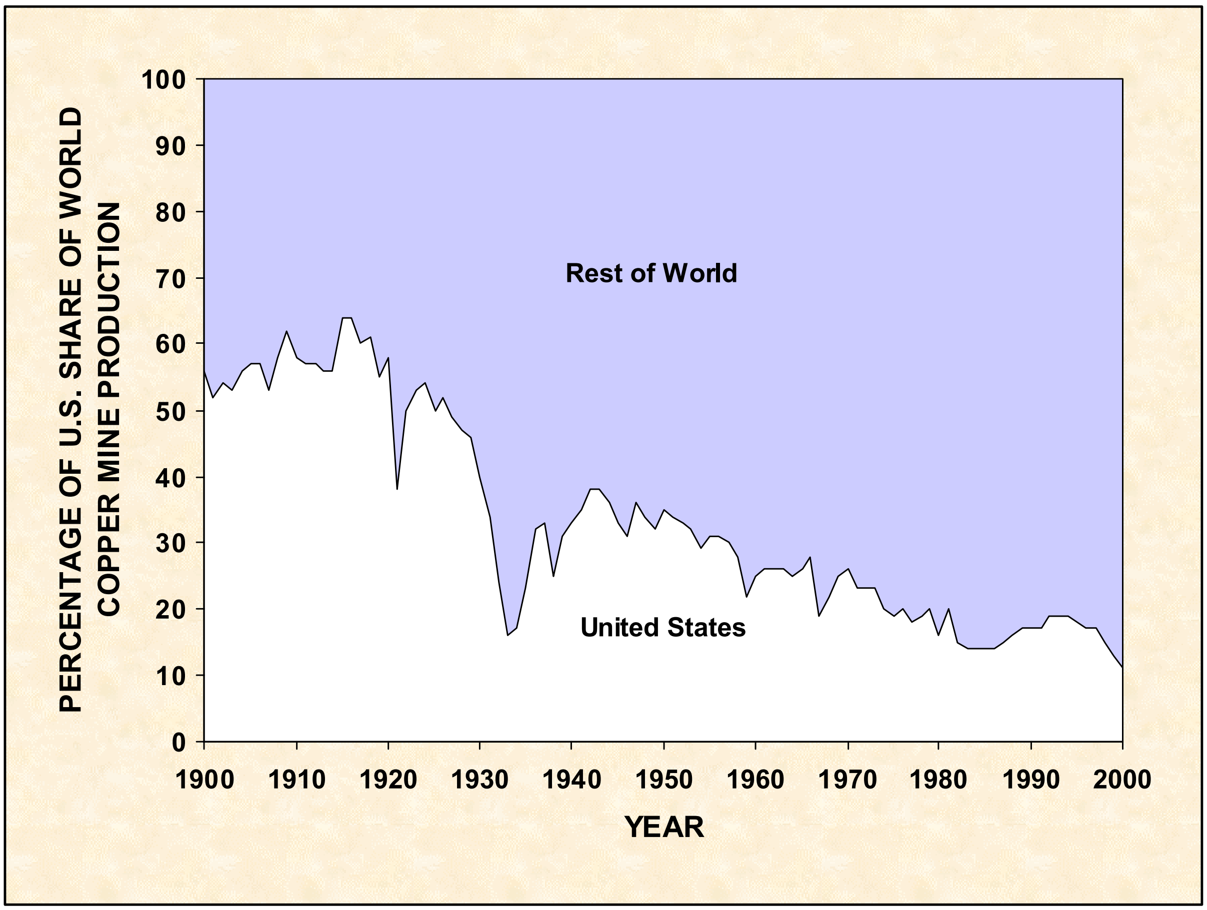

Figure E7. U.S. share of world copper mine production, by percent, copper content, 1900-2000 (data from Porter and Edelstein, 2001).

Reserves/resources

The 2000 world copper reserves were estimated to be 340 million tons of copper content; those of the United States were 45 million tons, 13 percent of the world total. The world copper reserve base for 2000 was estimated to be 650 million tons copper content. The 2000 reserve base for the United States was 90 million tons, almost 14 percent of the world estimate (Edelstein, 2001, p. 53). As a comparison, the 1981 world reserve base was estimated to be 505 million tons. For the United States, it was 90 million tons, almost 18 percent of the world estimate (Butterman, 1982, p. 41). The world reserve base increased as copper mining took place because more material was being added to the reserve base through exploration and changes in economic conditions than was removed through mining. New developments in mining and ore processing equipment have greatly increased reserves by making possible the recovery of copper from ore that was not economically feasible using older technologies (Wilburn, Goonan, and Bleiwas, 2001). This demonstrates that reserve base and reserves are dynamic concepts and should not be used as long run indicators of the future availability of the material.

Use

Copper use in the United States as measured by apparent consumption (fig. E8) has a strong increasing trend during the 20th century. Fluctuations reflect the economic and political events of the century. Apparent consumption of copper reached a new high during World War I because of an increased demand for copper for the war effort. It declined when the war effort ended. Apparent consumption increased again when the economic boom of the 1920s caused the demand for copper to increase. Demand dropped for most copper products during the Great Depression, resulting in the fall of copper apparent consumption. The war effort during World War II caused a strong demand for copper and large growth in apparent consumption. With the end of the war, copper apparent consumption declined, but remained much higher than before the war. Copper demand and apparent consumption increased during the post-war economic boom. The economic growth continued through 1998, with interruptions caused by the oil crisis of the 1970s and the recession of the 1980s. The reason copper demand follows the economy is because it is used in industries whose markets are integral parts of the economy. In the United States in 2000, 41 percent of copper was used in building construction, 27 percent was used in electrical and electronic products, 12 percent was used in transportation equipment, 10 percent in industrial machinery and equipment, and 10 percent in consumer and general products (Edelstein, 2001, p. 52).

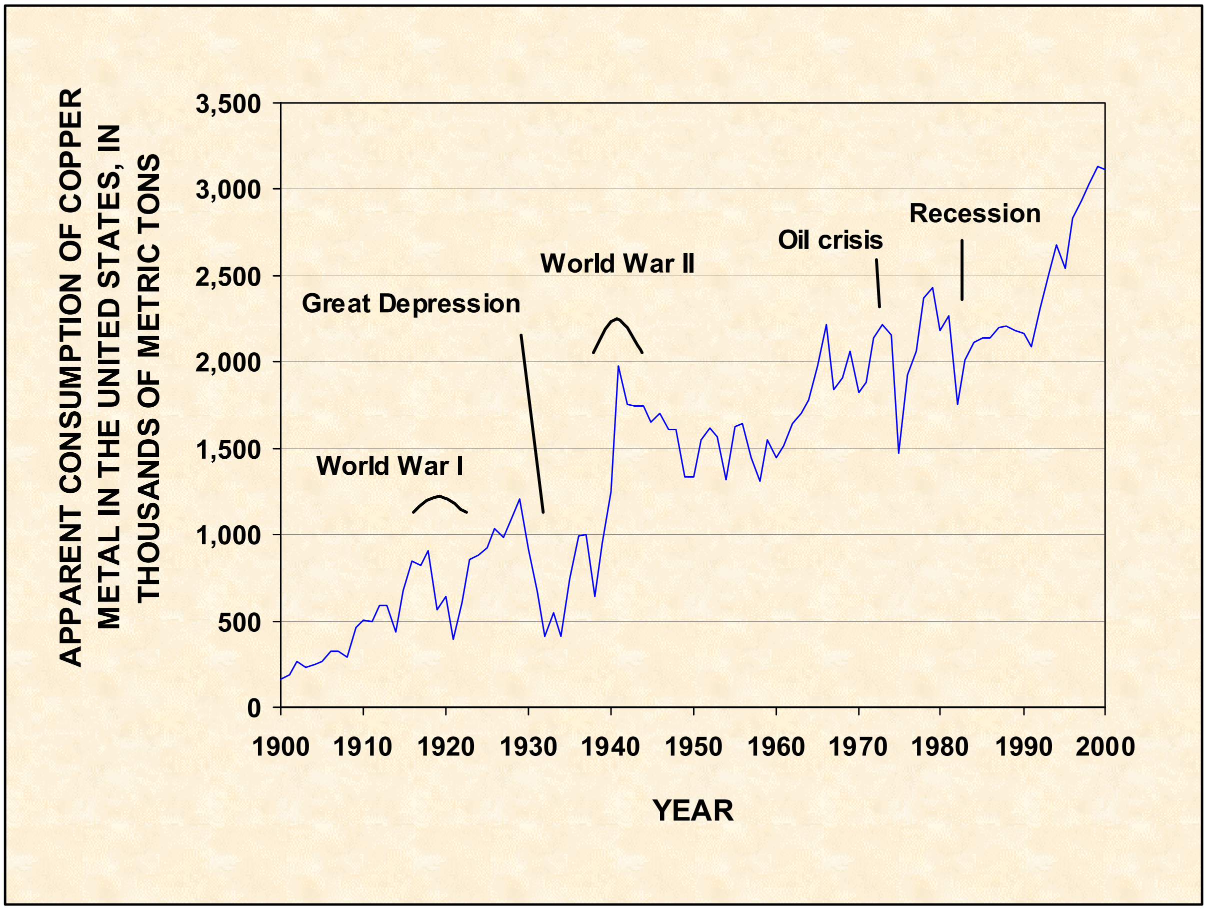

Figure E8. U.S. apparent consumption of copper metal, 1900-2000 (data from Porter and Edelstein, 2001).

Apparent consumption of copper per capita, figure E9, has the same pattern as total apparent consumption. It also has an increasing growth trend, but because population is growing during the same period its growth trend is not quite as strong as that for total apparent consumption. Per capita consumption of copper was at its all time high in 1941 as a result of the War effort. Since that time it leveled off, adjusting to economic conditions.

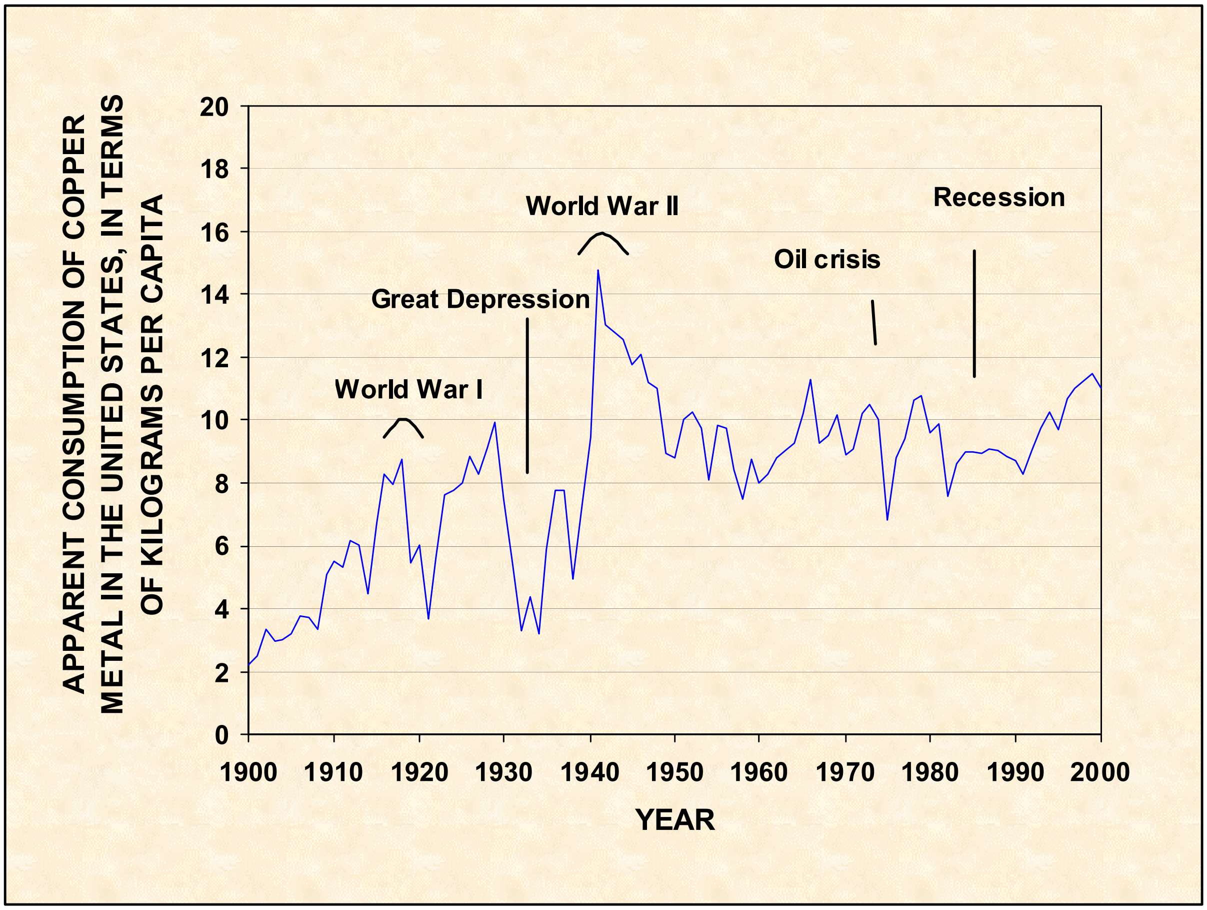

Figure E9. U.S. apparent consumption of copper, in metric tons per capita, 1900-2000 (data from Porter and Edelstein, 2001, U.S. Census Bureau, 2000, and U.S. Census Bureau, 2001).

Globalization -- trends in imports and exports

The pattern of U.S. net imports of refined copper changed during the 20th century. Net imports of refined copper are shown in figure E10. Net imports are defined as imports minus exports. The United States was a net exporter of refined copper between 1900 and World War II. During World War II and into the mid-1950s, the United States imported more copper than it exported because of the development of rich copper deposits overseas. Between the mid-1950s and the mid-1970s, the United States shifted between being a net importer and a net exporter. Since that time, the United States has been a net importer. Changes in net imports are related to price fluctuations. When the price is relatively high, the U.S copper industry is able to provide domestic requirements and compete on the world market, resulting in negative net imports or net exports. When prices are relatively low, marginal domestic producers cut back or cease production.

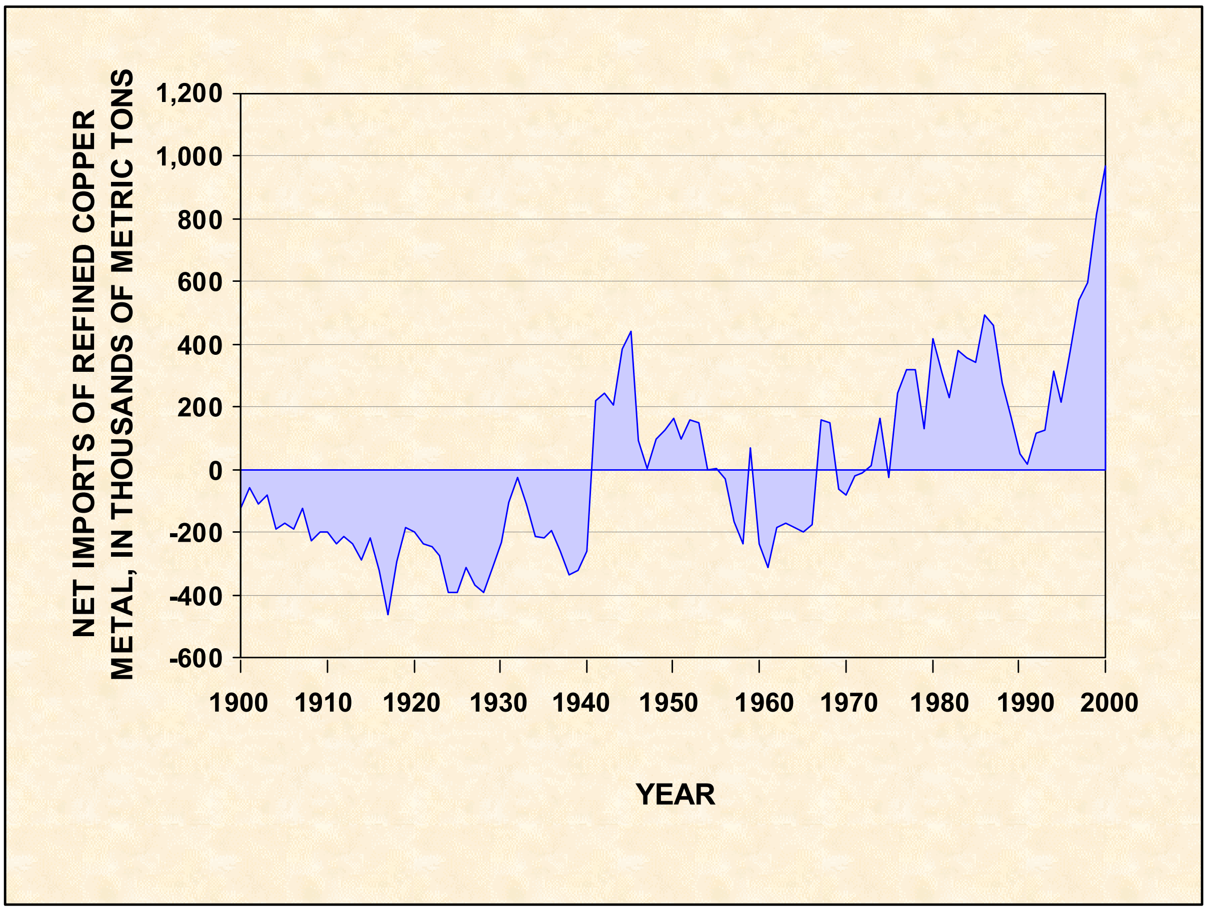

Figure E10. U.S. net imports of refined copper metal, thousand metric tons, 1900-2000 (data from Porter and Edelstein, 2001).

Productivity

Productivity estimated in terms of output per hour is a measure of the productivity of labor. A Department of Labor productivity index for copper is shown in figure E11. It covers the period from 1955 to 1998. Modernization and technological changes allowed one worker in 1986 to produce more output per hour as two workers in the late 1970s. This increase coincides with the implementation of solvent extraction and electrowinning. Increasing output per hour helps to reduce labor costs and allows mining to continue even while constant dollar prices are declining.

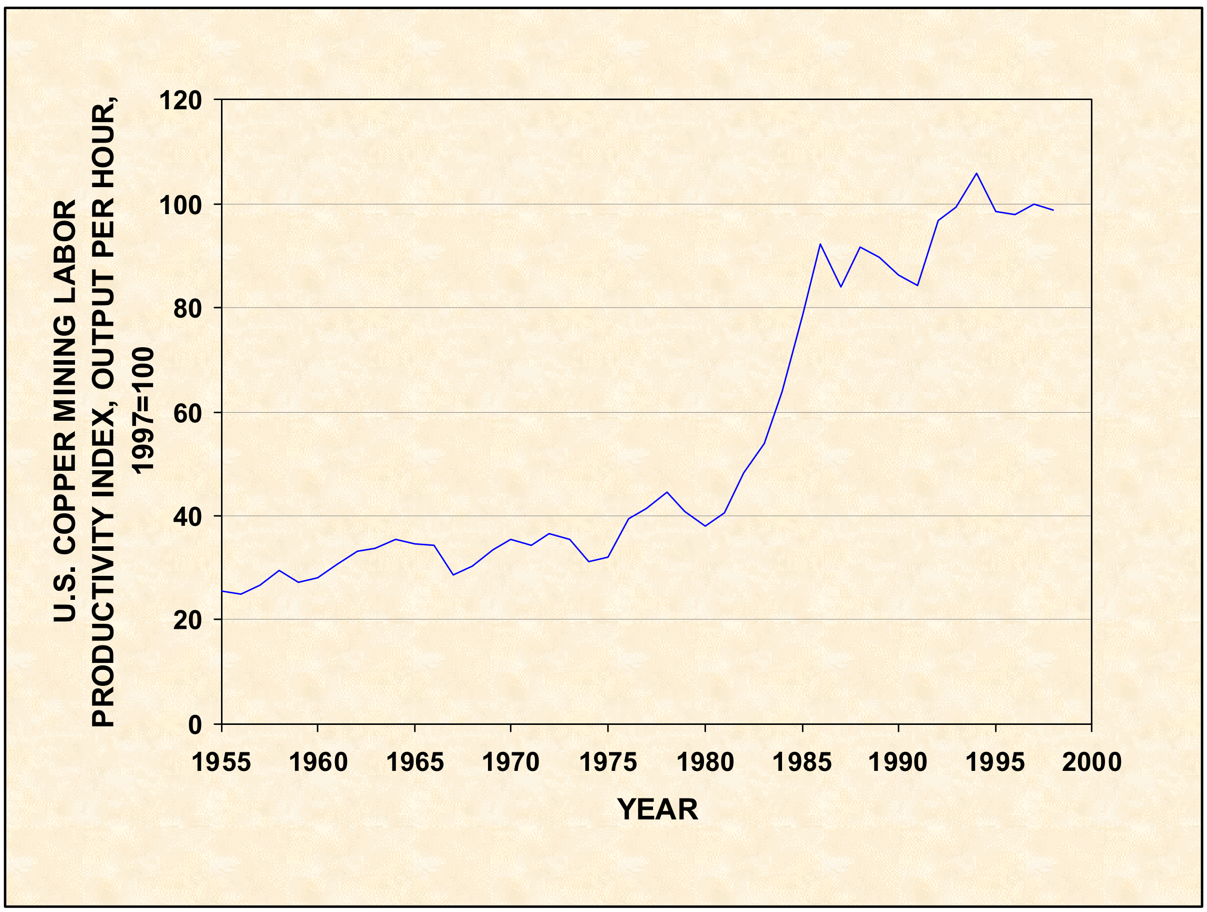

Figure E11. U.S. copper mining labor productivity index from the Bureau of Labor Statistics, output per hour, 1955-98 (data from Freidman, 2000).

Supply/demand relation

Copper mining operations are usually large undertakings. Copper mining entails the handling of large quantities of material to recover the copper because the amount of copper in the ore is low; it can be less than 1 percent (Jolly, 1985, p. 214). After the ore is removed from the ground, it is usually upgraded on site before it is shipped to the next stage of processing. Conventional copper operations have processed sulfide ores using flotation methods. Electrowinning technology was introduced commercially in the late 1960s and resulted in a redefinition of copper ore by including oxide ore that previously had not been economically recoverable.

Economic theory tells us that in order to continue operating, producers have to sell their product at a price that will allow them to recover their costs. The quantity available to the market is affected by production costs and the market price of the commodity. When costs are so high that a producer cannot recover them, they may cease production. This results in less material being offered to the market. If costs are reduced and can be recovered, more material is offered to the market. Costs affect the quantity offered to the market and therefore cause adjustments in the supply-demand equilibrium.

Production costs are made up of operating costs, and capital costs. Operating costs include direct operating costs such as material inputs, energy, and labor, indirect operating costs such as plant overhead, depreciation, interest, taxes, reclamation, and general mine development. Capital costs include exploration costs, acquisition costs, and capital equipment renewal. Table E1 contains data from the 1997 U.S. Economic Census. This Census contains a selection of total cost data for copper mining and does not represent the total costs of a mining operation.

Table E1. Production costs for U.S. copper mining industry in 1997.

[Data from U.S. Census Bureau, 1999]

Operating costs, in thousands of dollars	
Direct	
Supplies, material, and purchased machinery installed	1,333,575
Purchased fuels and purchased electricity	410,879
Production, development, and exploration wages	446,646
Indirect	
Total depreciation/depletion charges during the year	303,696
Capital expenditures, in thousands of dollars	
Exploration and development	88,870
Mineral land and rights	19,377
Buildings, structures, machinery and equipment	440,163

Direct operation costs

The mining and beneficiation process requires materials to recover ore. Table E1 shows the value of material inputs required for copper mining in the United States at $1,333.6 million. Energy is essential for modern-day mining. Machinery and equipment are powered by energy generated from fossil fuels. The cost of energy for copper mining was $410.9 million. Labor resources are another essential requirement for economic activity. Modern mining methods have lowered labor costs by increasing the productivity of labor. Table E1 shows labor costs for copper mining industries at $446.6 million in 1997.

Weighted average net operating costs for producing copper mines in the United States were estimated in a report on copper availability (Porter, and Peterson, 1992). As part of this work, the weighted average operating cost for copper mines in 1987 in the United States was estimated to be 53 cents per pound in 1987 dollars. The 1987 price of copper in 1987 dollars was 82.5 cents per pound (Porter and Edelstein, 2001).

Indirect operating costs

Indirect operating costs include items such as plant overhead that entails supervision, site administration, facilities maintenance, research, and technical, clerical, and sales support. These costs do not increase in direct proportion to the amount of copper produced. Depreciation is also an indirect operating cost. Table E1 shows total copper mining depreciation charges for 1997. Other indirect operating costs include interest, taxes, and reclamation. Reclamation is generally a required part of mining. Modern mine planning must include reclamation and its costs, which can be significant. The geometry of the copper deposit and how the ore is to be recovered, among many other factors, influence the cost of reclamation. There is a wide range in the magnitude of reclamation required around the globe, and a wide range in reclamation costs.

Administrative expenses

Administrative expenses include costs such as executive and clerical wages, office supplies, engineering and legal expenses, upkeep on office buildings, and general communications. The expenses connected with senior management or administrative expenses cannot be charged directly to manufacturing costs. Therefore, it is necessary to include these costs in administrative expenses if the economic analysis is to be complete. These costs may vary markedly from operation to operation.

Sales or marketing costs and distribution costs

Few operations can be considered to be successful until the products have been sold or put to some profitable use. It is necessary, therefore, to consider the expenses involved in selling the products. Included in this category are salaries, wages, supplies, and other expenses for sales offices; salaries, commissions and traveling expenses for salesmen; shipping expenses; cost of containers; advertising expenses; and technical sales service. Sales and marketing costs vary widely for different types of operations depending on the particular commodity produced, other products sold by the company, plant location, and various internal and external policies.

A distribution cost is any cost incurred to market a product or service. Distribution costs may include all amounts spent on advertising, warehousing, and shipping products to customers. Distribution and marketing expenses are costs incurred in the process of selling and distributing the various products. These costs include expenditures for materials handling, containers, shipping, and other products and activities.

Research and development costs

New processes and equipment are constantly being developed as technologies evolve. The associated research and development costs include salaries, fixed and operating expenses, materials, supplies, and direct overhead. Usually, only larger companies have research and development budgets for process improvements and modifications. The independent equipment manufacturers usually do the development of equipment. The total research and development costs may vary markedly from company to company. A small company may not have financial resources required for research while larger companies with financial resources fund research. In some cases, research and development is done by the government or a consortium.

The Phelps Dodge Corporation, a large copper producer conducts extensive research and development. The Corporation has programs relating to technology for exploration for minerals, recovery of metals from ores, concentrates and solutions, smelting and refining of copper, metal processing, and product development. It also has programs related to carbon black products, wire insulation and materials and conductor materials and processes. Expenditures for all of these research and development programs, together with contributions to industry and government-supported programs, totaled $24.7 million in the year 2000, compared with $16.5 million in 1999 and $18.0 million in 1998 (Phelps Dodge Corporation, 2001).

Capital costs

Some copper deposits require extensive exploration costs to be located. Acquisition costs vary significantly as a result of many factors including the physical setting in which each deposit is found, and the quantity and grade of ore. Properties can be acquired in order to look for deposits or property can be purchased where the deposit that has already been discovered and defined. Capital costs vary as a result of the capital intensity of the operation and the level of expenditures for a given year.

Strategies for efficient material usage

Efficient use of copper increases the amount of copper available for use. Activities that increase the efficiency of copper usage include substitution and recycling. Substitution takes place when copper is either replaced by or replaces another material. This can happen when a new material can replace copper in a specific product such as when fiber optics replaces copper in telecommunications. A more subtle form of material substitution occurs when a new product using different materials replaces the function of an original product, such as nonmetallic microwavable bowl replaces a copper saucepan. Substitution utilizes more economically available materials, thus contributing to efficient material usage. It also reduces the likelihood of materials scarcity.

Recycling is when copper is recovered at the end of the copper containing product's useful life. The value of copper is usually sufficient to make recovering it profitable. When natural market forces or are not sufficient to stimulate copper recycling, regulations or taxes make recycling financially attractive. When copper is recycled, it becomes a valuable resource instead of waste. By supplementing the quantity of copper available to the market, recycling conserves virgin copper and makes more copper available to the market. Copper used in construction is an example of material that once it is put in place can continue to be used for 30 to 50 years and longer. Copper lends itself to recycling. The apparent supply of copper from recycled sources was nearly 33 percent in 1999, but has been declining in recent years. The rate was almost 39 percent in 1995 (U.S. Geological Survey, 2001, p. 62.15). Recycling of copper is sensitive to price as scrap copper prices tend to follow refined copper prices. When prices are low, the scrap processors find it more difficult to compete with primary copper.

Source reduction means utilizing less of copper to attain the same economic benefit. This can be done with a change in design, more efficient manufacturing methods, or more efficient usage of products. As an example, when electronic products are minimized, less copper is required to perform the same function. Source reduction saves natural resources, reduces waste, and reduces costs.

Conclusions

Apparent consumption of copper has increased over the 20th century, supported by increased domestic production and net imports. Early in the 20th century, the U.S. economy's need for copper was satisfied using domestic ores. Through the century, as requirements increased, new deposits were found and new technologies were developed. With globalization, ores were imported to help satisfy the economy's need for copper. As a result of this increased availability of copper, the constant dollar price of copper has been declining. The domestic industry has been able to remain competitive by increases in productivity and through technological innovations.

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APPENDIX F: ECONOMIC CASE STUDY -- POTASH

Introduction/background

During colonial times, potash was produced by burning wood, leaching the soluble salts from the ashes, and recrystallizing them in iron pots. At this time, potash was used to make soap and glass. Significant world production began in Europe in the middle of the 19th century. Germany was an important source of potash; however this source was cut off during World War I. The U.S. potash mining industry began developing in response to the resulting shortages. The development of mines near Carlsbad, New Mexico in the 1930s made the United States nearly independent of imported potash. This lasted until 1962 when increasing production from large Canadian sources began to affect the U.S. market (Searls, 1985).

About 90 percent of U.S. potash sales are used by the fertilizer industry (Searls, 2001). Potash contains potassium, which is one of the three main ingredients in fertilizer along with nitrogen and phosphorus. Potash is usually defined as any form of water-soluble potassium salt that can be produced, transported to the crop acreage, and spread over the acreage to the economic benefit of the farmer. The most common form of potash is potassium chloride. Additional forms of potash are potassium magnesium sulfate, potassium nitrate, and potassium-sodium nitrate. Potassium oxide, which is not usually considered potash, is used in ceramics. In order to evaluate the amount of potassium in the various types of potash the grade is calculated in terms of K_2O (Searls, 1985, p. 617-619).

Historical economic trends

Table F1 contains the prices of potash in current dollars and in constant 2000 dollars. The constant 2000 dollars prices are also shown graphically in figure F1[25]. The constant dollar price of potash dropped in the early 1920s then rose to a high in 1932. The price fell to a low in 1935 as a result of the Great Depression, rebounding in 1938. The price fell again during World War II because potash was not directly required in the War effort. The price then leveled off until the development of low-cost Canadian potash mines caused a decline in the 1960s, (Searls, 1985, p. 617-619) to a low in 1969. The price then rose in the early 1970s because of increased demand before dropping during the recession of the 1980s. The price leveled off during the 1990s.

Table F1. Unit price of potash, in dollars per ton.

[Data from Buckingham and Searls, 2001, NA, not available]

Year	Current	2000$	Year	Current	2000$	Year	Current	2000$	Year	Current	2000$	Year	Current	2000$
1900	NA	NA	1920	210.33	1,810	1940	34.07	420	1960	36.75	210	1980	129.46	270
1901	NA	NA	1921	158.67	1,530	1941	39.33	460	1961	38.74	220	1981	156.17	296
1902	NA	NA	1922	82.29	840	1942	33.62	350	1962	41.64	240	1982	145.77	260
1903	NA	NA	1923	78.26	790	1943	33.28	330	1963	41.92	240	1983	135.52	234
1904	NA	NA	1924	70.35	710	1944	36.99	360	1964	41.29	230	1984	135.25	224
1905	0.90	20	1925	72.00	710	1945	36.78	350	1965	42.63	230	1985	126.87	203
1906	NA	NA	1926	73.92	720	1946	33.72	300	1966	41.32	220	1986	110.19	173
1907	NA	NA	1927	83.61	830	1947	31.05	240	1967	34.05	180	1987	123.91	188
1908	NA	NA	1928	71.83	730	1948	30.77	220	1968	28.09	140	1988	163.81	238
1909	NA	NA	1929	76.95	780	1949	31.21	230	1969	23.71	111	1989	171.73	239
1910	0.35	10	1930	75.97	780	1950	41.72	300	1970	35.26	157	1990	131.79	174
1911	NA	NA	1931	75.42	860	1951	41.33	270	1971	39.61	169	1991	162.86	206
1912	NA	NA	1932	69.96	870	1952	43.12	280	1972	39.27	162	1992	170.52	209
1913	73.28	1,290	1933	59.81	800	1953	43.27	280	1973	39.92	155	1993	159.12	190
1914	81.91	1,410	1934	52.39	670	1954	41.73	270	1974	57.18	200	1994	159.38	185
1915	146.67	2,490	1935	41.39	520	1955	42.31	270	1975	74.65	239	1995	152.50	172
1916	731.25	11,610	1936	48.92	600	1956	41.07	260	1976	79.77	242	1996	146.35	161
1917	589.19	7,960	1937	49.31	590	1957	39.21	240	1977	78.91	224	1997	144.86	155
1918	588.10	6,680	1938	51.93	630	1958	36.81	220	1978	86.46	228	1998	175.00	185
1919	279.22	2,790	1939	42.94	530	1959	37.36	220	1979	104.12	247	1999	162.38	168
												2000	155.62	156

[25] The prices were not available in some years and when data was available, it was based on a limited market.

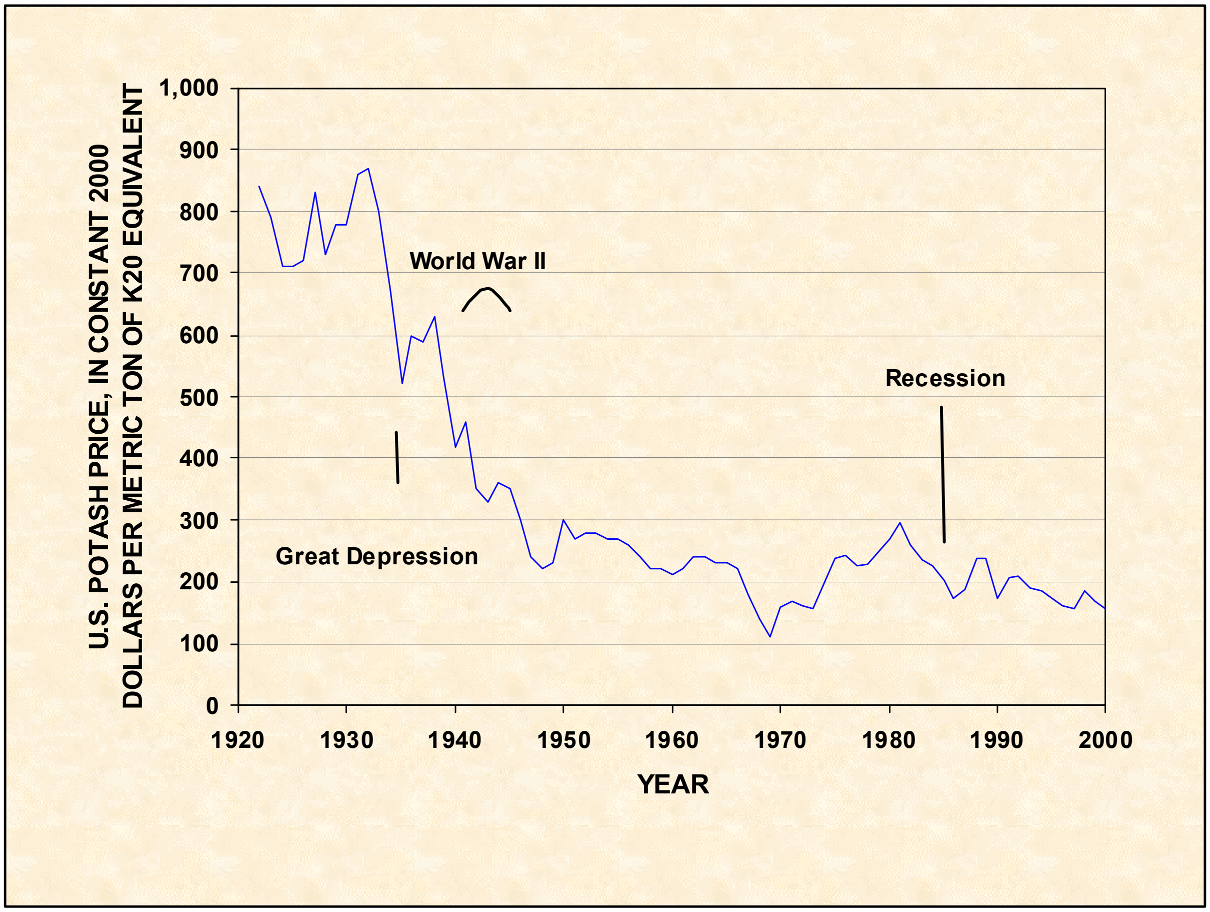

Figure F1. U.S. potash average price, in constant 2000 dollars, 1922-2000 (data from Buckingham and Searls, 2001).

Production

Mine production of potash is shown in figure F2 and table F2. Production data was not available before 1915. U.S. mine production began to grow significantly with the discovery of potash and the development of the mines in New Mexico in the 1930s (Searls, 1985, p. 617-619). This strong growth (fueled by the growth of the agriculture industry and the expanding use of chemical fertilizers) continued until the mid-1960s when it reached a peak of 3 million tons. At this time, mines exploiting the large resources of Saskatchewan, Canada began to ship potash to the United States. The Canadian mines, with the natural advantage of large high-grade reserves and proximity to U.S. markets, produced potash for the U.S. market at lower prices. As a result of this competitive advantage, U.S. mine production potash generally declined, reaching a low of 1.2 million tons in 1986. After a brief resurgence to 1.75 million tons in 1991; production leveled off to in the neighborhood of 1.4 million tons through 2000.

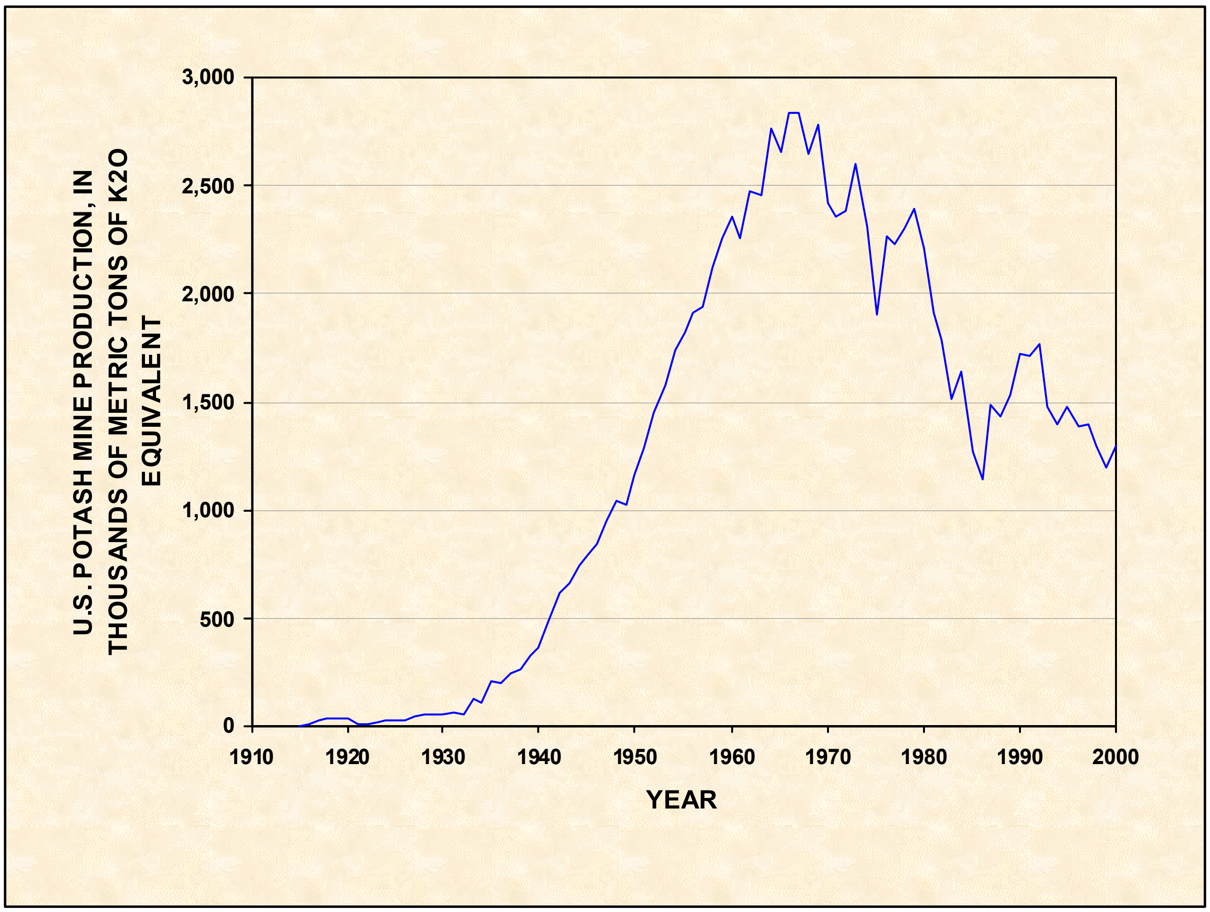

Figure F2. U.S. potash mine production, 1915-2000 (data from Buckingham and Searls, 2001).

Table F2. Domestic production of potash, in tons.

[Data from Buckingham and Searls, 2001, NA, not available]

Year		Year		Year		Year		Year	
1900	NA	1920	43,620	1940	344,400	1960	2,393,000	1980	2,239,000
1901	NA	1921	9,227	1941	476,200	1961	2,478,000	1981	2,156,000
1902	NA	1922	10,630	1942	616,200	1962	2,224,000	1982	1,784,000
1903	NA	1923	18,340	1943	670,500	1963	2,598,000	1983	1,429,000
1904	NA	1924	20,780	1944	757,100	1964	2,628,000	1984	1,564,000
1905	NA	1925	23,090	1945	793,100	1965	2,849,000	1985	1,296,000
1906	NA	1926	21,200	1946	845,300	1966	3,012,000	1986	1,202,000
1907	NA	1927	39,470	1947	934,300	1967	2,993,000	1987	1,262,000
1908	NA	1928	54,350	1948	1,034,000	1968	2,469,000	1988	1,521,000
1909	NA	1929	55,870	1949	1,015,000	1969	2,544,000	1989	1,595,000
1910	NA	1930	55,580	1950	1,168,000	1970	2,476,000	1990	1,713,000
1911	NA	1931	57,950	1951	1,288,000	1971	2,347,000	1991	1,750,000
1912	NA	1932	56,240	1952	1,511,000	1972	2,412,000	1992	1,710,000
1913	NA	1933	130,100	1953	1,734,000	1973	2,361,000	1993	1,510,000
1914	NA	1934	131,000	1954	1,768,000	1974	2,315,000	1994	1,400,000
1915	989	1935	130,900	1955	1,887,000	1975	2,269,000	1995	1,480,000
1916	8,818	1936	224,400	1956	1,970,000	1976	2,177,000	1996	1,390,000
1917	29,550	1937	258,100	1957	2,056,000	1977	2,229,000	1997	1,400,000
1918	49,720	1938	287,500	1958	1,948,000	1978	2,253,000	1998	1,300,000
1919	29,460	1939	283,200	1959	2,162,000	1979	2,225,000	1999	1,200,000
								2000	1,300,000

Figure F3, with price and production on the same chart, illustrates the relation between these two variables. From the development of potash operations in New Mexico in the 1930s to the development of potash operations in Canada in the 1960s, U.S. production of potash showed steady growth. During this same time, the price in constant 2000 dollars showed a declining trend. The commencement of production of lower cost potash in Canada meant stiff competition for U.S. potash mines. As a result, U.S. potash mines that could no longer compete closed, and production in the United States began to decline. The decline in U.S production began in 1966 and continued through the 1980s. Prices declined until 1969, at which time they began an increasing trend that reached a peak in the 1970s. These price increases were not enough to prevent the decline in production that lasted into the early 1980s. By the mid-1980s prices were at a level at which the U.S. mines that were still operating could compete with Canadian imports (Searls, 1985, p. 617-619).

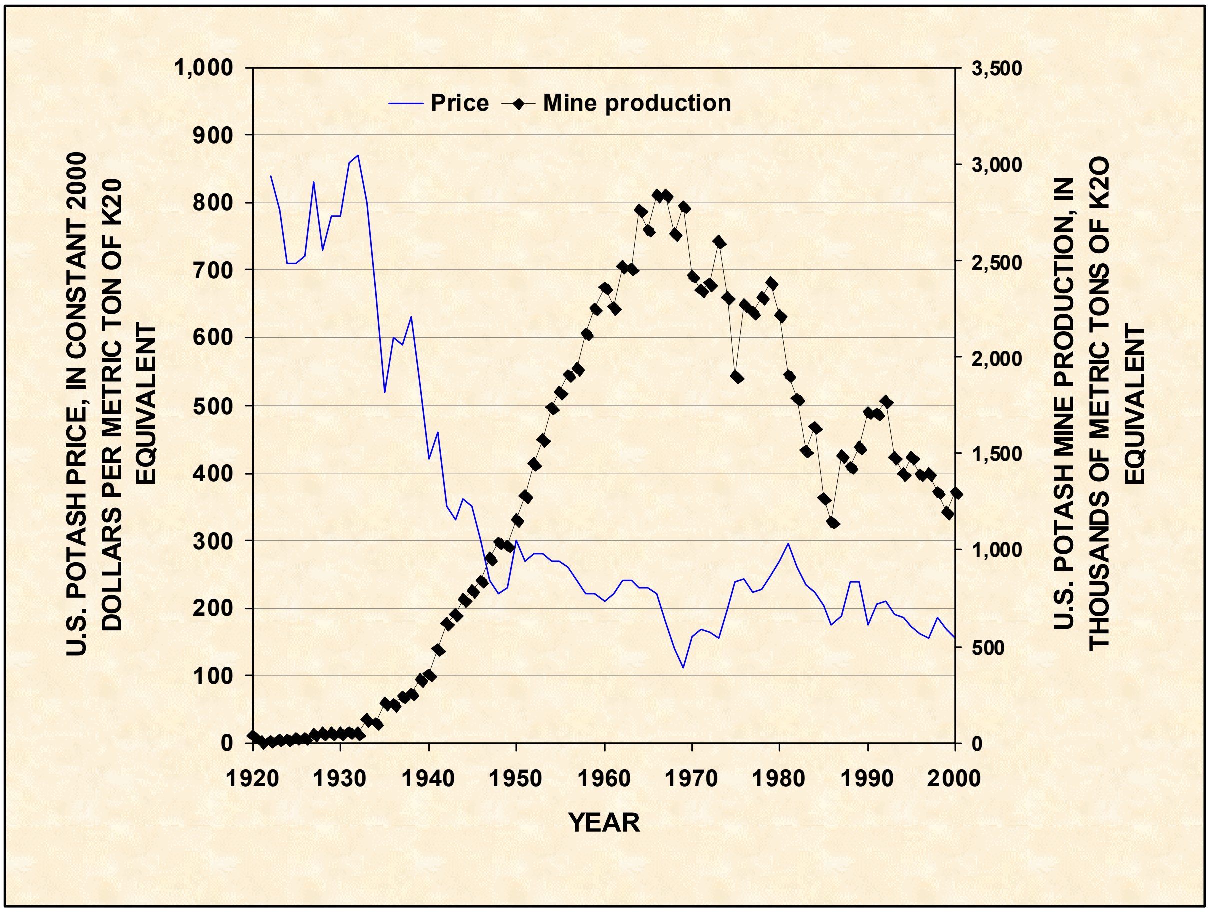

Figure F3. U.S. potash price compared to U.S. mine production, 1920-2000 (data from Buckingham and Searls, 2001).

World production

Figure F4 shows that world potash production grew very slowly from the 1920s through the 1940s. In the 1950s, production began to increase at a substantially faster rate because of increased in demand. The discovery and development of potash in Saskatchewan, Canada in the 1960s contributed to the production increase. This growth peaked at almost 32 million tons of K_2O equivalent in 1988. It has since declined to near 20 million ton tons in 1993 and remained close to 25 million tons in the late 1990s. In 2000, Canada was the source of approximately one-third of world potash production. Russia and Belarus together produced 28 percent of world production. Germany produced 13 percent and Israel and Jordan together produced 11 percent. The United States produced less than 5 percent of world production in 2000 (Searls, 2001).

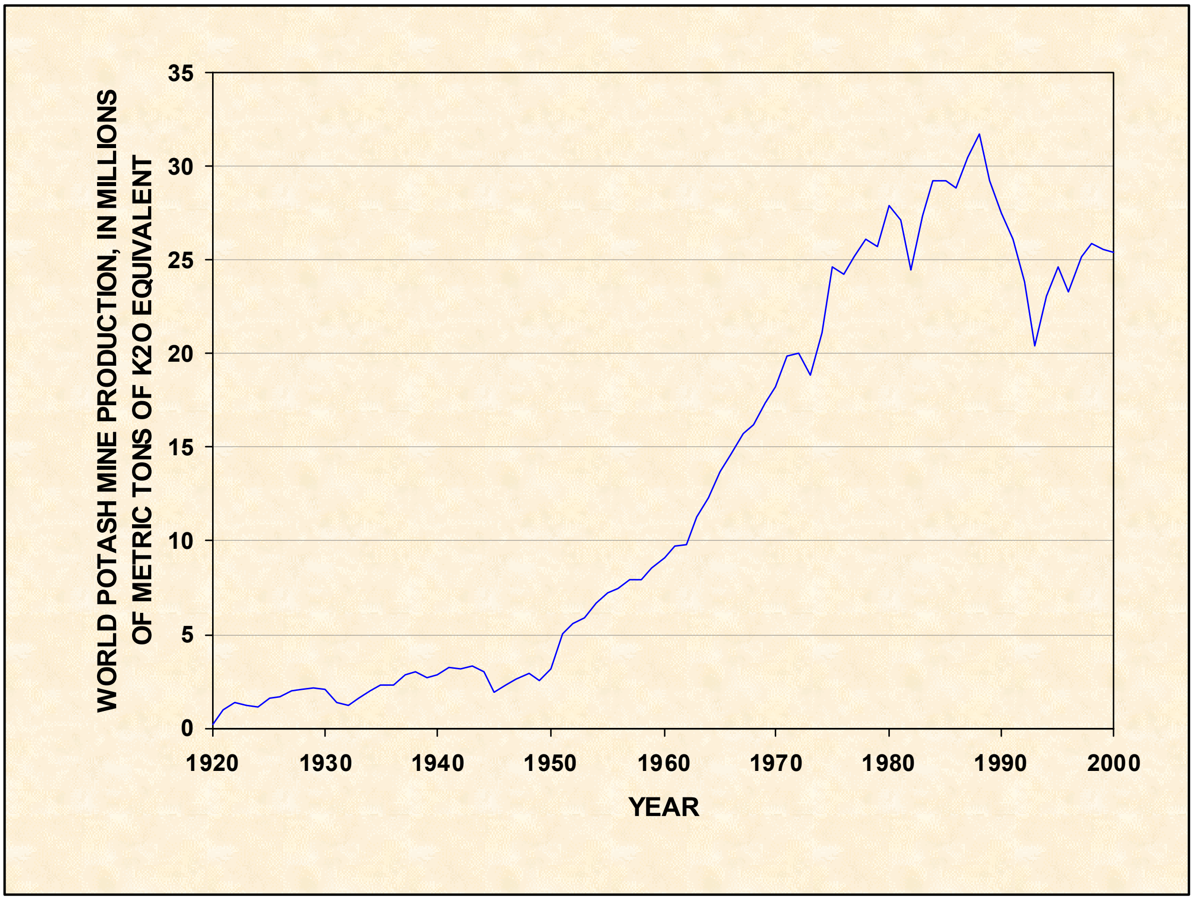

Figure F4. World potash mine production, 1920-2000 (data from Buckingham and Searls, 2001).

Figure F5 shows U.S. potash mine production as a percent of world mine production. After the early 1920s, the U.S. share of world potash production began to increase. The discovery and development of potash in New Mexico in the 1930s was a major factor in this growth. The U.S.

share peaked at over 41 percent in 1945, remained in the upper 30 percentile through 1950, and then in 1953 began a gradual decline to approximately 4 percent in 1987 because of continued competition from Canadian potash operations.

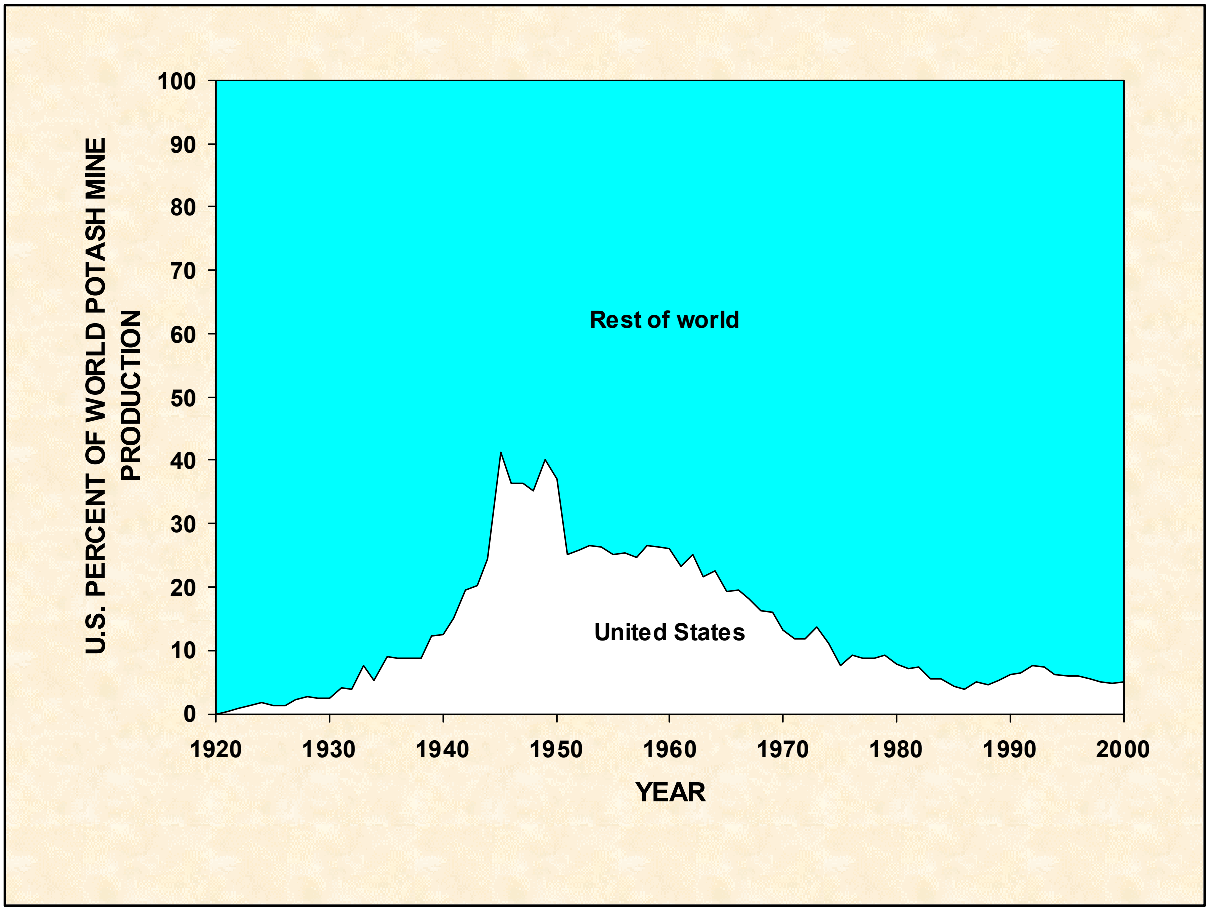

Figure F5. U.S. share of world potash mine production, 1921-2000 (data from Buckingham and Searls, 2001).

Reserves and reserve base

The world potash reserve base for 2000 was estimated to be 17 billion tons K_2O equivalent; more than half of this, 9.7 billion tons, was in Canada. The reserve base for the United States was 300 million tons, less than 2 percent of the world estimate. World reserves were estimated to be 8.4 billion tons K_2O equivalent; more than half of this, 4.4 billion tons, was in Canada. Those of the United States were 100 million tons, about 1 percent of the world total (Searls, 2001).

Use

Potash use in the United States as measured by apparent consumption (figure F6) had a strong increasing trend until 1979 when it reached a peak of 6.9 million tons K_2O equivalent. Apparent consumption is defined as production plus imports minus exports plus or minus changes in stocks. This increase in fertilizer usage was fueled by a strong increase in the production of grain crops. After the peak in 1979, apparent consumption dropped to a low of 4.5 million tons in 1989. The high relative value of the dollar in 1980 and 1981 on the international market led to poor sales of U.S. grains. This caused reductions in prices, thus lowering profits for U.S. farmers in 1982 and 1983. Lower profits in turn reduced the capability of growers to purchase potash fertilizers, (Searls, 1985). Since that time, the demand for fertilizer increased, and potash usage has trended upward, to above 6 million in the late 1990s.

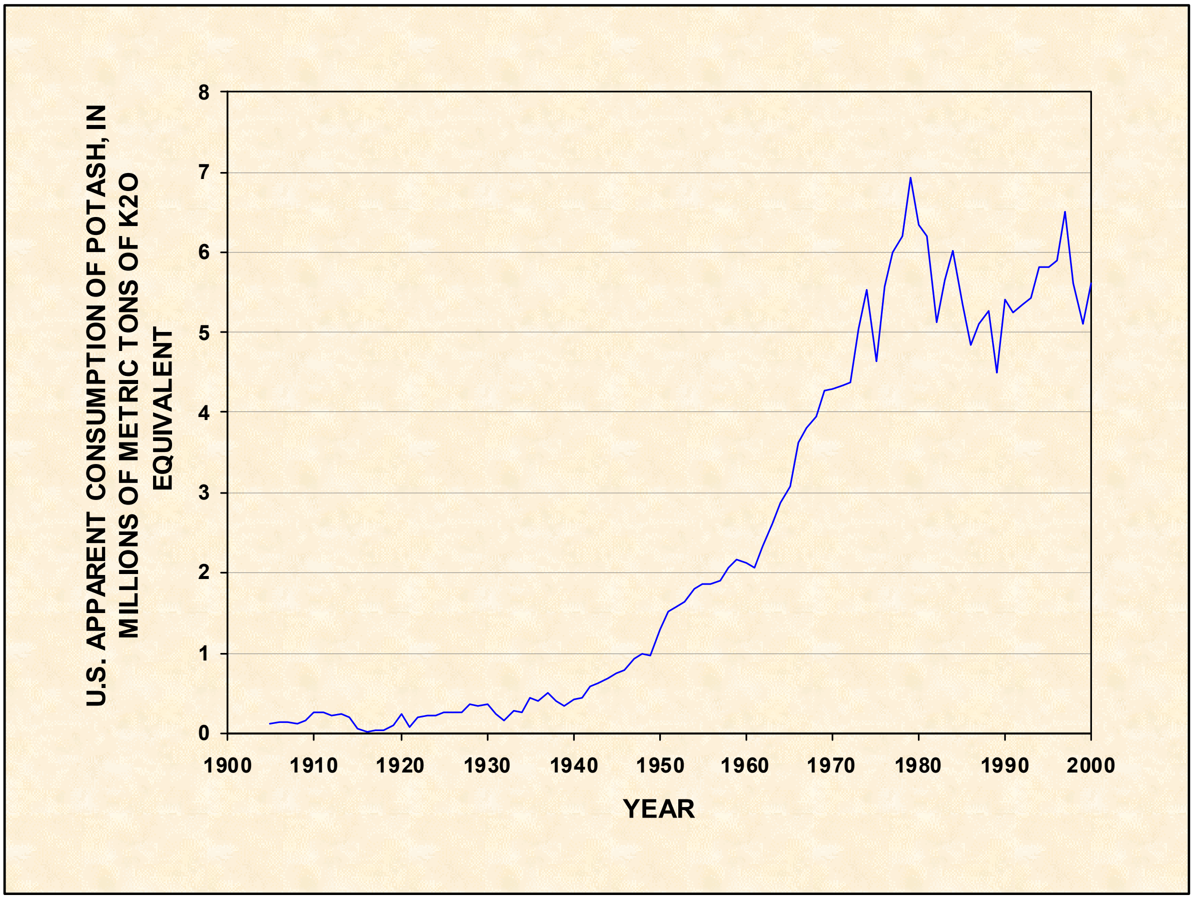

Figure F6. U.S. apparent consumption of potash, 1905-2000 (data from Buckingham and Searls, 2001).

Apparent consumption of potash per capita is shown in figure F7. The growth pattern mirrors the strong growth trend in total apparent consumption. The growth trend is not as strong because population was growing during the same period. As with total consumption per capita, apparent consumption of potash reached its peak in 1979. Since then it generally declined and leveled off at the end of the 20th century because of declines in fertilizer demand.

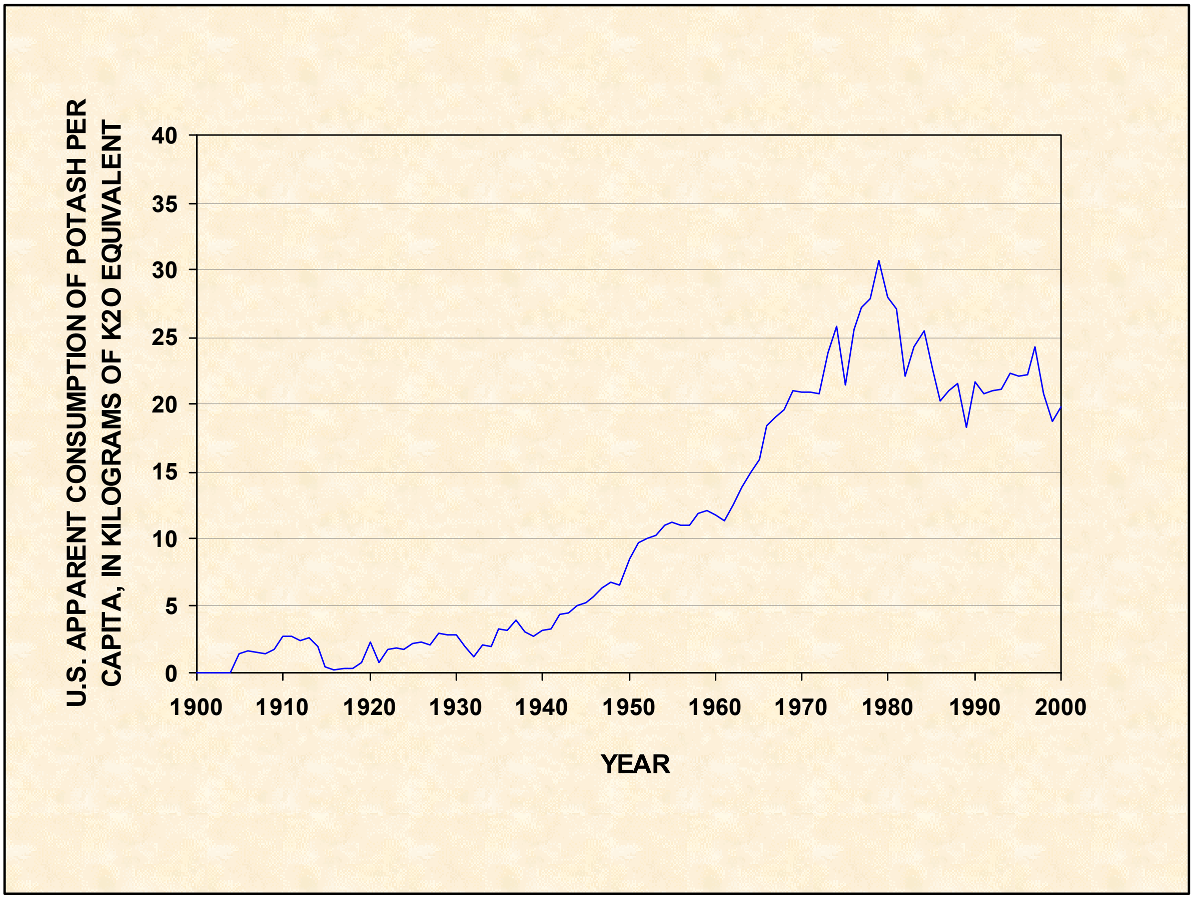

Figure F7. U.S. apparent consumption of potash per capita, 1924-2000 (data from Buckingham and Searls, 2001, U.S. Census Bureau, 2000, and U.S. Census Bureau, 2001).

Globalization -- trends in imports and exports

U.S. imports of potash shown in figure F8 were less than 300 thousand tons before 1962. This was because the United States supplied most of its own potash during this time frame. The development of large, high-grade, potash deposits in Canada in the 1960s, at a time when use in the United States was increasing and the ore grade at domestic mines was declining, resulted in large increases in imports into the United States. Between 1962 and 1979, imports increased more than sixteen fold. A slump in the grain markets in the 1980s caused a decline in fertilizer use, resulting in reduced potash, but the markets staged a recovery in the 1990s (Searls, 1985).

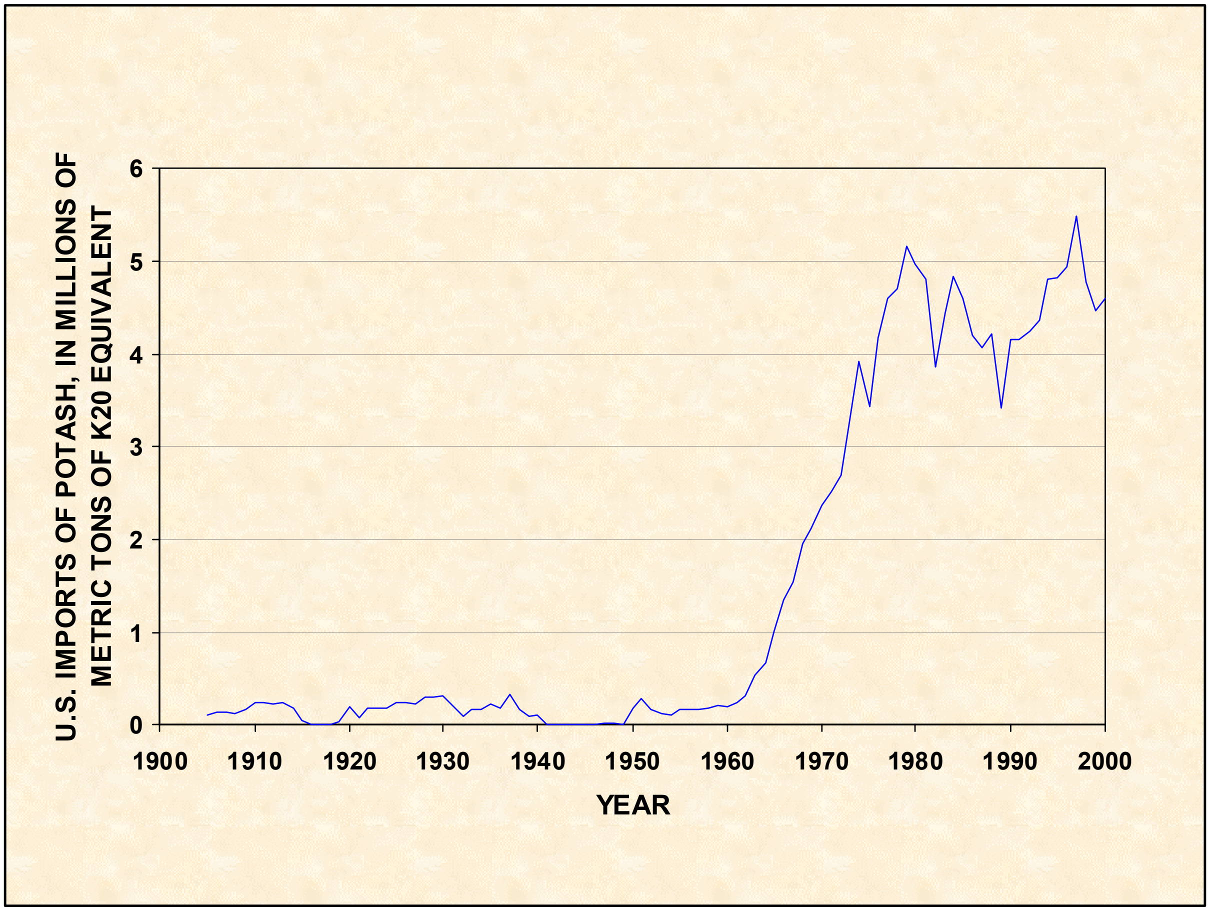

Figure F8. U.S. imports of potash, 1905-2000 (data from Buckingham and Searls, 2001).

Potash exports are shown in figure F9. From 1937 through 1954, the pattern of exports remained in a narrow range around 50 thousand tons. After 1955, exports began a period of growth, spurred by the increased demand for fertilizer. This growth continued through 1977 in spite of Canadian competition. Exports reached a low in 1983 because of a lack of demand. Exports leveled of in the late 1990s.

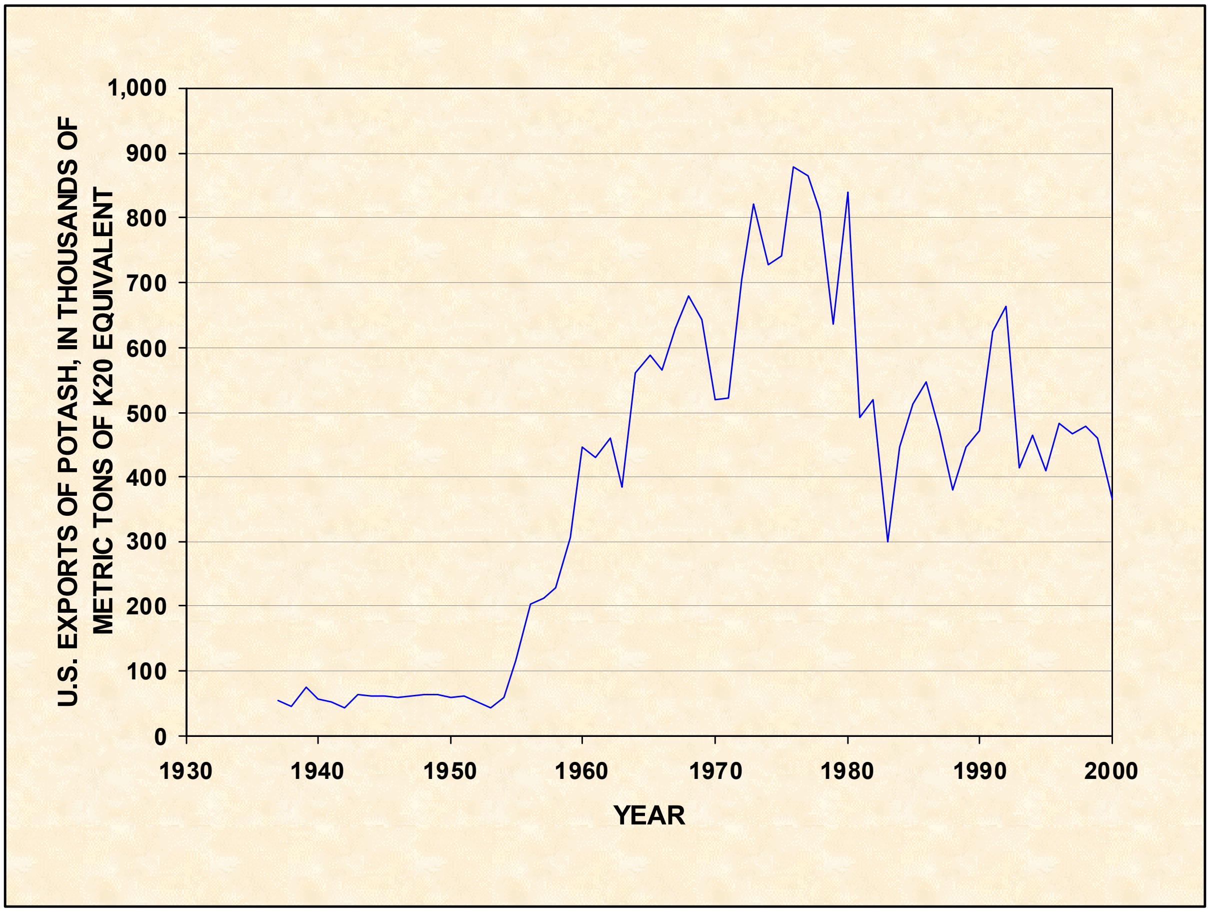

Figure F9. U.S. exports of potash, 1937-2000 (data from Buckingham and Searls, 2001).

Net imports are defined as imports minus exports. Figure F10 shows imports and exports balanced each other out in the first half of the century. After the mid-1960s, net imports grew substantially. The impact of the large volume of imports of Canadian potash after 1963 swamped U.S. potash trade. In 1998 imports supplied almost three-fourths of U.S. apparent consumption (Searls, 1985).

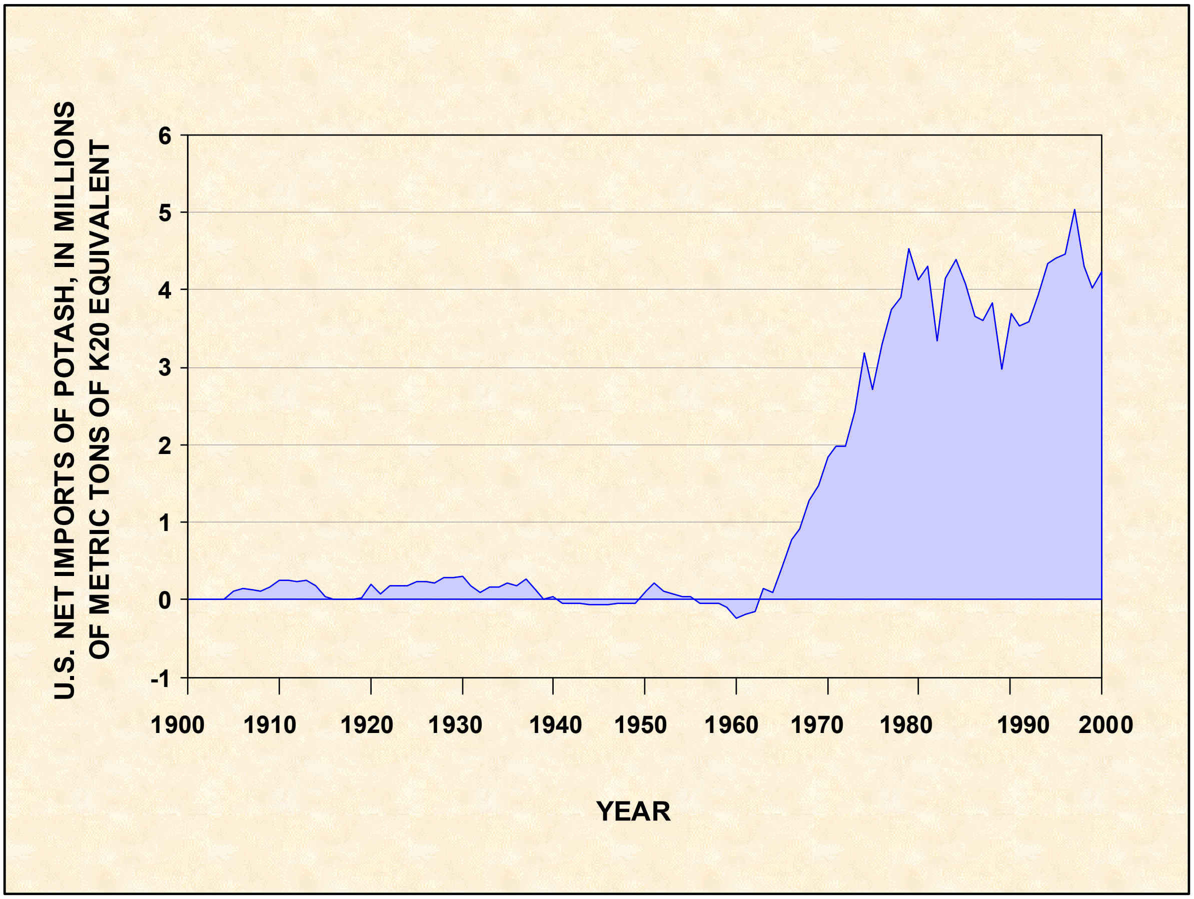

Figure F10. U.S. net imports of potash, 1905-2000 (data from Buckingham and Searls, 2001).

Productivity

Productivity is determined by many factors. Some of these factors include the grade of the ore, the location of the ore, and the mining technology used. In 1986, Sullivan and Michael reported that potash mines using underground mining methods in the United States had a weighted average in situ grade of 13.1 percent. The weighted average in situ grade, (the grade of the ore in place) for Canadian mines using underground mining methods was 26.7 percent. The higher grades and larger operations in Canada combined with ample reserves allow them to produce large quantities of potash at a lower cost than U.S. mines. Canadian potash occurs at a greater depth requiring that a larger quantity of potash be left in the form of pillars (Sullivan and Michael, 1986). This affects the percent of in situ ore recovered but does not prevent the Canadian mines from operating at lower costs because of the substantially higher grade.

Costs

Potash mining operations use underground mining methods (room and pillar, sublevel stoping, longwall caving, and cut-and-fill stoping), solution mining, and brine recovery. Potash is mined, sold, and used in large volumes so mining entails the handling of large quantities of material. After the potash ore is mined, it is upgraded (beneficiated) on site before it is shipped. Beneficiation methods include washing, flotation, and crystallization (Sullivan and Michael, 1986).

The quantity producers are willing to sell is a result of their production costs and the market price of the commodity. Production costs are made up of operating costs and capital costs. Operating costs include direct operating costs such as material inputs, energy, and labor, indirect operating costs such as plant overhead, depreciation, interest, taxes, reclamation, and general mine development. Capital costs include exploration costs, acquisition costs, and capital equipment renewal.

Table F3. Production costs for potash, soda, and borate mineral mining industry in 1997.

[Data from U.S. Census Bureau, 1999; D, withheld to avoid disclosing data of individual companies]

Operating costs, in thousands of dollars	
Direct	
Supplies, material, and purchased machinery installed	300,819
Purchased fuels and purchased electricity	172,648
Production, development and exploration wages	177,739
Indirect	
Total depreciation/depletion charges during the year	94,404
Capital expenditures, in thousands of dollars	
Exploration and development	D
Mineral land and rights	14,694
Buildings, structures, machinery and equipment	D

Operating costs

Potash mining requires materials such as roof supports and chemicals. Table F3 shows production costs for potash, soda, and borate mineral mining from the 1997 U.S. Economic Census (U.S. Census Bureau, 1999, p. 8). The U.S. Economic Census does not show the mining costs for potash separately but included it with soda and borate, which are not potash. It does show that the value of product shipments for potassium salts and borate compounds are 42 percent of total value of product shipments in this category.

Energy is essential for mining. Machinery and equipment are powered by energy generated generally from fossil fuels. The cost of energy to potash, soda, and borate mining for these industries was $173 million in 1997.

Labor resources are another essential requirement for economic activity. Modern mining methods have lowered labor costs by increasing the productivity of labor. The table shows labor costs at $178 million for potash, soda, and borate mining in 1997.

Indirect operating costs include items such as plant overhead that entails supervision, site administration, facilities maintenance, research, and technical, clerical, and sales force. These costs do not increase in direct proportion to the amount of material produced. Depreciation is an indirect operating cost. The table shows total depreciation charges during the year for 1997. Depreciation was $94 million for the potash, soda, and borate mining industry.

In 1987, the U.S. Bureau of Mines published estimates for net operating costs for underground muriate of potash producers in the United States, Canada and Europe (U.S. Bureau of Mines, 1987). Net operating costs includes transportation and credits for byproducts. Net operating costs for mines in the United States were $96.50 per ton in January 1985 dollars. Canadian mines net operating costs were $55.60 and net operating costs for mines in Europe were $14.90 (note: the mines evaluated in Europe had large credits for byproducts and low transportation costs).

Strategies for efficient material usage

Potassium, along with nitrogen and phosphorus, is an essential nutrient for plant growth and is used extensively in fertilizers. Fertilizers complement naturally occurring potassium in the soil and may be considered a substitute for soil potash when it is lacking. The most efficient application of fertilizers can result in the highest crop yields. When potash is used as a fertilizer, it is dissipated into the environment and is not available for recycling.

Source reduction means utilizing less material to attain the same economic benefit. This has the effect of reducing the requirement for materials. Source reduction could occur in fertilizers if they are applied carefully so as not to be used excessively. Global Positioning Systems (GPS) using satellites are used to insure the correct application of fertilizers. Soil samples are taken in a grid pattern and the GPS is used to determine what area of the grid is being treated to apply the appropriate amount of fertilizer (Russell E. Koeller Family Farms, 2001§). Source reduction saves natural resources, reduces waste, and reduces costs.

Conclusions

The United States was self-sufficient in potash from the 1930s until the development of Canadian potash operations in the 1960s. Since that time, the bulk of potash used in the United States has come from Canada. Because Canada has large reserves of potash, scarcity is not an issue, and there is little concern of running out of potash. The price of potash in 2000 dollars has a downward overall trend from 1922 through 2000. Prices in the late 1990s were less than those in the late 1950s. They reached a low below $110 in 1969 and a high above $294 in 1981. These price fluctuations were products of political and economic factors other than scarcity.

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APPENDIX G. ECONOMIC CASE STUDY – SULFUR

Introduction/background

Sulfur (chemical symbol S), is a tasteless, odorless, nonmetallic element. Also called brimstone (liquid sulfur) because it was synonymous with fire and evil, sulfur has been known since prehistoric times (Microsoft® Encarta® Online Encyclopedia, 2002§). Sulfur is the raw material for sulfuric acid processing and the manufacturing of other materials. Its consumption has been regarded as an index of a nation's industrial development (Buckingham, 1986).

Sulfur occurs freely in the vicinity of volcanoes and hot springs and is often associated with limestone, gypsum, natural gas, and petroleum. Sulfur deposits are found in Iceland, Italy, Japan, Mexico, and Spain. The island of Sicily (Italy) was the major supplier for the world until the beginning of the 20th century.

Sulfur and sulfuric acid are largely consumed in the manufacture of various products such as fertilizers, gunpowder, insecticides, and sulfa drugs. Chemically, sulfur combines with hydrogen to form hydrogen sulfide (H_2S), a colorless, poisonous gas with the smell of rotten eggs. When burned in air, sulfur combines with oxygen to form sulfur dioxide (SO_2). In moist air, SO_2 oxidizes to sulfuric acid (H_2SO_4), sulfur's most important compound (Morse, 1985). Figure G1 presents sulfur and sulfuric acid flows from origination through various applications and shows industry classifications.

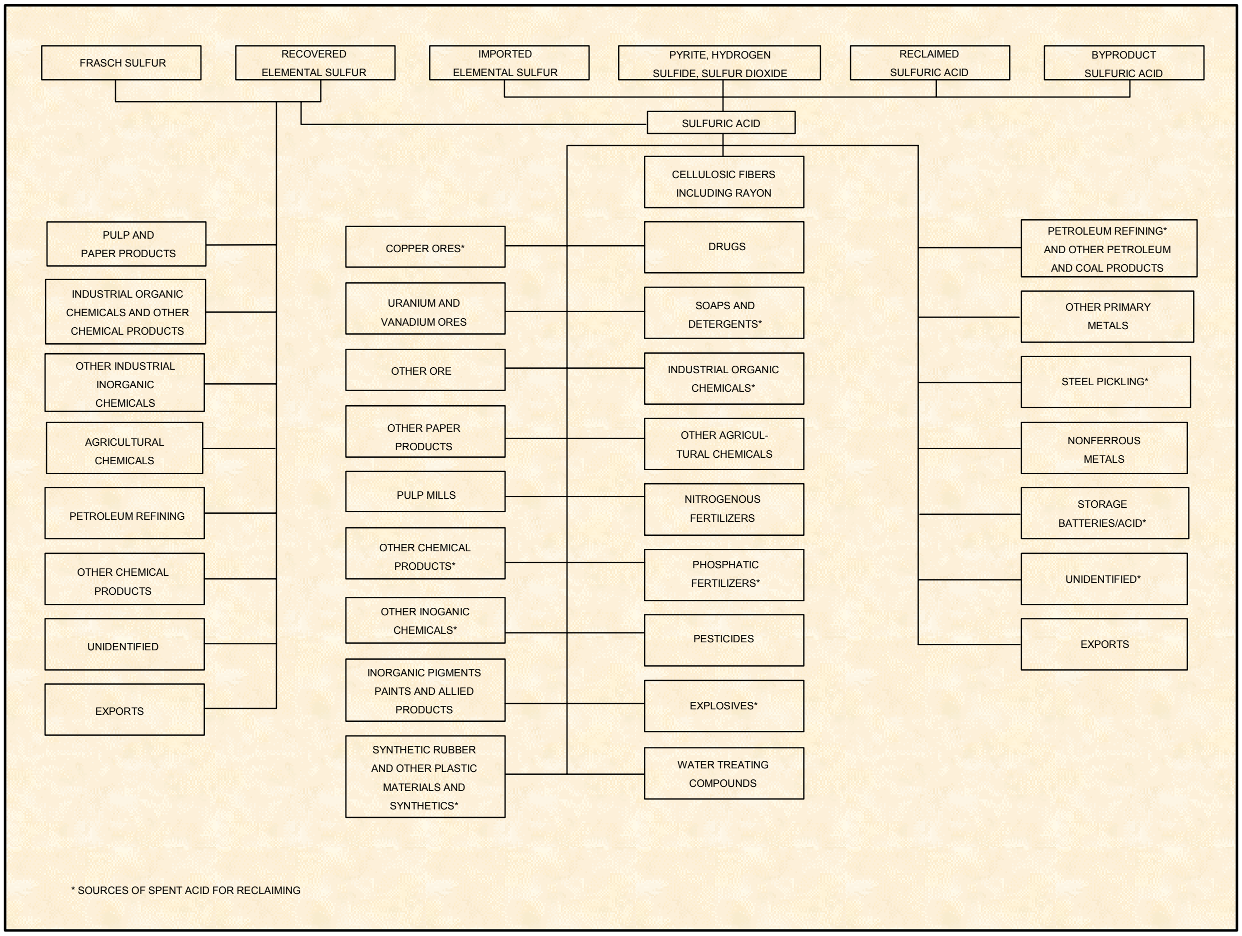

Figure G1. U.S. sulfur flow diagram (adapted from Ober, 1992).

Supply/Demand

During the 20th century there were three main sources for sulfur and sulfuric acid: (1) mined sulfur using the Frasch process, (2) recovered sulfur from fossil fuels; and (3) byproduct sulfuric acid from metal mining, plus sulfides from mining pyrites. These sources can be further classified as discretionary and nondiscretionary. Discretionary sulfur is voluntarily supplied to the marketplace driven by the potential of economic profits. Nondiscretionary sulfur is involuntarily supplied to the market due to regulatory mandates with no relationship to demand. During the last several decades, the sulfur supply has increasingly come from nondiscretionary sources, primarily recovered sulfur from sour natural gas and petroleum refining. Meanwhile, the supply of discretionary sulfur[26], produced by using the Frasch process, has continued to diminish. The demise of the domestic Frasch process was not only due to lower sulfur prices, but also due to high natural gas costs associated with heating water to melt the sulfur deposit. Global pyrites production, also categorized as discretionary, has decreased in recent years because of environmental and cost considerations.

In 2000, domestic demand for sulfuric acid corresponded to approximately 77 percent of reported sulfur consumption. Sulfur and sulfuric acid, used in the manufacturing of agricultural fertilizers, represented over 60 percent of total consumption (Ober, 2002). The overall demand for sulfur in recent years has remained steady, as increased uses in the agricultural industry have been offset with decreases in industrial applications. "Unlike other industries that are searching for economical methods to produce a usable product from decreasing reserves and poorer grades of ore, sulfur producers must strive to find innovative uses for the continuing growing sulfur supplies" (J.A. Ober, U.S. Geological Survey, written communication, May 22, 2000).

Historical economic trends

For most of the 20th century, both domestic production and apparent consumption of sulfur have consistently increased, but at different rates. In 1900, domestic production of sulfur was 86 thousand tons (U.S. Geological Survey, 1901) and apparent consumption was 415 thousand tons with an estimated value of $83 million in constant 2000 dollars. It should be noted that in 1900 almost 80 percent (328 thousand tons) of the sulfur consumed was imported. There was 10.3

[26] The last domestic sulfur mine in the Gulf of Mexico closed in August 2000.

million tons of sulfur produced in the United States in the year 2000, an approximate 120 times increase from 1900. The 2000 domestic apparent consumption was reported as 12.5 million tons (Ober, 2002) with an estimated value of $309 million (2000 dollars). This increase of apparent consumption in terms of weight for the years 1900 through 2000 is 30 times. Sulfur imports contributed slightly over 22 percent to apparent consumption in the year 2000, as domestic sources were major suppliers. There were no sulfur exports of any kind in 1900, while in 2000; sulfur exports totaled 824 thousand tons.

The most significant change in sulfur and sulfur compound's historic trends has been related to their production sources. In 2000, over 81 percent of total production was supplied from recovered elemental sulfur from petroleum refining, natural gas processing, and coking plants, as nondiscretionary byproducts. In 1900, this component of supply did not even exist.

Prices

After hitting a century high of $370 (2000 dollars) per ton in 1907, the price[27] of sulfur has continued its decline to its 2000 level of slightly under $25 (2000 dollars) per ton (figure G2). There have been three major price movements during this time period. A thirty-year high (1938 – 1968) was reached in 1968 partly due to high demand for sulfur used in the manufacturing of phosphatic fertilizers and a tight supply. After a precipitous price drop in 1969, a new historic low followed in 1973 as the worldwide oversupply of sulfur was felt in the markets. This supply condition was a function of very large increases in Canadian sulfur production recovered from

[27] Elemental sulfur prices from 1900 through 1967 are posted prices and from 1968 forward are the sales value of shipments, free on board (f.o.b.) mine/plant.

sour natural gas, increased Polish Frasch production, and worldwide increases in byproduct sulfur production (Merwin and Briggs, 1972). Another price peak was reached in 1981 when domestic apparent consumption was much greater than domestic production and the United States was a net importer of sulfur. The economic recession of 1982 started the downward trend in sulfur prices that continued through 2000.

Table G1. Price of sulfur, in dollars per ton.

[Data from Buckingham and Ober, 2001]

Year	Current	2000$	Year	Current	2000$	Year	Current	2000$	Year	Current	2000$	Year	Current	2000$
1900	$9.73	200.00	1920	$19.46	168.00	1940	$14.25	175.00	1960	$22.75	132.00	1980	$89.06	186.10
1901	$5.12	106.00	1921	$17.53	169.00	1941	$14.56	171.00	1961	$22.80	131.00	1981	$111.48	211.20
1902	$4.48	89.00	1922	$16.11	165.00	1942	$14.33	151.00	1962	$21.45	122.00	1982	$108.27	193.20
1903	$4.69	90.00	1923	$15.81	159.00	1943	$14.13	141.00	1963	$19.61	110.00	1983	$87.24	150.80
1904	$10.21	190.00	1924	$16.00	161.00	1944	$15.03	147.00	1964	$19.84	110.00	1984	$94.31	156.30
1905	$14.27	270.00	1925	$14.81	146.00	1945	$15.45	148.00	1965	$22.08	121.00	1985	$106.46	170.40
1906	$14.87	280.00	1926	$17.16	167.00	1946	$15.18	134.00	1966	$25.31	135.00	1986	$105.22	165.30
1907	$20.36	370.00	1927	$17.49	173.00	1947	$15.95	123.00	1967	$32.06	165.00	1987	$89.78	136.10
1908	$16.18	310.00	1928	$16.80	169.00	1948	$16.27	116.00	1968	$38.94	190.00	1988	$85.95	125.10
1909	$18.23	350.00	1929	$16.85	170.00	1949	$16.30	118.00	1969	$26.62	124.90	1989	$86.62	120.30
1910	$17.74	330.00	1930	$16.67	172.00	1950	$17.80	127.00	1970	$22.77	101.06	1990	$80.14	105.60
1911	$17.73	330.00	1931	$16.29	185.00	1951	$19.63	130.00	1971	$17.20	73.13	1991	$71.45	90.34
1912	$17.05	300.00	1932	$16.75	211.00	1952	$19.73	128.00	1972	$16.76	69.04	1992	$48.14	59.09
1913	$17.31	301.00	1933	$16.64	220.00	1953	$24.26	156.00	1973	$17.56	68.10	1993	$31.86	37.97
1914	$17.88	308.00	1934	$15.96	205.00	1954	$24.19	155.00	1974	$28.43	99.30	1994	$30.08	34.95
1915	$16.61	283.00	1935	$15.69	197.00	1955	$25.49	164.00	1975	$44.91	143.70	1995	$44.46	50.24
1916	$15.72	248.00	1936	$15.94	197.00	1956	$24.14	153.00	1976	$45.72	138.40	1996	$34.11	37.44
1917	$21.07	283.00	1937	$16.16	193.00	1957	$21.91	134.00	1977	$44.38	126.10	1997	$36.06	38.69
1918	$21.65	247.00	1938	$14.54	178.00	1958	$23.38	139.00	1978	$45.17	119.30	1998	$29.14	30.78
1919	$14.88	148.00	1939	$14.24	176.00	1959	$23.07	137.00	1979	$55.75	132.20	1999	$37.81	39.08
												2000	$24.73	24.73

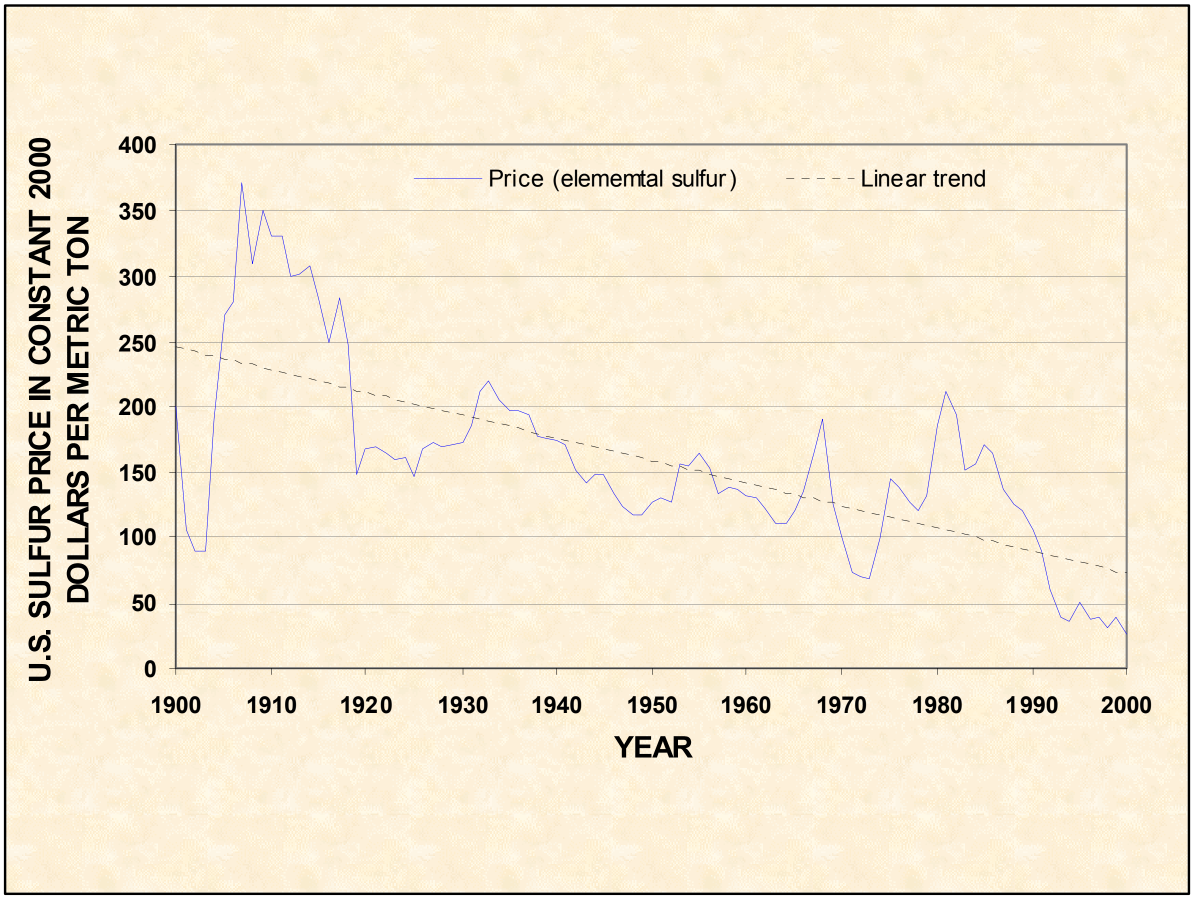

Figure G2. U.S. sulfur price, in constant 2000 dollars, 1900-2000 (data from Buckingham and Ober, 2001).

Domestic production

Over the last century elemental sulfur was mined using the Frasch process and recovered from crude oil and natural gas. In the beginning of the 20th century, Herman Frasch invented the superheated method of mining sulfur. In the Frasch process, sulfur is recovered from wells sunk into salt domes by forcing heated water into the wells to melt the sulfur, which is then brought to the surface. U.S. production of sulfur utilizing the Frasch process rose from 3,200 tons in 1900 to a production peak of 8.0 million tons in 1974 as shown in figure G3. Since then, it has consistently declined, as recovered sulfur has become the main supplier of sulfur to the U.S. economy. In 2000, sulfur production using the Frasch process was estimated as 900 thousand tons (Ober, 2002) or 9 percent of domestic production as compared to 69 percent in 1974.

Sulfur is recovered during the processing of various products and fuels. These refining processes reduce sulfur levels, in order to meet emission standards as part of pollutant abatement regulations. The production of sulfur by this recovery process was practically nonexistent prior to the 1940s. From that period forward, there was a steady increase in recovered production until the early 1970s when new demands for fuels, specifically natural gas, dramatically increased the rate at which production of recovered sulfur was advancing (figure G3). In 1940, production of recovered sulfur was 4.0 thousand tons and by 1971, the production of recovered sulfur had increased by over 400 times to slightly over 1.6 million tons. Petroleum refining and natural gas processing continued their trend of increased sulfur production in 2000, with domestic production reported at 8.38 million tons. From 1971 to 2000, recovered sulfur production, as a percent of total sulfur production, gradually increased from approximately 17 percent to about 81 percent, replacing the Frasch process as the major supplier of sulfur in the United States (figure G3).

Table G2. Domestic production of sulfur, in thousands of tons.

[Data from Buckingham and Ober, 2001]

Year		Year		Year		Year		Year	
1900	86	1920	2,320	1940	3,680	1960	7,310	1980	12,000
1901	242	1921	1,920	1941	4,030	1961	6,870	1981	10,200
1902	208	1922	2,140	1942	3,140	1962	6,770	1982	9,330
1903	233	1923	1,320	1943	3,940	1963	7,180	1983	10,500
1904	334	1924	1,500	1944	4,490	1964	8,310	1984	11,600
1905	402	1925	1,990	1945	4,550	1965	9,270	1985	11,100
1906	297	1926	2,210	1946	5,170	1966	9,340	1986	10,600
1907	475	1927	2,340	1947	5,630	1967	9,820	1987	10,800
1908	368	1928	2,780	1948	5,490	1968	9,640	1988	11,500
1909	351	1929	3,010	1949	6,020	1969	9,670	1989	11,500
1910	306	1930	2,560	1950	6,210	1970	9,780	1990	10,800
1911	1,020	1931	1,230	1951	6,380	1971	10,400	1991	10,700
1912	782	1932	1,630	1952	6,370	1972	11,200	1992	10,900
1913	708	1933	1,700	1953	6,760	1973	11,600	1993	11,500
1914	840	1934	1,960	1954	7,050	1974	11,200	1994	11,500
1915	1,030	1935	2,390	1955	7,900	1975	10,600	1995	11,800
1916	1,600	1936	3,170	1956	7,070	1976	10,900	1996	11,800
1917	1,910	1937	2,860	1957	6,300	1977	10,900	1997	12,000
1918	1,640	1938	2,510	1958	6,280	1978	11,900	1998	11,600
1919	1,630	1939	3,200	1959	6,750	1979	12,100	1999	11,300
								2000	10,300

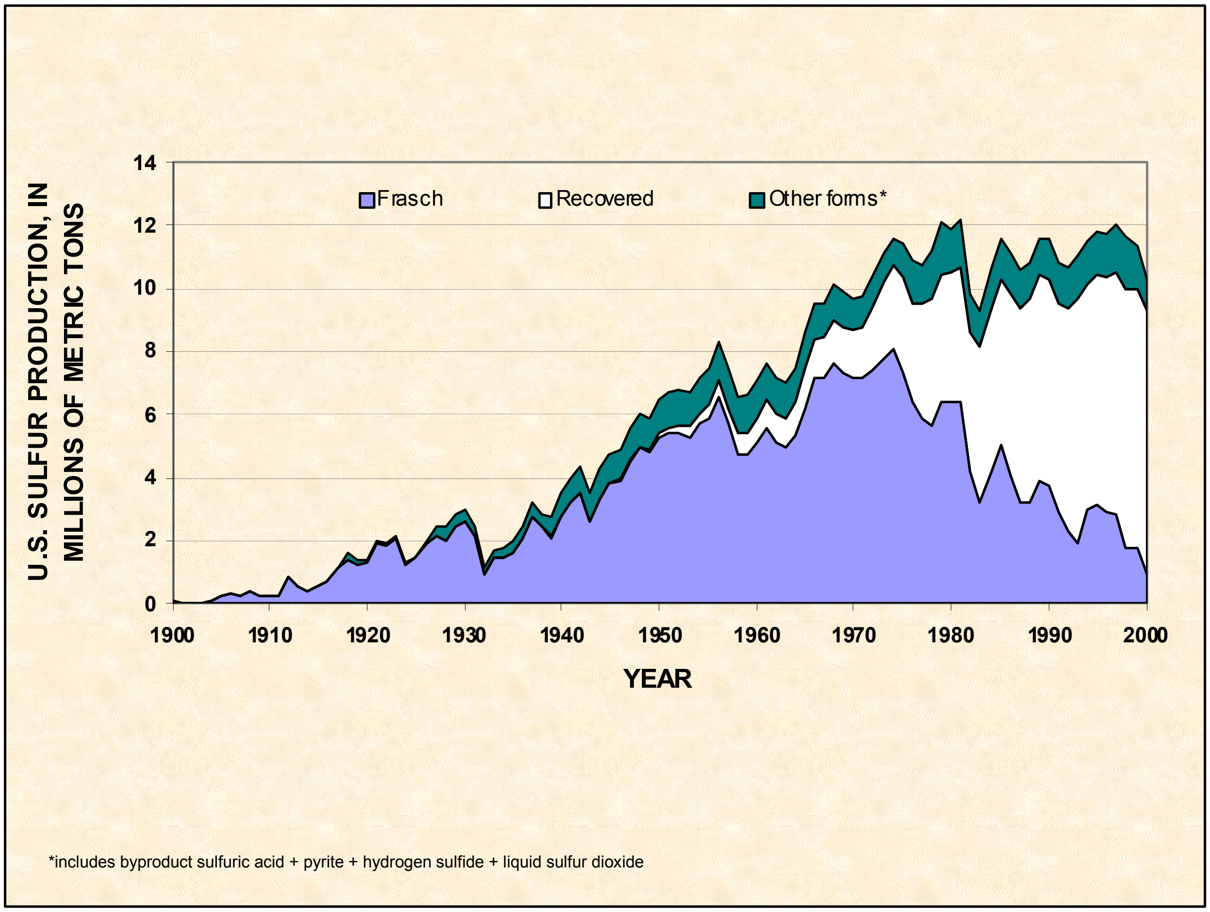

Figure G3. U.S. sulfur production trends, 1900-2000 (data from Buckingham and Ober, 2001).

A third production category is a composite of byproducts, pyrites, and others. “Byproducts” include SO_2 off gases that are converted to sulfuric acid (H_2SO_4) from nonferrous roasters and smelters (metallurgical operations) and coal gasification (coking operations). “Pyrites” are the source of pyrite concentrates (20-50 percent sulfur), which are usually processed into intermediate chemicals such as sulfuric acid. Many agricultural and industrial processes that manufacture fertilizer and pigment products require intermediate sulfur-based chemicals for their manufacturing and processing compound (Morse, 1985). The “others” category includes minor amounts of hydrogen sulfide, liquid sulfur dioxide, and data that was withheld (to avoid disclosing company proprietary information). During the 20th century, the byproducts/pyrites/others category's production trend showed a slow, but steady increase, breaking through the one million ton mark in 1947 and 30 years later, in 1997, exceeding 1.5 million tons for the first time as shown in figure G3. In 2000, this category's production had dropped to 1.03 million tons (Ober, 2002).

World production

World production[28] of sulfur has consistently increased over the last century to meet the global demands of both industrial and agricultural operations. The largest increase occurred between late 1960s and early 1970s, when world production jumped over 30 percent. Major contributors that boosted sulfur production were Russia (from pyrites) and Canada (from natural gas). Reaching a peak of approximately 55 million tons in 1980, world production of sulfur started a 3-year decline brought on by the recession in the early 1980s. A historic high of 59 million tons of sulfur was produced in 1988. Since then, world production has varied from a low of 51 million tons in 1992 to slightly over 57 million tons in 2000 (Ober, 2002).

Similar to U.S. production, world production has seen the same dramatic shift in the sources of sulfur. In 1975, world Frasch production reached a high of 14.6 million tons, which represented approximately 29 percent of world production from all sources. World Frasch production in 2000 was 2.29 million tons and was 4 percent of world production from all sources (Ober, 2002).

[28] Most data prior to 1940 is incomplete or not specific enough to generate accurate accounts.

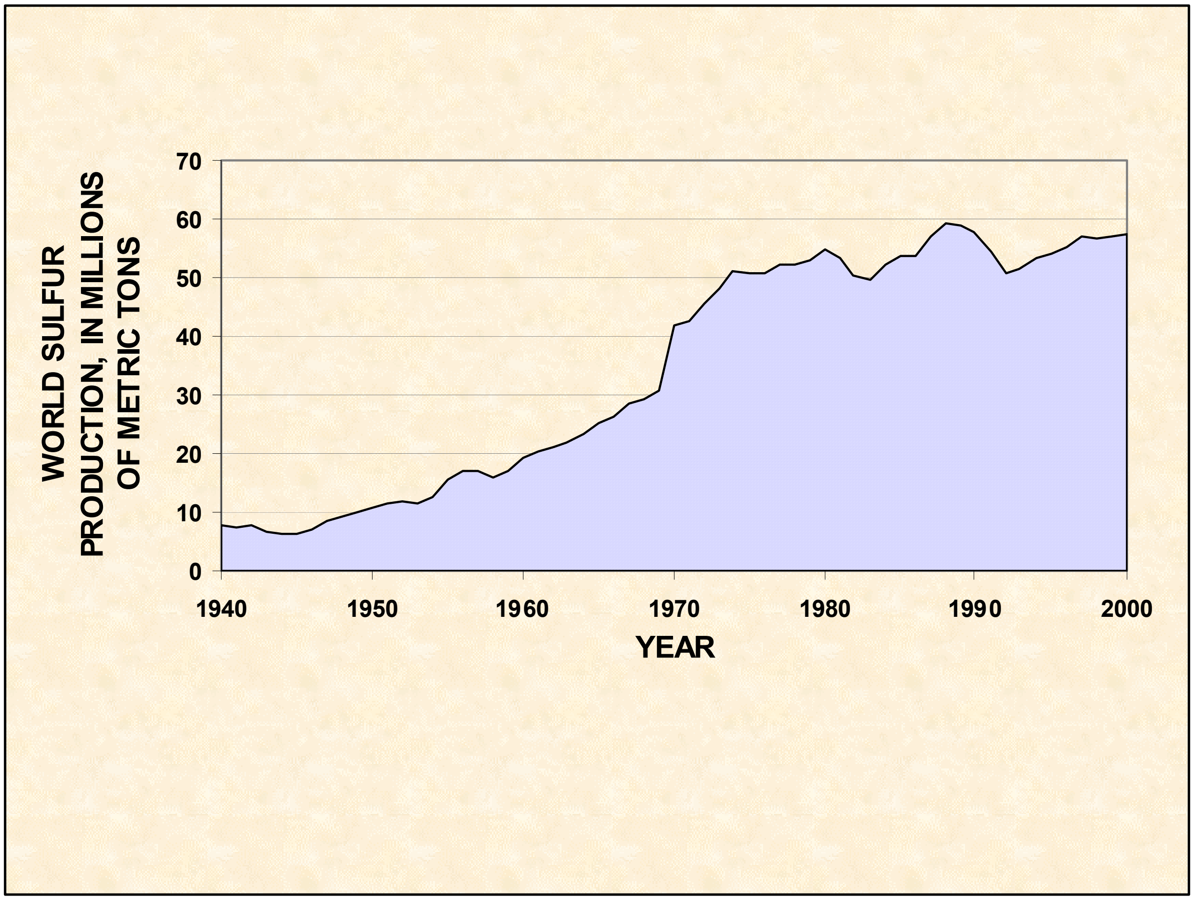

Figure G4. World sulfur production, 1940-2000 (data from Buckingham and Ober, 2001).

As the Frasch component of total world sulfur production continued to decrease, world byproduct production increased to fill this supply gap. In 1989, world byproduct sulfur production totaled 33.2 million tons and was about 56 percent of total world production (U.S. Bureau of Mines, 1995b). By 2000, world byproduct production had risen 49 percent to 49.5 million tons and represented approximately 87 percent of total world production (Ober, 2002).

The world byproduct[29] category is composed of the following: metallurgy; petroleum; natural gas, petroleum, tar sands, undifferentiated; and unspecified sources including coal gasification. Figure G5 represents the individual sulfur production from each of the major components and the overall totals within the byproduct sector.

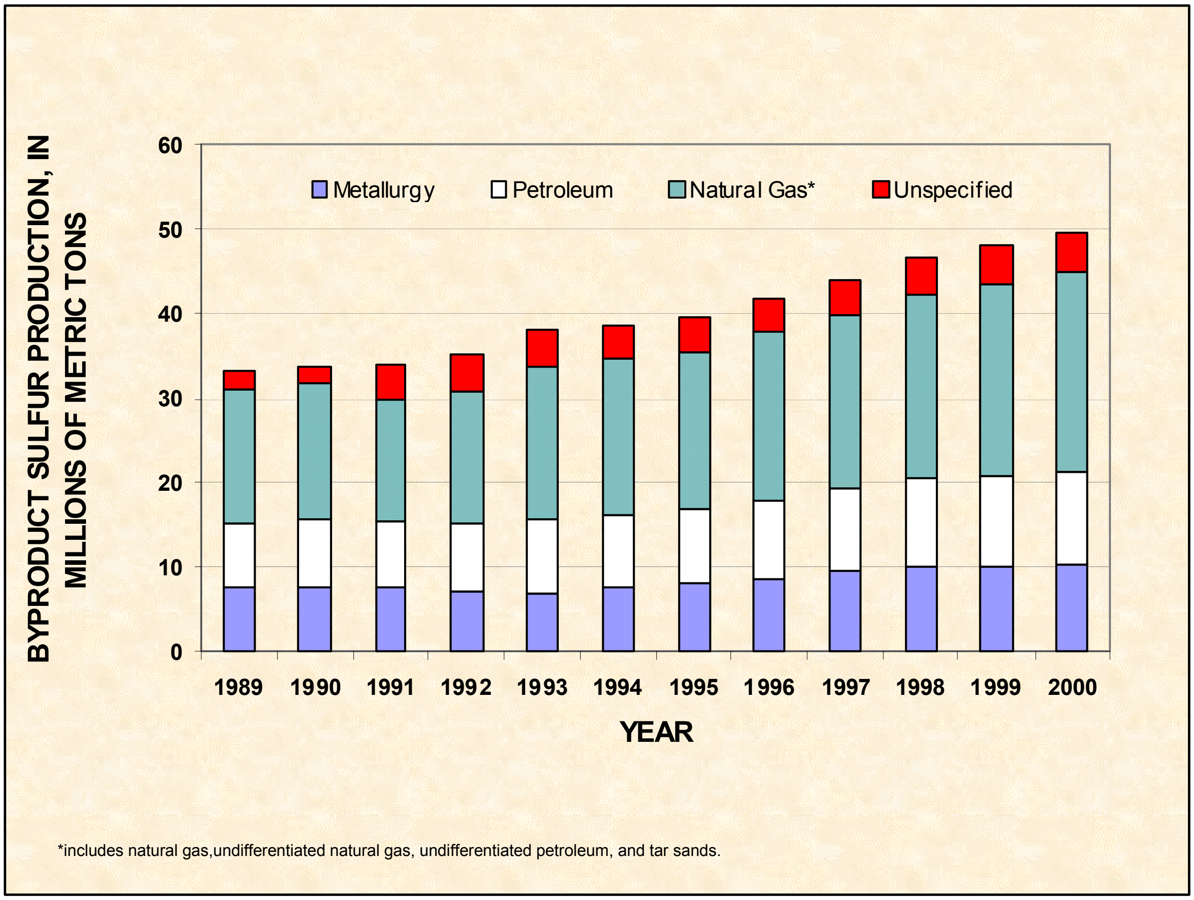

Figure G5. World byproduct sulfur production, 1989-2000 (data from Ober, 1997–2002 and 1995–96).

[29] The U.S. byproduct classification includes SO_2 off gases that are converted to sulfuric acid (H_2SO_4) from nonferrous roasters and smelters (metallurgical operations) and coal gasification (coking operations).

After rising to over 76 percent in 1945, domestic production of sulfur as a percent of world production had decreased to the low 20s in 1970 and in 2000, it was 18 percent (figure G6). This is a reflection of the stabilization of both domestic production as well as world production over the last three decades.

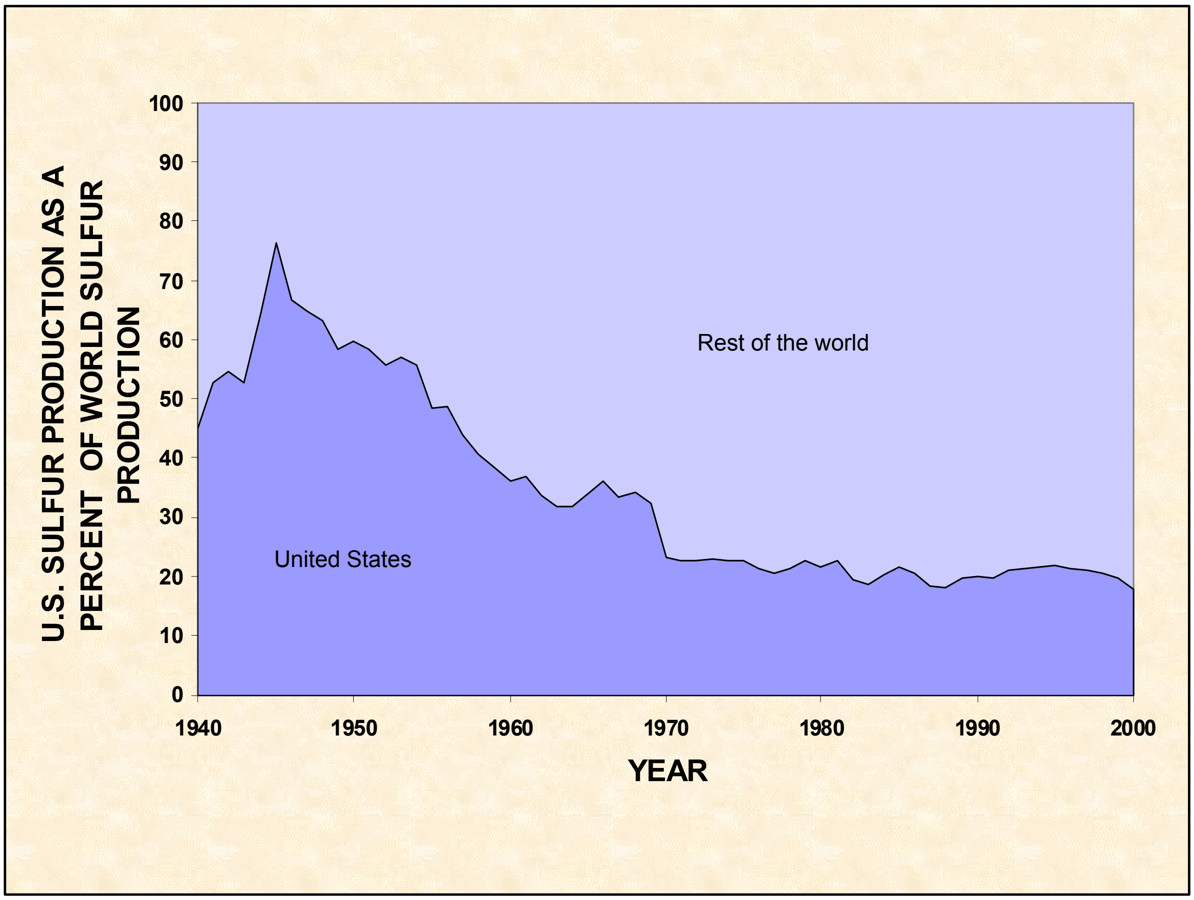

Figure G6. U.S. sulfur production as a percent of world sulfur production, 1940-2000 (data from Buckingham and Ober, 2001).

Reserves/resources

Sulfur resources are diverse and found worldwide. In addition to being found in its elemental state, various forms of sulfur are found in pyrites and natural gas as sulfides, in gypsum and anhydrides as sulfates, and in natural gas, petroleum and coal as complex sulfur compounds. These are all potential sources of sulfur, but they are not all necessarily economically viable. As a result of increased global pollution concerns, the refining of fuels to conform to environmental regulations has provided an increasing source of sulfur worldwide. Table G3 contains world total reserves and reserve base estimates for the last two decades.

Table G3. Sulfur reserves and reserve base estimates, in million tons of sulfur.

[Data from U.S. Bureau of Mines, 1981a and 1991a; and U.S. Geological Survey, 2001]

Countries	1980	1990		2000	
	Reserve Base	Reserves	Reserve Base	Reserves	Reserve Base
Canada	250	158	330	160	330
United States	175	140	230	140	230
Mexico	90	75	120	75	120
World total	1,760	1,400	3,500	1,400	3,500

Domestic usage

Acting as a barometer of industrial activity within the United States, the domestic apparent consumption of sulfur rises and falls parallel to economic cycles. Reviewing figure G7, the growth of U.S. apparent consumption has generally increased linearly over the 20th century. There were two significant growth periods, one in the early 1960s and another in the late 1970s.

Between 1963 and 1966, domestic consumption of sulfur was up over 37 percent. This large rise was a result of growing demands from the fertilizer industry, which were met by increased production and heavy withdrawals from producers' stocks (Ambrose, 1966). From 1976 through 1979, there was another large increase in domestic consumption of nearly 27 percent during this period. Once again, the fertilizer industry's demands were responsible for the majority of this increase.

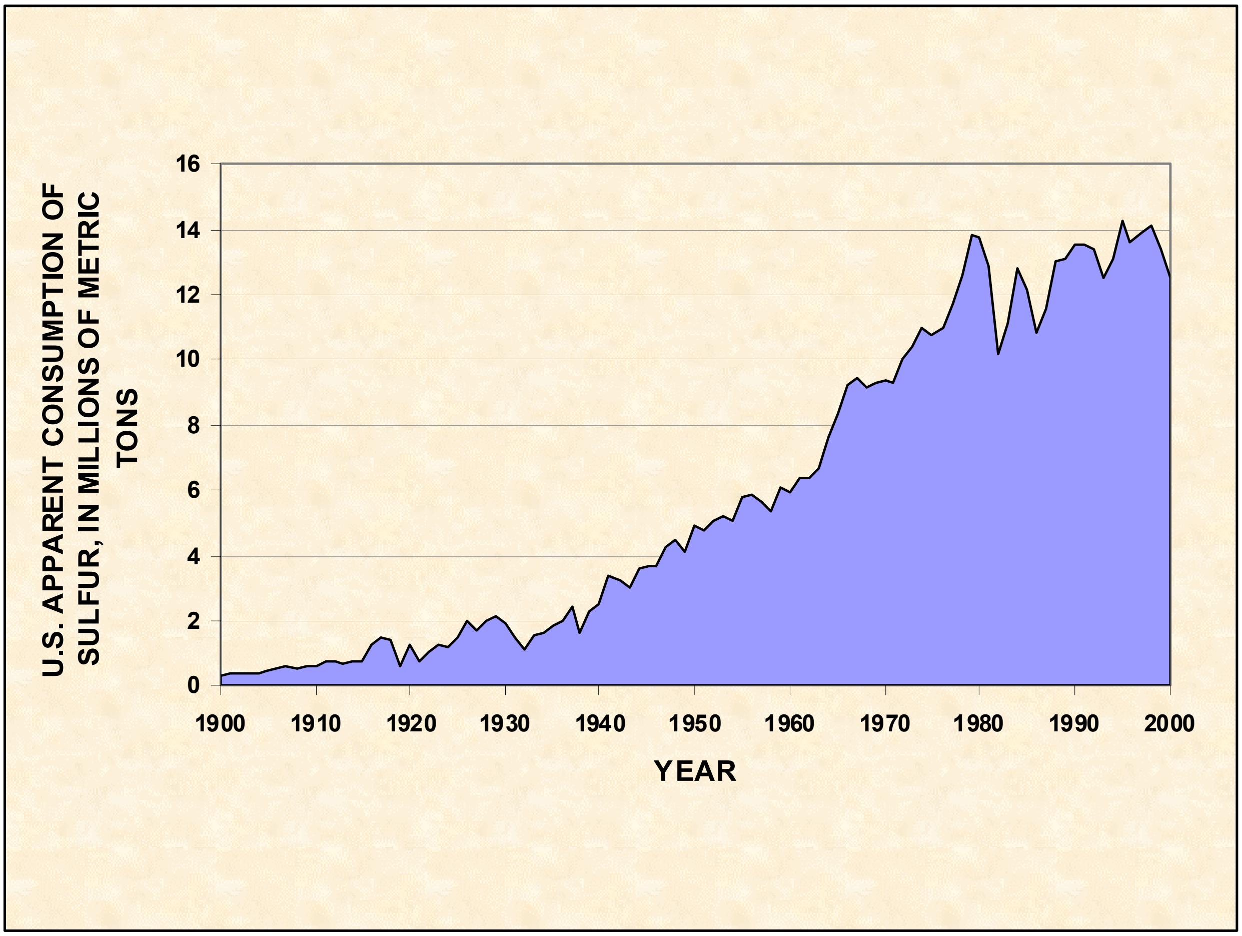

Figure G7. U.S. apparent consumption of sulfur, 1900-2000 (data from Buckingham and Ober, 2001).

Historically, the primary consumption of sulfur is associated with agriculture. In recent years, nearly 60 percent of all sulfur consumption is in the production of phosphate fertilizers with another 10 percent used in other agricultural applications, including the production of nitrogenous fertilizers and plant nutrient sulfur (Jasinski, Kramer, Ober, and Searls, 1999).

Sulfur is somewhat unusual considering that it is consumed in the form of an intermediate chemical (sulfuric acid), rather than being integrated into a final product like most mineral commodities. Sulfuric acid represented 77 percent of reported 2000 consumption associated with an identifiable end use (Ober, 2002). Also in 2000, end uses for sulfur listed by importance were agricultural chemicals (63 percent), petroleum refining and coal products (14 percent), copper ores (5 percent), and others making up the balance. Reviewing figure G8, the trends for all categories appear to be fairly consistent. However, the petroleum refining and coal products sector has shown a sharp increase in use of sulfur and sulfuric acid in the last several years. From 1994 (765 thousand tons sulfur content) to 2000 (1.96 million tons sulfur content), there was an increase of over 150 percent (Ober, 1997 and 2002). This large increase was due to high production in the petroleum refining industry during this time period, which is reflected by a greater demand for sulfuric acid[30] in the production of gasoline.

[30] This sulfuric acid is typically produced in an associated chemical processes at the petroleum-refining complex where sulfur was originally recovered as a co-product during the petroleum refining process.

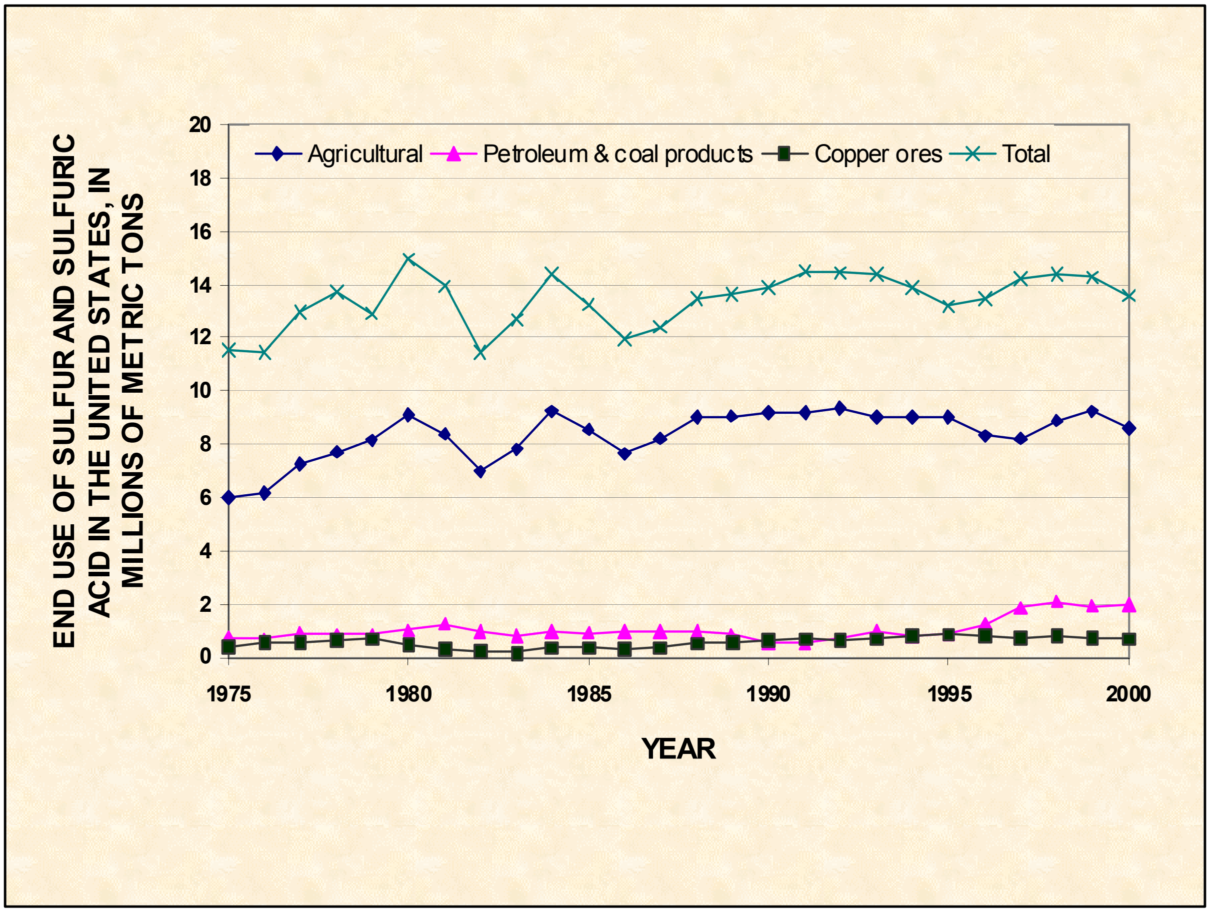

Figure G8. End use of sulfur and sulfuric acid in the United States, 1975-2000 (data from Ober, 1997–2002 and U.S. Bureau of Mines, 1978b–96b).

Globalization

In 2000, countries exporting more than one million tons of elemental sulfur each were Canada, Japan, Russia, Saudi Arabia, and the United Arab Emirates. They accounted for 64 percent of sulfur trade. International importers of more than one million tons of sulfur each were Brazil, China, India, Morocco, Tunisia, and the United States (Ober, 2002).

Reviewing figure G9, there are three apparent trade phases as the United States went from a net importer in the early 1900s to a net exporter for most of the middle of the 20th century and back to a net importer for the last several decades. Prior to 1917, elemental sulfur imports to the United States were relatively insignificant with the majority coming from Japan. Pyrites, which made up the bulk of total sulfur imports during this time frame, were primarily from Europe with Spain being one of the major exporters (Smith, 1920). When domestic production of elemental sulfur almost doubled from 1916 to 1917, the United States started its transition into a net exporter as the Frasch process enabled the continued expansion of major deposits in the Gulf of Mexico. In the final quarter of the 20th century, the United States became a net importer as it shifted away from production of domestic discretionary sulfur due to economics and imported considerably more non-discretionary sulfur supplied by Canada, who had become a major worldwide exporter of recovered sulfur from the production of its huge natural gas deposits[31]. In 2000, Canada provided 57 percent of U.S. imports of sulfuric acid, more than likely from byproduct smelter operations (Ober, 2002).

Sulfur is truly a global commodity in all aspects. Production of nondiscretionary sulfur in recent years has become more commonplace as many countries upgrade their gas and oil refineries and improve the capture of sulfur at their nonferrous metal smelters to meet environmental standards. Also, consumption of sulfur for the production of agricultural fertilizers has spread across international boundaries.

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[31] Wilburn, Goonan, and Bleiwas (2001) provide a more detailed discussion of the technologies involved with the recovery of sulfur from petroleum and natural gas.

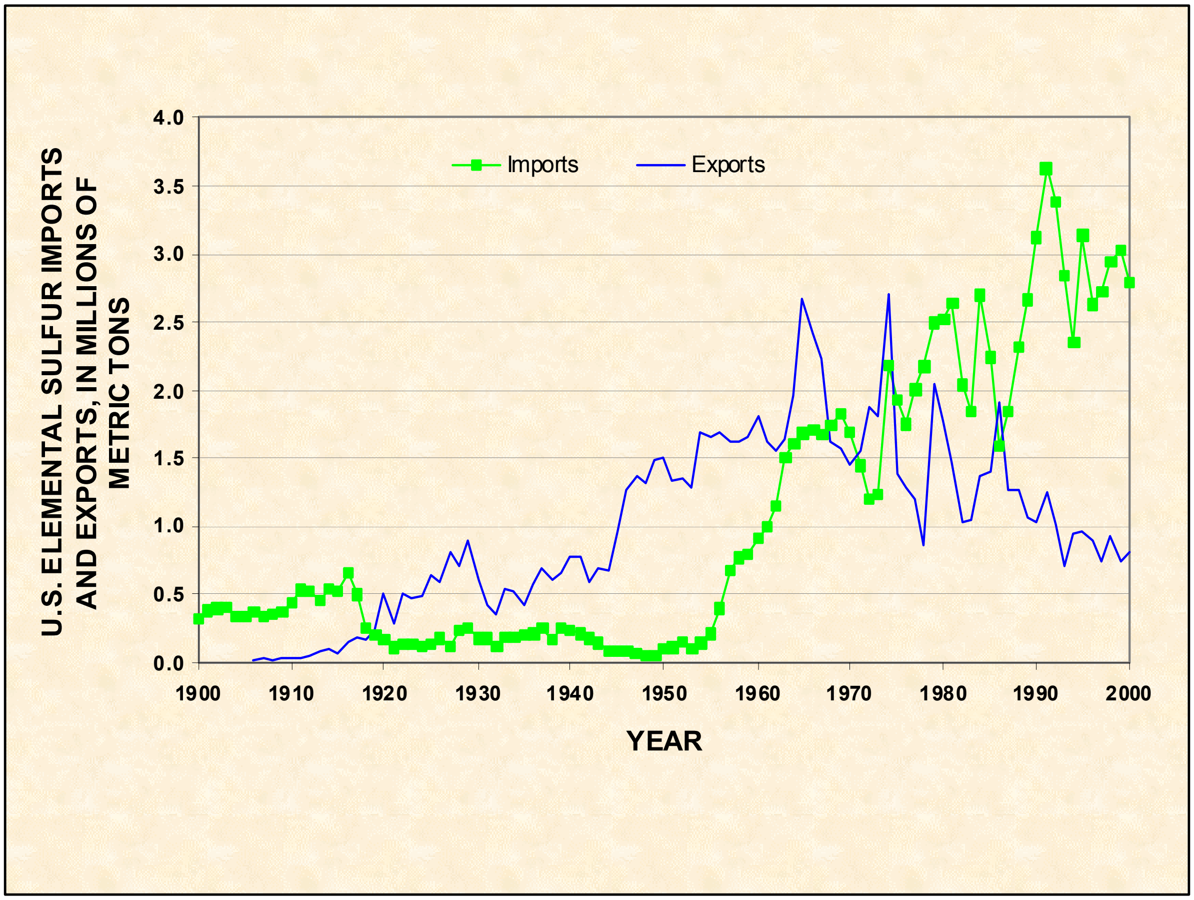

Figure G9. U.S. elemental sulfur imports and exports, 1900-2000 (data from Buckingham and Ober, 2001).

Productivity

From 1955 to 2000, the numbers of employees in domestic mines and/or plants[32] decreased approximately 41 percent (figure G10). Over this same time period, domestic production of sulfur increased 38 percent. The changes for both of these components of productivity were primarily the results of incremental advances in technology, which are a function of improving

[32] Employment numbers for the sulfur industry were reported for the first time in the 1962 Mineral Commodity Summaries for 1955 and later years (U.S. Bureau of Mines, 1962).

economic efficiencies. In the last decade, the productivity trend line in the sulfur industry has flattened as technological improvements have focused on "fine tuning" current processes that do not have a significant impact on increasing production amounts (figure G10).

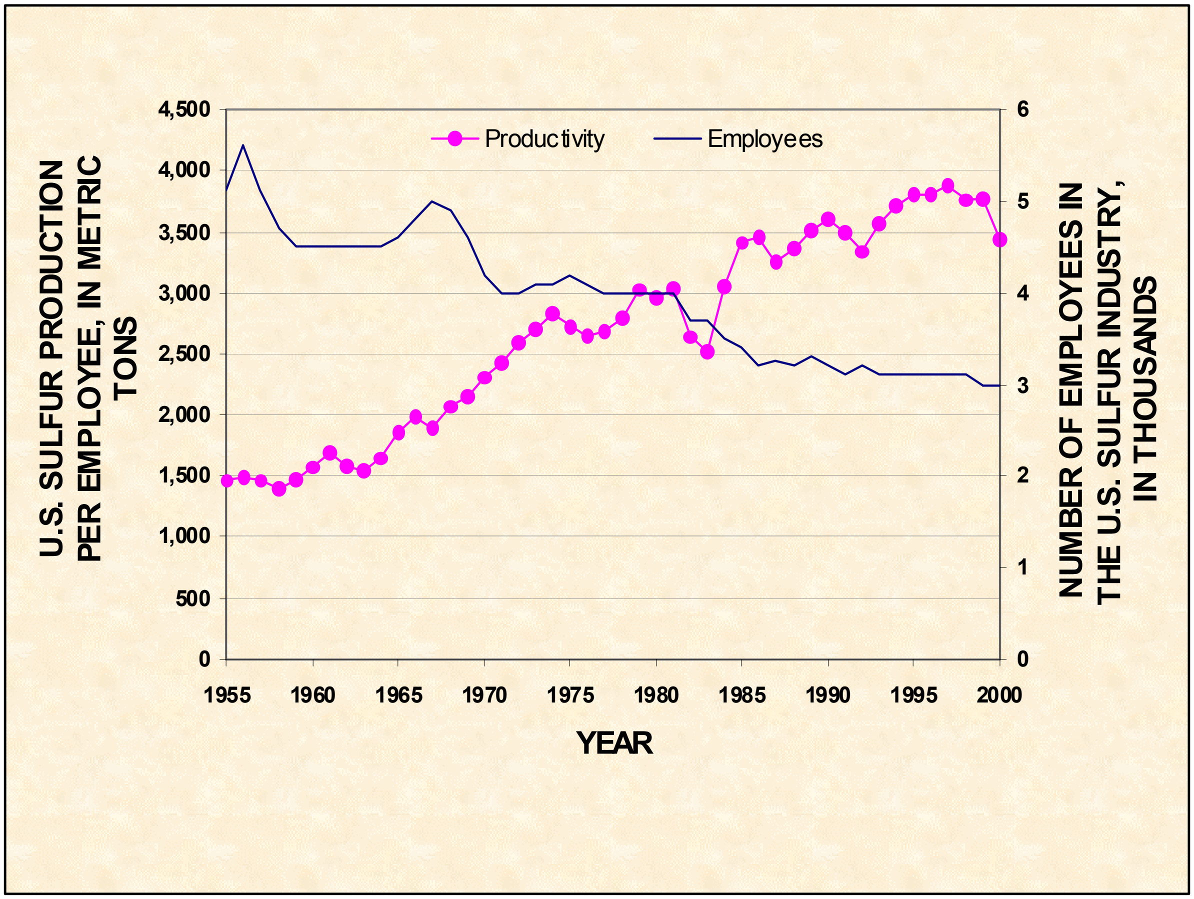

Figure G10. U.S. sulfur productivity and number of sulfur industry employees, 1955-2000 (adapted from U.S. Geological Survey, 1997–2001 and U.S. Bureau of Mines, 1962a–96a).

Costs

Today, the recovery of nondiscretionary sulfur from fossil fuels is mandated by the government and carries a monetary cost that is passed on to the consumer. Over the last century, operating costs for discretionary sulfur varied greatly depending on factors such as size of operation, deposit location, geology, and mining and processing methodology. Even though price is not the same as cost, when cost data is not available, price data can be used as a crude proxy for costs. However, it is important to keep in mind that other factors (such as profit) are also included in the price, which is not included in the cost estimates. Therefore price is usually (but not necessarily always) somewhat higher than costs. Current day domestic costs for mining pyrites are not available because this source of sulfur is no longer economically competitive.

Conclusions

Over the last century, the most significant trend associated with elemental sulfur has been on the supply side as discretionary mining of sulfur deposits has yielded to the nondiscretionary recovery of sulfur from oil and natural gas refining. In addition, after being a major source of sulfur at the beginning of the 20th century, global production of pyrites has almost been eliminated because of related environmental and cost concerns.

Demand for sulfur, particularly for the manufacturing of agricultural fertilizers is expected to continue throughout the world to help feed the ever-expanding global population. International demand for sulfuric acid as an intermediate chemical should also continue as long as it maintains its low cost profile in the chemical industry.

In the future, new applications may be developed that incorporate sulfur as a low cost raw material. Thus, technological progress can provide additional markets for sulfur producers as they face the potential global oversupply due to countries upgrading their manufacturing and refining operations to eliminate sulfur-associated pollutants.

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