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Total Materials Consumption

An Estimation Methodology and Example Using Lead—A Materials Flow Analysis

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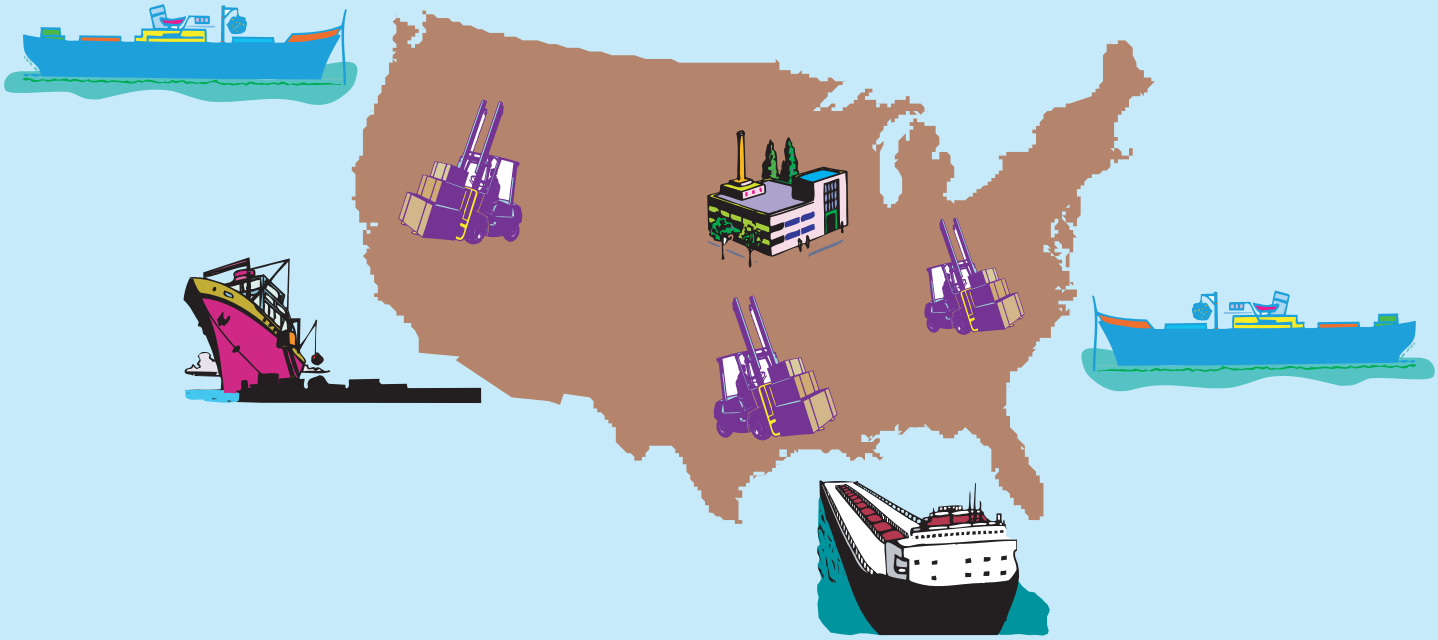

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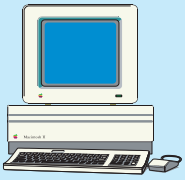
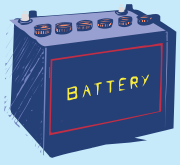
Monitors 

Batteries 

Glassware 

U.S. Department of the Interior
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By Marilyn B. Biviano, Daniel E. Sullivan, *and* Lorie A. Wagner

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U.S. Department of the Interior
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Abstract

Materials consumption estimates, such as apparent consumption of raw materials, can be important indicators of sustainability. Apparent consumption is estimated as production of the raw material plus the difference between imports and exports, plus or minus changes in its stocks. However, apparent consumption of raw materials does not account for material contained in manufactured products that are imported or exported. When imports and exports of manufactured goods that contain the material are significant, apparent consumption may under- or over-estimate total consumption of materials in the domestic economy, depending on the net direction of trade.

A methodology to measure the amount of material contained in net imports (imports minus exports) was developed by the U.S. Department of Commerce (DOC) in consultation with the U.S. Geological Survey (USGS), and is demonstrated with lead as an example. The methodology builds upon a technique used by the U.S. Department of Defense to estimate strategic material requirements and utilizes the gross domestic product, input-output techniques, raw materials consumption by industrial sector, and net imports of manufactured products by industrial sector. This analysis illustrates the DOC-USGS methodology, presents illustrations of differences between apparent and total consumption of lead, and further distributes these differences into individual lead-consuming sectors.

An estimate of the 1993 total consumption of lead in the United States, including lead contained in the net imports of manufactured products, was 1.45 million tons,[1] 14 percent above the apparent consumption of raw lead. Future projections of U.S. lead consumption show that by the year 2003, total lead consumption will be more than 1.6 million tons. Nearly all of this increase was attributed to the projected increase in lead contained in imported products, specifically, lead-acid batteries. When the per capita apparent consumption of lead is projected to 2003, the United States is decreasing its per capita lead consumption. However, when projecting total per capita lead consumption, which includes lead contained in net imports of manufactured products, the United States appears to be increasing its per capita consumption to 5.7 kilograms per person, a 2.3 percent increase from the 1993 level.

Introduction

Materials flow is the study of materials use and how it affects society, the economy, and the environment from extraction, through production, consumption, and final disposition. Published statistics on materials consumption, for example, apparent consumption of unprocessed raw material (U.S. Geological Survey, 1998), do not account for raw materials contained in manufactured products imported to, or exported from, the United States. As U.S. imports of manufactured goods have increased over time, omitting the materials contained in these goods may result in a significant measurement error of consumption and, perhaps more importantly, of the observed trend in materials consumption.

Some available material consumption estimates suggest that mature economies such as the United States are "dematerializing," that is, are consuming less material on a per capita basis (World Resources Institute, 1997). However, some of these estimates of U.S. materials consumption reflect only domestic consumption of unprocessed raw materials and do not include materials contained in imports of manufactured products. Imported products include direct consumables such as products sold in retail stores and intermediate goods which are used as inputs to production by industry. As the United States becomes more of a service-based economy and imports more manufactured goods, not accounting for the consumption of materials contained in imported goods will result in increased underestimating of our consumption of materials. On the other hand, raw

[1] In this report, all tons are metric.

materials included in products that are exported are not consumed in the United States and should not be included in U.S. materials consumption data.

A methodology to estimate the amount of materials contained in imported and exported goods has been developed using macro-economic and input-output tools. As an application of the methodology, the U.S. consumption of lead was investigated. The total consumption of lead includes lead consumed in all forms (examples include automobiles, batteries, and glass). Apparent consumption only accounts for domestic production of the commodity lead modified by imports and exports and stock changes of the commodity. As this does not account for the domestic consumption of lead that is imported as part of a manufactured product, and does include as domestic consumption lead that is exported as part of another product, the apparent consumption estimate does not necessarily give an accurate picture of the real domestic consumption of lead.

Methodology

The methodology developed to estimate the materials contained in imports to, and exports from, the United States builds upon a technique used by the U.S. Department of Defense to estimate strategic material requirements (Krueger, 1976, p. 21–32). Figure 1 illustrates the methodology proposed to estimate the materials contained in net imported products. Gross Domestic Product (GDP), the Input-Output (I-O) table, the raw materials consumption by industrial sector, and net imports of manufactured goods by industrial sector are all used to estimate material requirements for net imports. Note that to simplify the analysis, the U.S. I-O table is used as a proxy to estimate the inputs used in goods manufactured in other countries and imported into the United States.

Gross Domestic Product. GDP is the sum of all final expenditures for personal consumption; gross private domestic investment; Federal, State, and local government; and net exports (International Monetary Fund, 1997, p. xxiii). It can also be derived by either summing income or by summing value added (either by industry, firm, or establishment).

Input-Output Table. The I-O table represents the structure of the economy by utilizing a matrix of transactions between industries (Miernyk, 1965; Miller and Blair, 1985). This transactions matrix shows interindustry purchases and final sales to users and shows the amount of inputs required by an industry to produce its output. Detailed I-O tables for the United States generally contain 500 or more industrial sectors. A hypothetical example of a simplified I-O table is shown in Appendix 1.

Translation of Industry Contribution to GDP to Total Gross Output by Industry. The first step in determining the materials component of net imports of manufactured products is to develop total gross output by sector for the relevant year. This is done by using the industry contribution to GDP, and with the I-O table, translating this amount to the total gross output by industry. Total gross output by industry represents the total dollar value of outputs produced by each industry. It is the sum of each industry's value of output sold to consumers (final demand) and the dollar value of its output sold to other industries and used as inputs in their products.

Raw Material Consumption by Industry (s). Raw material consumption by industry is the quantity of material consumed by an industry. It is the quantity of material required by an industry to produce its output. The U.S. Department of Commerce provided estimates of lead consumed by the major domestic lead-consuming industries (Henry, 1997).

Raw Material Consumption Ratio (r). The material consumption ratio defines a relationship between the value of economic output and physical material consumed. It is the quantity of material consumed by an industry per dollar value of total gross output for that industry for a particular year. The "r" for each industry (for example, the battery industry) is derived by dividing the quantity of material (such as lead) consumed by that industry by the total gross output of that industry.

Translation of Imports and Exports to Total Gross Output by Industry. The next step is to translate imports and exports by GDP sector to the total gross output using the I-O table. The result is the total gross output required to produce imports (and exports) domestically. Even though technologies are not the same between countries, it is assumed for this study that an imported item and a domestically produced item are produced by similar methods and that inputs to the process are used in the same proportions. This may result in some differences.

Material Consumed in Net Imports of Manufactured Products (Q). The next step is to estimate the material used to produce net imports of manufactured products (imports less exports). First, material consumption is estimated for net imports for each industry by multiplying the industry "r" by the total gross output by industry for net imports. Total consumption is then estimated as the sum of material consumed in net imports plus apparent consumption of raw material.

Mathematical Expression

Mathematically this methodology can be expressed as shown following. Variables by industrial sector are shown in lower case.

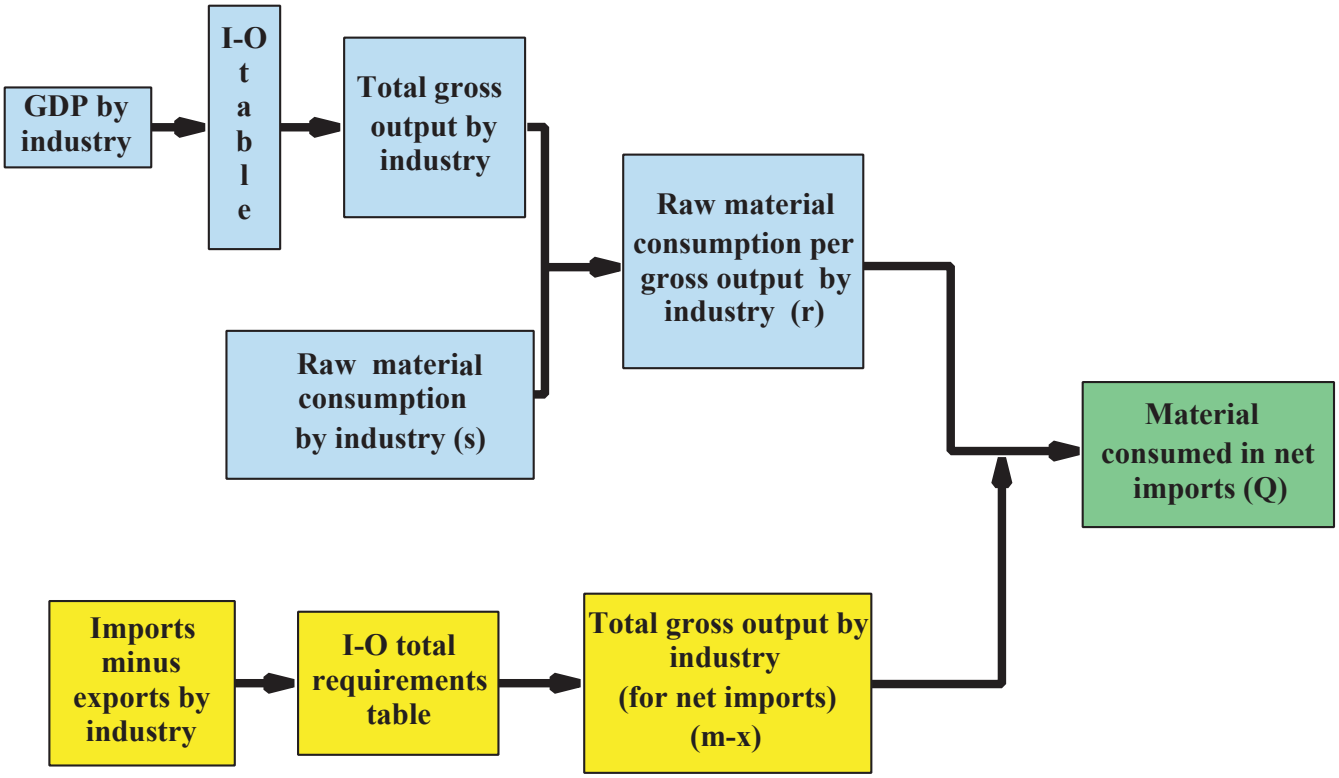

Figure 1. Generalized methodology for estimating the quantity of materials contained in net imported products.

$$Q = \sum_{i=1}^{k} [(m_i - x_i) r_i] \quad (1)$$

$$S = \sum_{i=1}^{k} s_i \quad (2)$$

$$T = S + Q \quad (3)$$

where

Q = quantity of material contained in net imports of manufactured products (tons)

m_i = value of industrial output required to produce imported goods for each material-consuming industry (dollars)

x_i = value of industrial output required to produce exported goods for each material-consuming industry (dollars)

r_i = raw materials consumption ratio, that is, physical material consumption divided by the value of industrial output for each material-consuming industry (tons/dollars)

s_i = raw material consumption by industrial sector (tons)

S = raw material consumption for all industrial sectors (tons)

T = total material consumption (tons)

and

$i = 1 \rightarrow k$, where k is the number of material-consuming industries

and

$$A = C + (P - E) \pm \Delta V \quad (4)$$

where

A = apparent raw material consumption

C = domestic raw material (primary and secondary) production

P = imports of raw material

E = exports of raw material

ΔV = inventory change (of raw material)

Estimating Total Lead Consumption[2,3]

Apparent domestic consumption of lead as a raw material (not including net imports of manufactured products) for 1993 was estimated at 1.26 million tons.[4]

[2]David Henry, U.S. Department of Commerce, performed the calculations for the lead application using the methodology developed in conjunction with the USGS and using the University of Maryland's Iliad input-output model.

[3]Gerald Smith, USGS lead commodity specialist, contributed to the interpretation of the consumption trends.

[4]All numerical data in this report are from the working draft, *Procedure to estimate total U.S. consumption of raw materials, including raw materials embedded in imports and exports*, by David Henry, Office of Business and Industrial Analysis, Economics and Statistics Administration, U.S. Department of Commerce, and may differ somewhat from comparable USGS data.

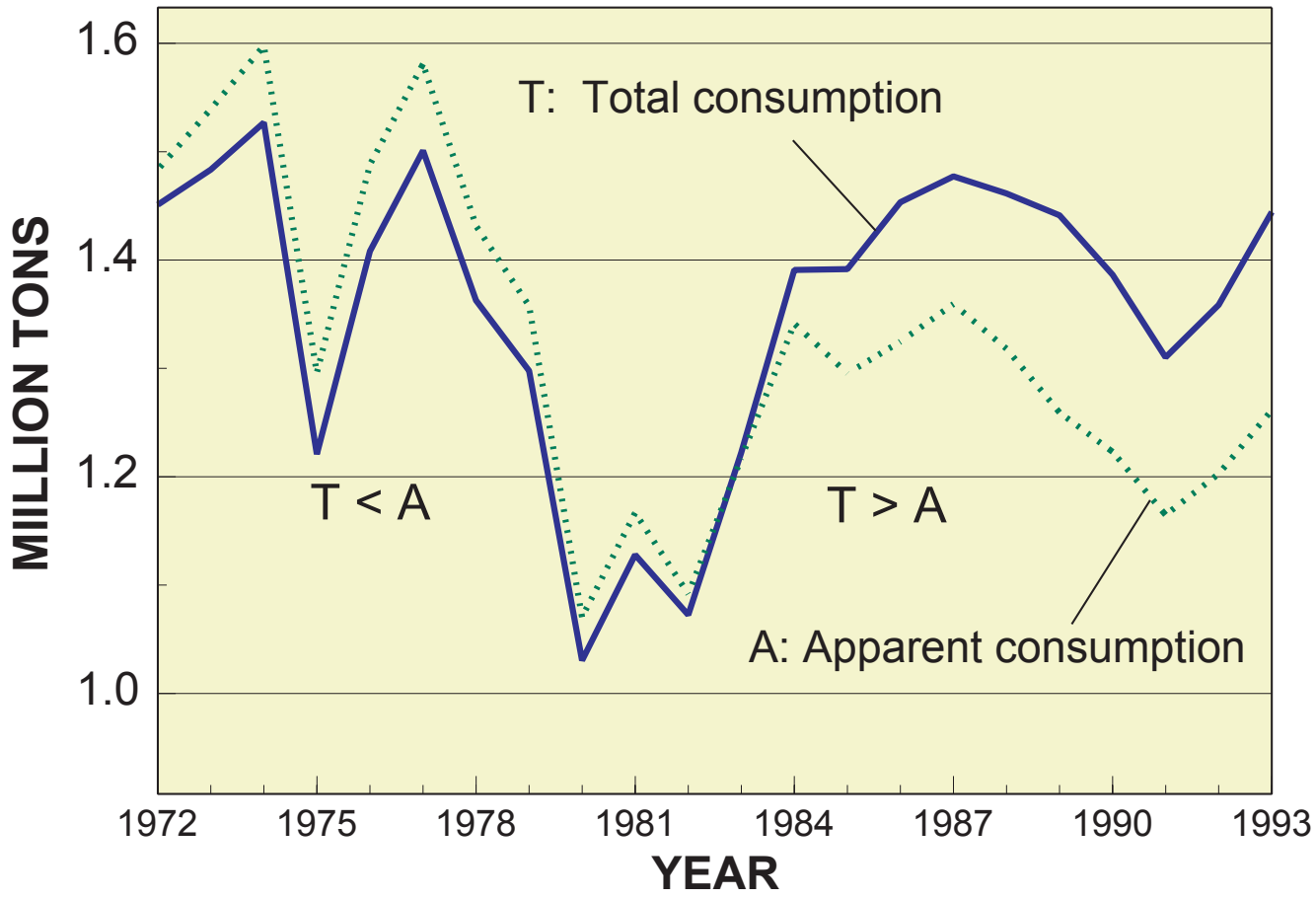

Figure 2. U.S. consumption of lead.

After excluding lead contained in products that are exported, such as batteries and automobiles, and including lead contained in imported products, the U.S. total consumption of lead for 1993 is estimated to be 1.44 million tons, a 14 percent increase above the estimate of lead raw material (domestic industrial consumption).

Figure 2 compares apparent (raw material) lead consumption with total consumption (which includes lead contained in net imported products). It shows several trends and a reversal of trend in lead consumption in the United States. Between 1972 and 1982, lead contained in exports exceeded lead contained in imports so that the estimate for lead consumption without including net imports of products containing lead was 2 percent to 6 percent higher than the estimate that included net imports. In 1983, lead in imported products began to exceed lead in exported products so that total lead consumption "T" exceeded apparent lead consumption "A," which does not include lead in imported products, by a gradually increasing amount, reaching 14 percent in 1993.

The consumption of lead, when net imported products containing lead are included, was around 1.44 million tons for both 1972 and 1993. In the intervening years, it increased to almost 1.53 million tons in 1974 and declined to about 1 million tons in 1980. The low consumption of lead in 1975 was the result of a general business recession. The trough between 1977 and 1984 was the result of a drop in the consumption of lead because of health concerns and adjustment to the cost of environmental controls in addition to the two recessions that occurred between 1980 and 1981. The low in the early 1990's reflects the last recession. During the period shown in the figure, trends in the consumption of lead by the major lead-consuming industries changed dramatically. In spite of these fluctuations, by 1993 total lead consumption regained its 1972 level.

The consumption of lead per capita is shown in figure 3. This figure is similar to figure 2, except that per capita consumption has declined over the 22-year period, 1972-93, for both apparent consumption "A" and total consumption "T," which includes lead contained in net imported products. Per capita apparent consumption declined from about 7 kilograms to about 5 kilograms over the 22-year study period; per capita total consumption declined from about 7 kilograms to about 5.6 kilograms.

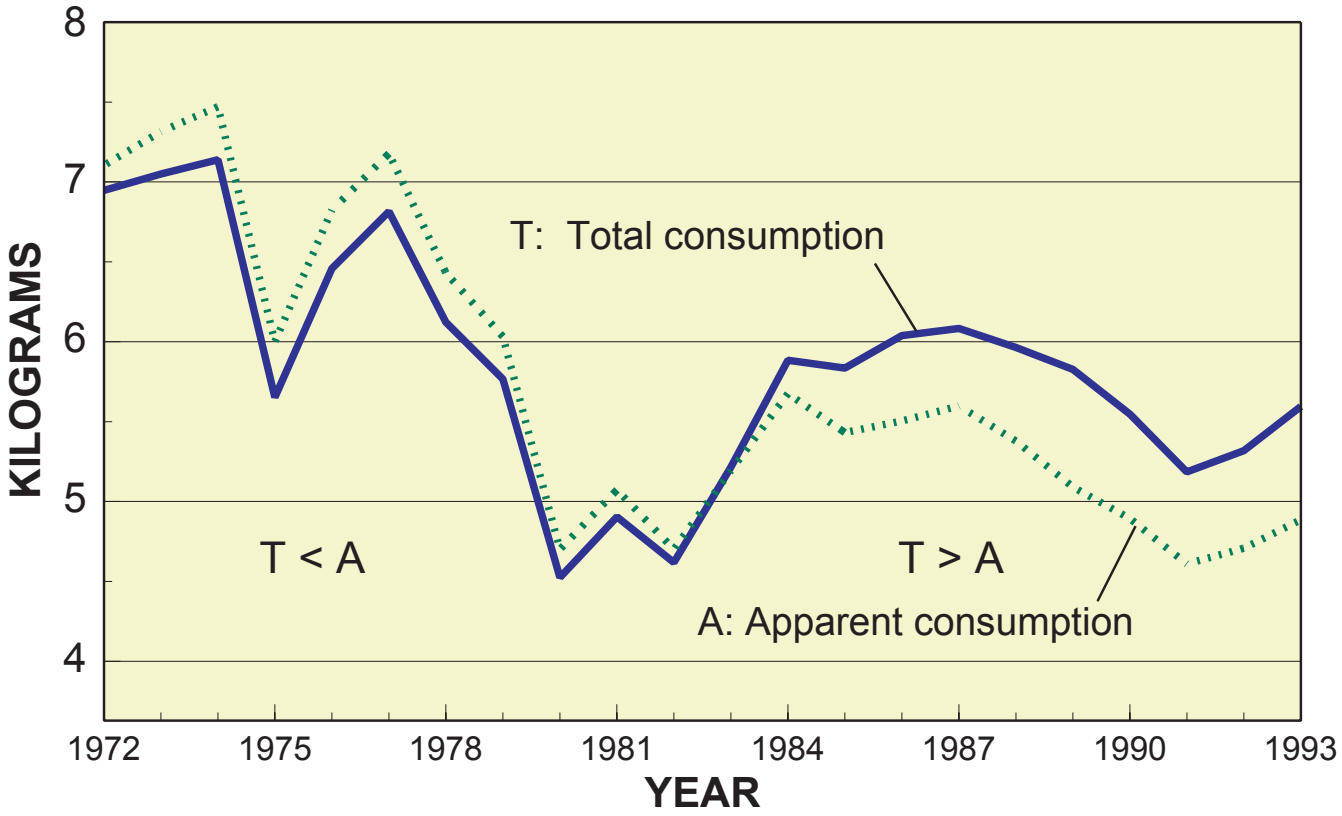

Figure 3. U.S. consumption of lead per capita.

Figure 4 shows the total consumption of lead per million dollars of GDP. The dramatic decline in lead per current dollar GDP reflects inflation in the U.S. economy rather than a sharp drop in lead consumption. However, the constant dollar ratio has declined more than 40 percent over the period. It shows that lead use per dollar of real GDP has fallen at about 2.4 percent per year from 1972 to 1993.

Figure 5 shows that the lead consumption pattern has changed dramatically. In 1972, the major consuming industries were lead-acid storage batteries (50 percent), dissipative uses (gasoline additives, ammunition, paints and allied products, and industrial inorganic chemicals) (20 percent), and all other uses (30 percent). By 1993 dramatic decreases in the consumption of lead by some industries had taken place (see Appendix 2 for details). In 1993, the consumption of lead as a gasoline additive dropped to zero, the use of lead in paints and allied products decreased more than 80 percent, the use of lead in brass and bronze mill products decreased more than 90 percent, and lead use in ammunition decreased by more than 30 percent. Two of the major lead consuming industries (glass and ceramic products and, most notably, lead-acid storage batteries) increased their consumption of lead. In 1972, lead-acid batteries accounted for 50 percent of domestic consumption; in 1993, the lead-acid battery industry accounted for 84 percent of lead consumption.

Over the study period (1972–93), lead consumption changed in relation to (1) the quantity of lead used to produce a given level of output, (2) the level of output of domestic lead-consuming sectors, and (3) the level of lead-containing imports and exports. Further, for most of the major lead-consuming industries, the consumption of lead per dollar value of output has declined. To better understand the reasons for the observed trends in lead consumption and to gather insight to project future consumption, an analysis of each major lead-consuming sector was performed. This analysis is provided in Appendix 2.

Future Lead Consumption

The projection of future lead consumption is based on an industry-by-industry analysis of lead consumption and respective trends. In the industry-by-industry analysis,we found that for most industries, U.S. lead consumption declined during the study period (1972–93). A noted exception to this decline is the increase in the consumption of lead in lead-acid batteries. Because of the very different trends taking place in lead consumption, the projections for lead consumption shown in this report are the sum of two projected components: (1) lead used in lead-acid batteries and (2) lead used in other applications.

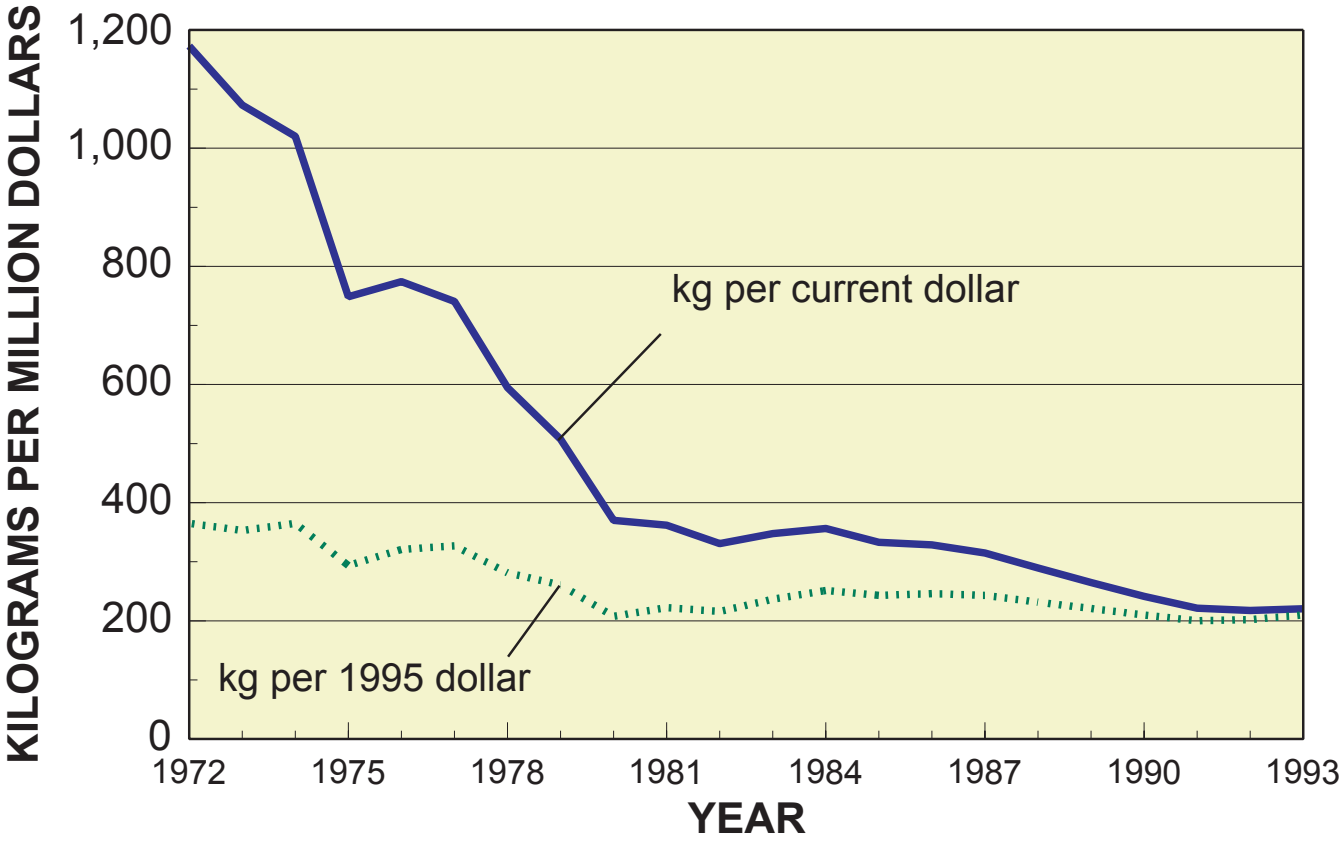

Figure 4. U.S. consumption of lead per unit of GDP.

Lead-acid batteries are presently the predominant use of lead (about 85 percent of the lead used in the United States). In addition, lead consumed in batteries has increased, especially within the most recent 10 years for which published data are available. Most of this increase results from lead contained in imported batteries. Using a simple method to project future lead consumption, we estimated that domestic consumption of lead in batteries, including the lead contained in imported batteries, will increase 14 percent by the year 2003 to near 1.4 million tons. This estimate was made using the average annual growth rate over the period 1983–93 (1.3 percent) for lead consumption in batteries (including refined lead and lead contained in imported products). This projection methodology does not attempt to account for changes in technology, economic conditions, or other such variables.

Virtually all of the growth in the projected lead consumption for batteries is the result of the increase estimated for lead contained in imported batteries. By 2003, apparent consumption in batteries is estimated to be more than 1 million tons (fig. 6). Total lead consumption, which includes apparent lead (raw material) consumption and the lead contained in net imports of batteries, is estimated to be about 34 percent greater than apparent consumption in 2003. Thus, if apparent consumption alone were used to measure U.S. consumption of lead in batteries, consumption would be underestimated by one-third; and a slightly negative trend, rather than an annual growth trend of 1.3 percent, would be projected.

The second component of the U.S. lead consumption projection is the use of lead in products other than batteries, including ammunition, paints, glass and ceramics, brass and bronze metal, gasoline additive, and industrial inorganic chemicals. On average, over the last 10 years analyzed in this study, 1984–93, consumption of lead in the nonbattery applications declined by 6 percent, that is, the growth rate was a negative 6 percent. Because many industries have eliminated lead in their products, such as gasoline and paint, and therefore their projection of lead consumption in nonbattery applications can decline no more, it is assumed that nonbattery consumption of lead does not decline further but rather remains at the 1993 level of 226 thousand tons.

The resulting projections of total U.S. lead consumption are illustrated in figure 7. By the end of the projection period, the year 2003, domestic consumption of lead, including the lead contained in net imported products, will be more than 1.6 million tons, 12 percent higher than the 1993 level. Total lead consumption in all applications is projected to be about 28 percent greater than apparent lead (raw material) consumption in 2003. Note that the entire estimated increase

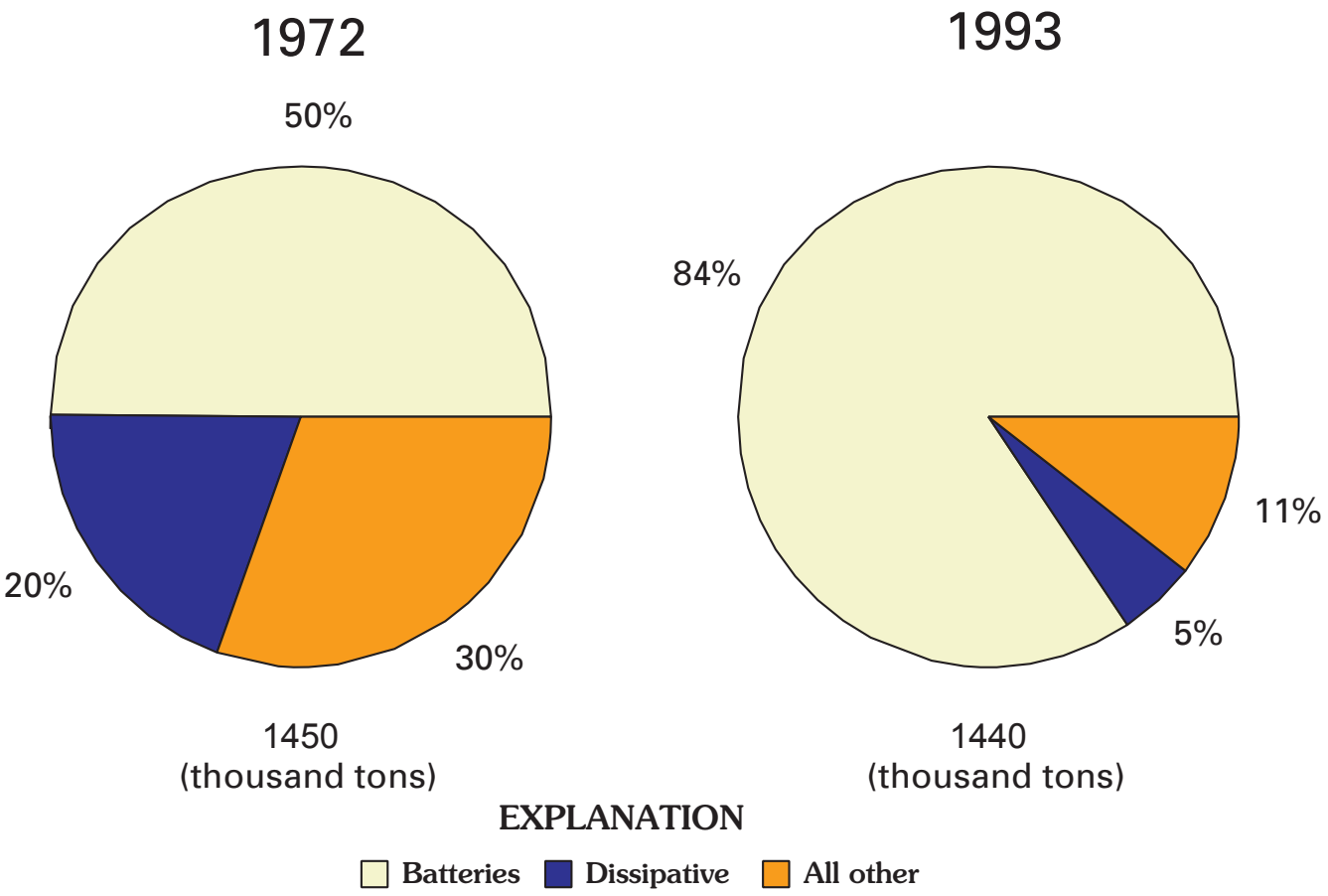

Figure 5. U.S. lead consumption pattern, including lead contained in net imports of manufactured products. Dissipative uses include gasoline additives, ammunition, paints and allied products, and industrial inorganic chemicals. All other uses include construction, synthetic rubber, glass and ceramic products, brass and bronze mills, and other metallic applications.

in consumption is attributed to the projected increase in lead contained in imported products, specifically, lead-acid batteries. Like the results just presented for lead consumption in batteries, if apparent consumption alone were used to measure U.S. consumption, consumption would be underestimated by 28 percent and a slightly negative trend projected, rather than an annual growth trend of 1.1 percent. The gap between total and apparent consumption increases from about 180 thousand tons in 1993 to more than 350 thousand tons in 2003.

Using the projections of apparent and total U.S. consumption of lead and future U.S. population figures estimated by the U.S. Bureau of the Census (U.S. Bureau of the Census, 1996), the resulting per capita consumption projections are illustrated in figure 8. The gap between total and apparent consumption widens between 1993 and 2003, and the trends of total and apparent consumption are in opposite directions. By the end of the projection period, the year 2003, per capita apparent consumption of lead (which excludes the lead contained in net imported products) declines to less than 4.5 kilograms, an 8.5 percent decline from the 1993 level. Per capita consumption of total lead, however, shows a modest increase to 5.7 kilograms, a 2.3 percent increase from the 1993 level. Thus, by the end of the projection period, per capita consumption estimates differ by more than 1.2 kilograms; total per capita consumption is 28 percent higher than apparent per capita consumption. Using the measure of apparent consumption alone, it would appear that the United States is projected to decrease its per capita lead consumption, but using the total consumption measure, which includes imported products containing lead, the United States is projected to increase its per capita consumption.

Conclusions

The results of using the methodology show that total 1993 consumption of lead in the United States, including lead contained in the net imports of manufactured products,

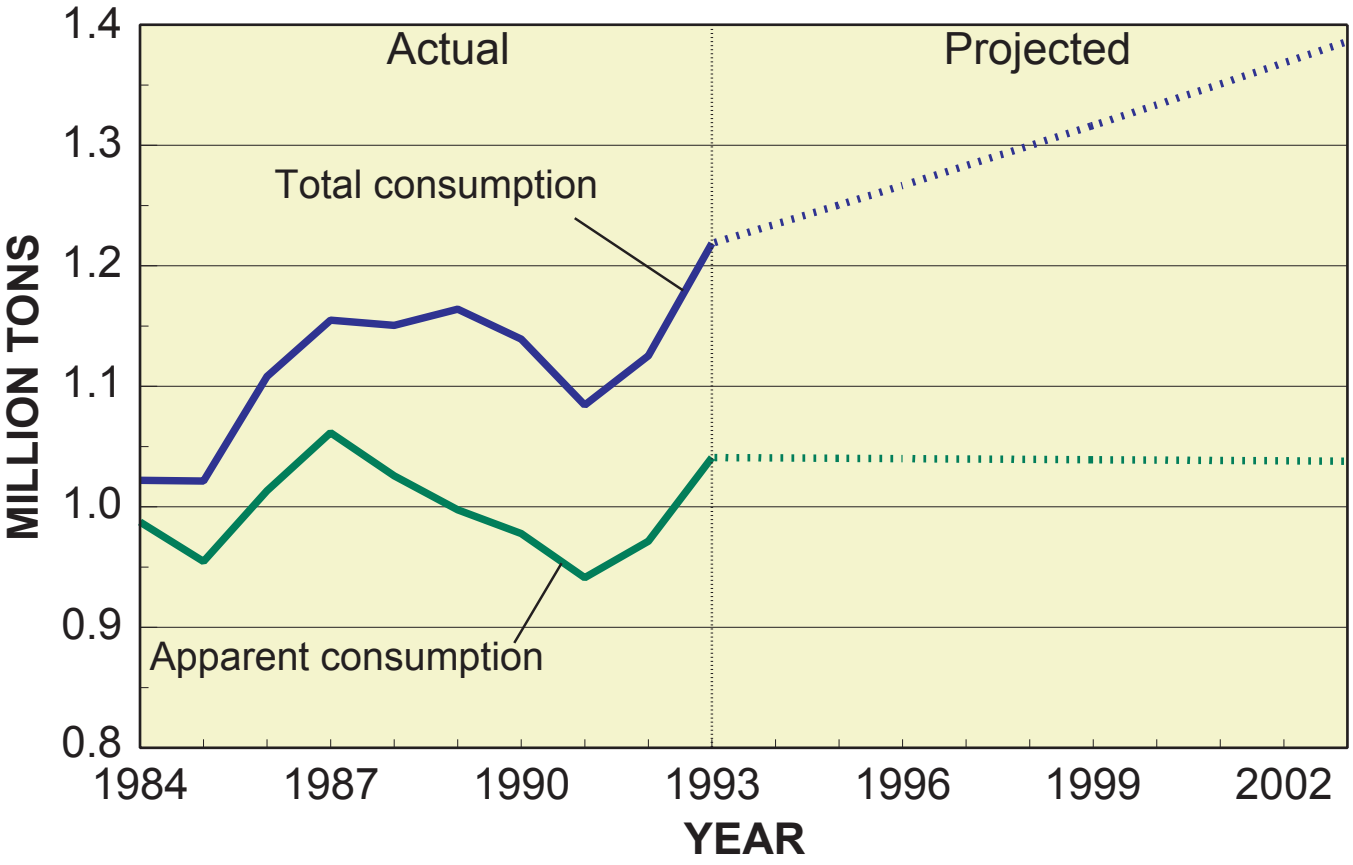

Figure 6. U.S. lead consumption in lead-acid batteries with projections to 2003.

was 1.45 million tons, 14 percent above the apparent consumption of raw lead only. This analysis shows that when imports and exports of manufactured products are significant (as in the case of lead), a truer estimate of total materials consumption can be gained by including an estimate for raw materials contained within manufactured products that are imported or exported. The methodology can be applied to materials flows of other commodities to yield better estimates of materials consumption and more valid indicators of a commodity's sustainability.

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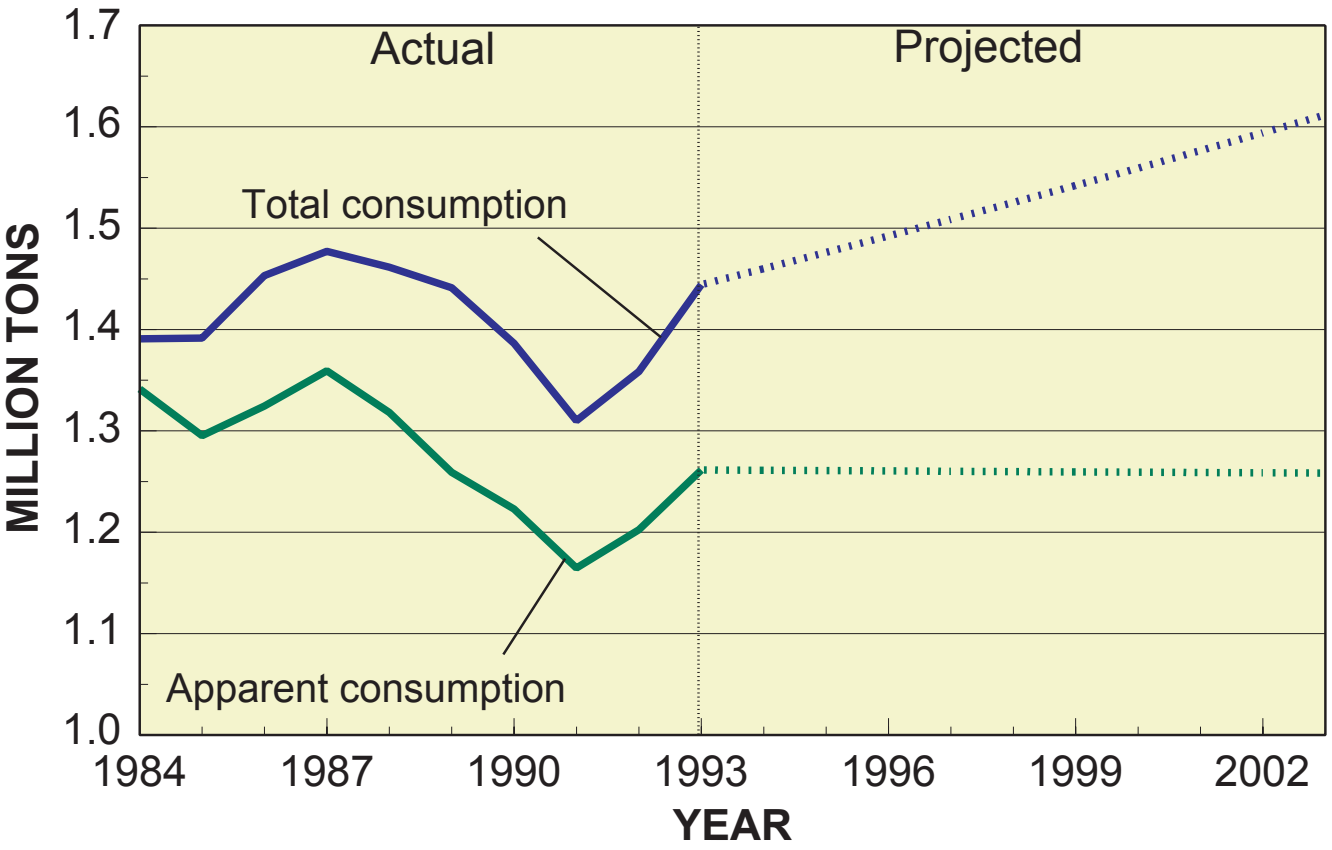


Figure 7. U.S. consumption of lead with projections to 2003.

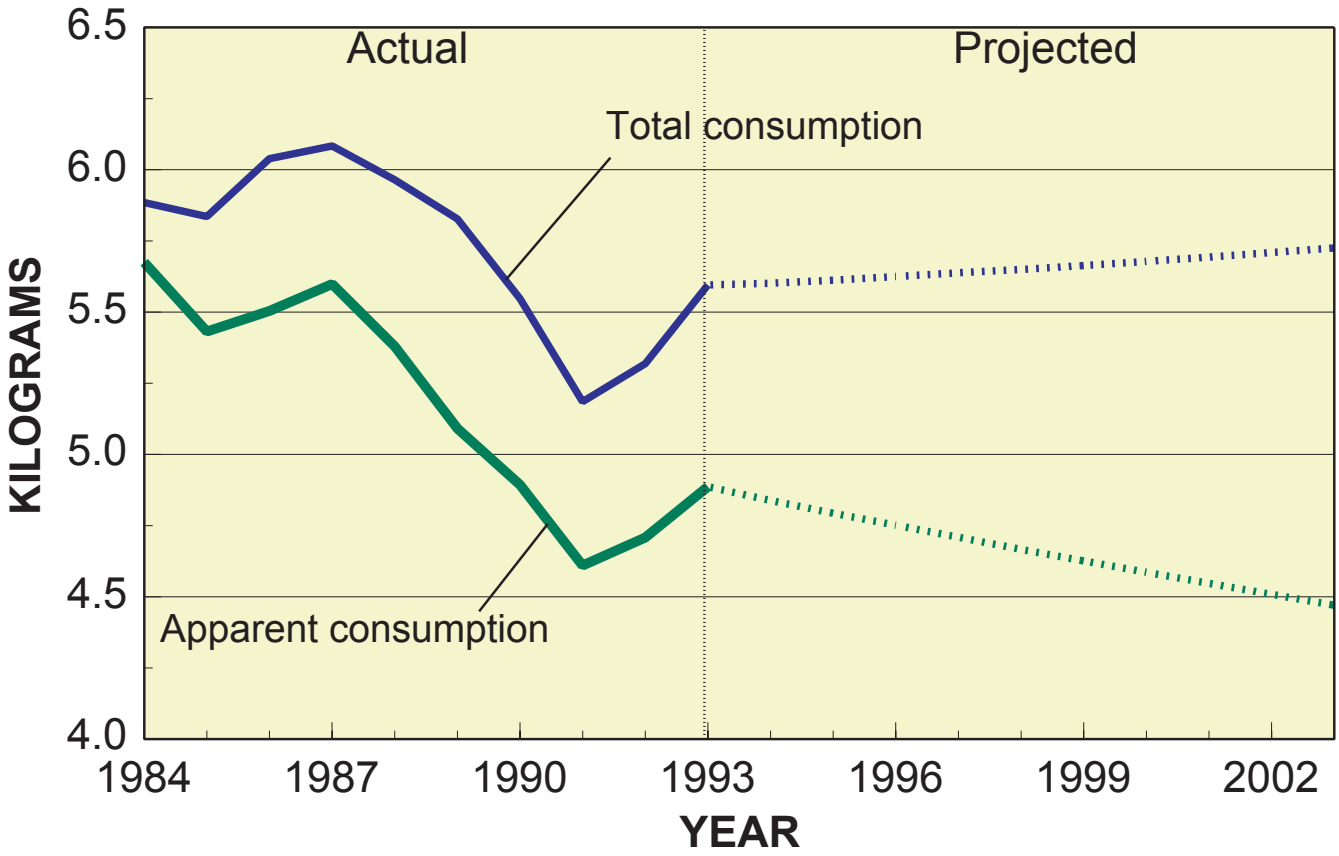


Figure 8. U.S. consumption of lead per capita with projections to 2003.

Appendix 1. Hypothetical Input-Output Table

Table 1 is an example of an I-O table using hypothetical data. As shown by the table, Industry A purchases $44 of inputs and produces $44 of output. The purchases of Industry A are shown in the Industry A column. They consist of $10 of inputs from Industry A, $5 from Industry B, $7 from Industry C, and $22 of value added items such as compensation to labor, depreciation of capital equipment and buildings, and payments to the government. The distribution of

Table 1. Example I-O table using hypothetical data (in dollars)

	Industry A	Industry B	Industry C	Final demand	Total gross output
Industry A	10	15	1	18	44
Industry B	5	4	7	34	50
Industry C	7	2	8	13	30
Value added	22	29	14	65	
Total gross input	44	50	30		124

the products of Industry A are shown in the Industry A row. They consist of $10 purchased by Industry A, $15 purchased by Industry B, $1 purchased by Industry C, and $18 consumed by the final demand sector, which consists of household and government consumption, the formation of capital, inventory change, and net exports.

Total final demand and total value added are equal and represent Gross Domestic Product (GDP) for the economy, $65. The final demand by sector represents the industry sales for final consumption that is part of GDP final demand. For example Industry B contributed $34 to GDP. The value-added figure for each industry in row four is the contribution of each industry to GDP.

Appendix 2. Analysis of Lead Consumption by Lead-Consuming Industries

As noted in the text, David Henry, U.S. Department of Commerce, performed the calculations for the lead application using the methodology developed in conjunction with the USGS and using the University of Maryland's Iliad input-output model. All data in this report are from the working draft, *Procedure to estimate total U.S. consumption of raw materials, including raw materials embedded in imports and exports*, by David Henry, Office of Business and Industrial Analysis, Economics and Statistics Administration, U.S. Department of Commerce.

Ammunition. Lead used in ammunition was almost 6 percent of total U.S. consumption in 1993. Figure 9 shows U.S. consumption of lead in ammunition products from 1972 through 1993. Consumption was approximately 24 thousand tons less in 1993 than it was in 1972. It had declined more than 43 thousand tons in the early 1980's and has been generally recovering since then. The United States is a net exporter of ammunition; therefore, apparent consumption is higher than total consumption, which includes imports of ammunition products. Figure 10 shows lead consumption in terms of tons per million 1987 dollars of output by the U.S. ammunition industry. Consumption was 82 tons per million dollars of output in 1972, rose to a high of more than 115 in 1977, and has remained less than 54 since 1983. In 1993,

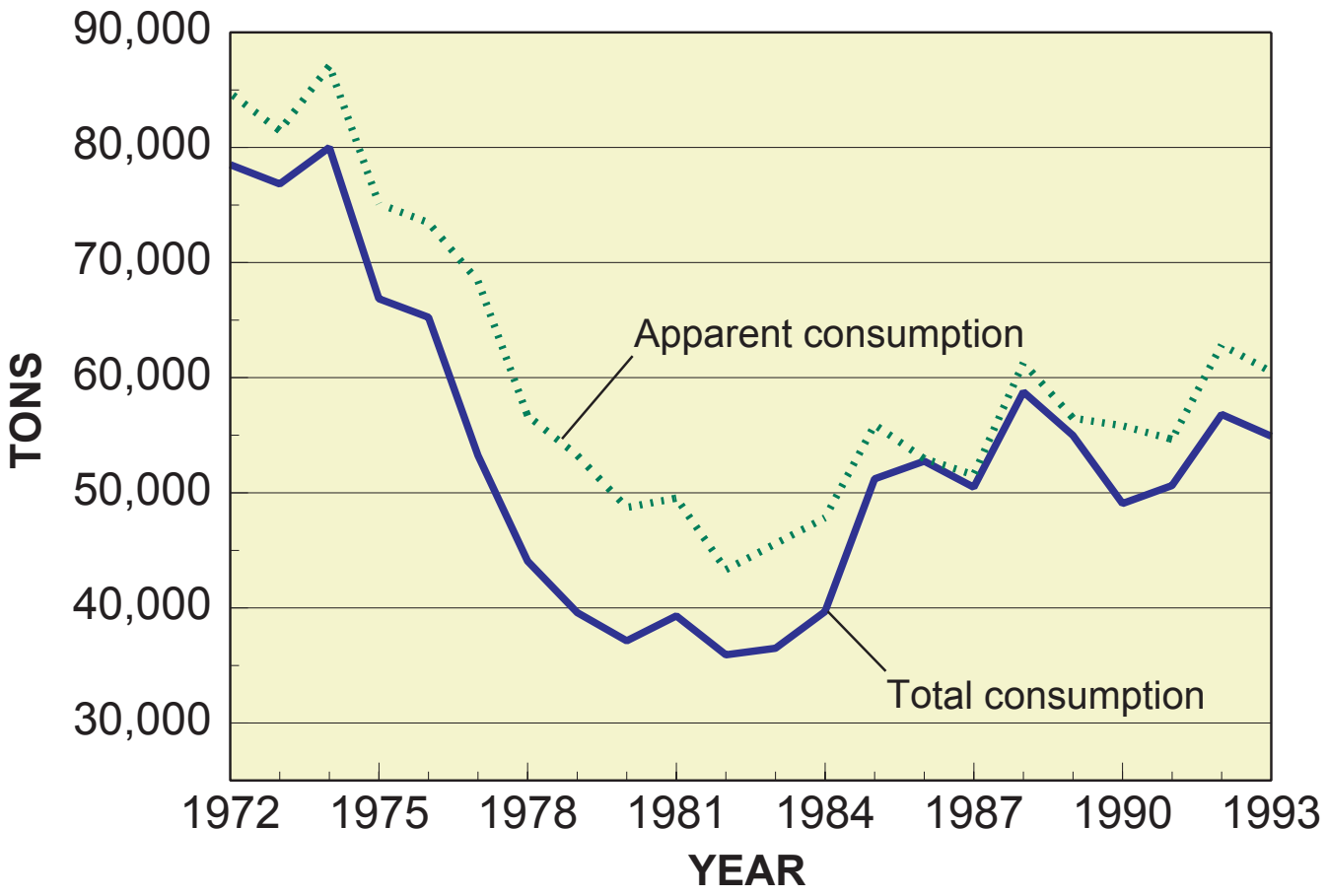


Figure 9. Lead consumed in ammunition products.

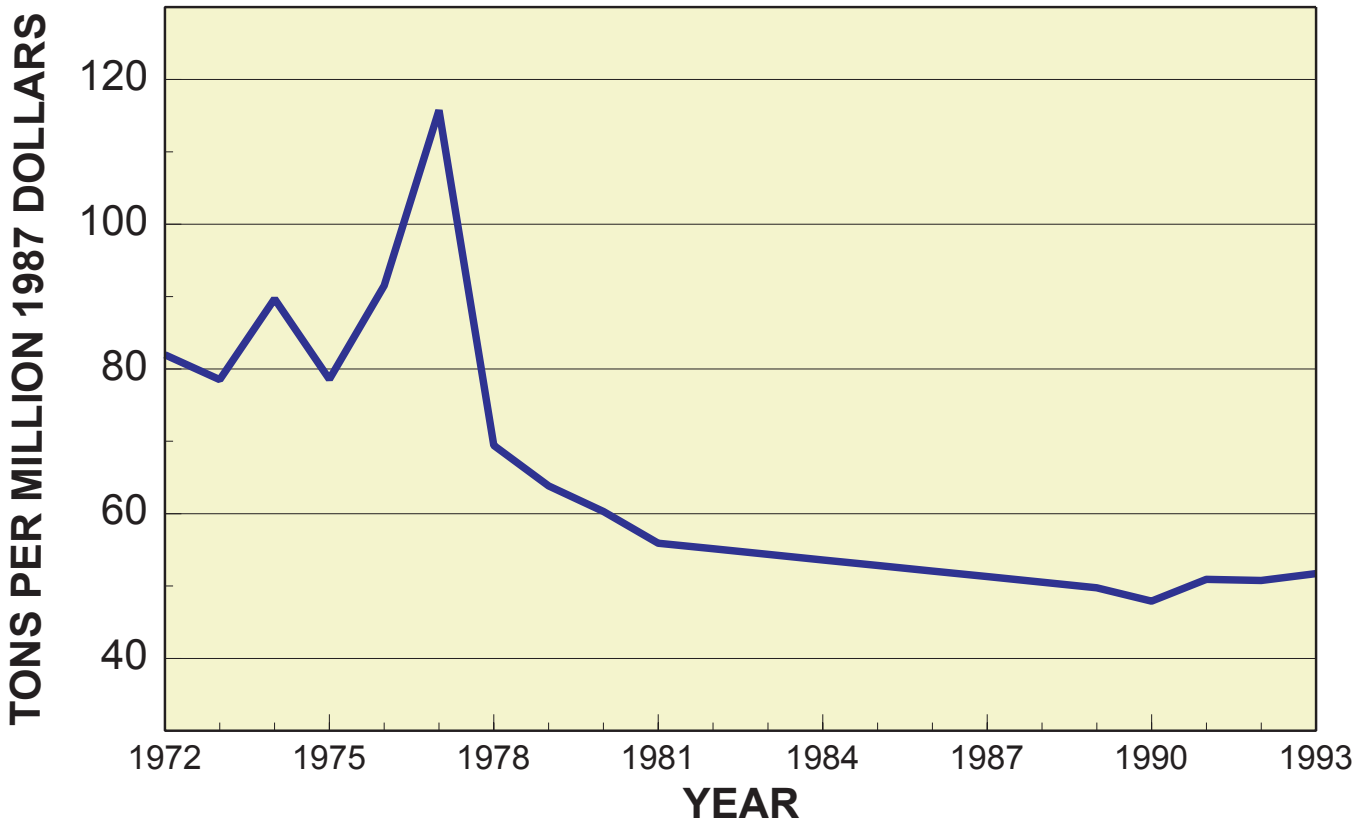


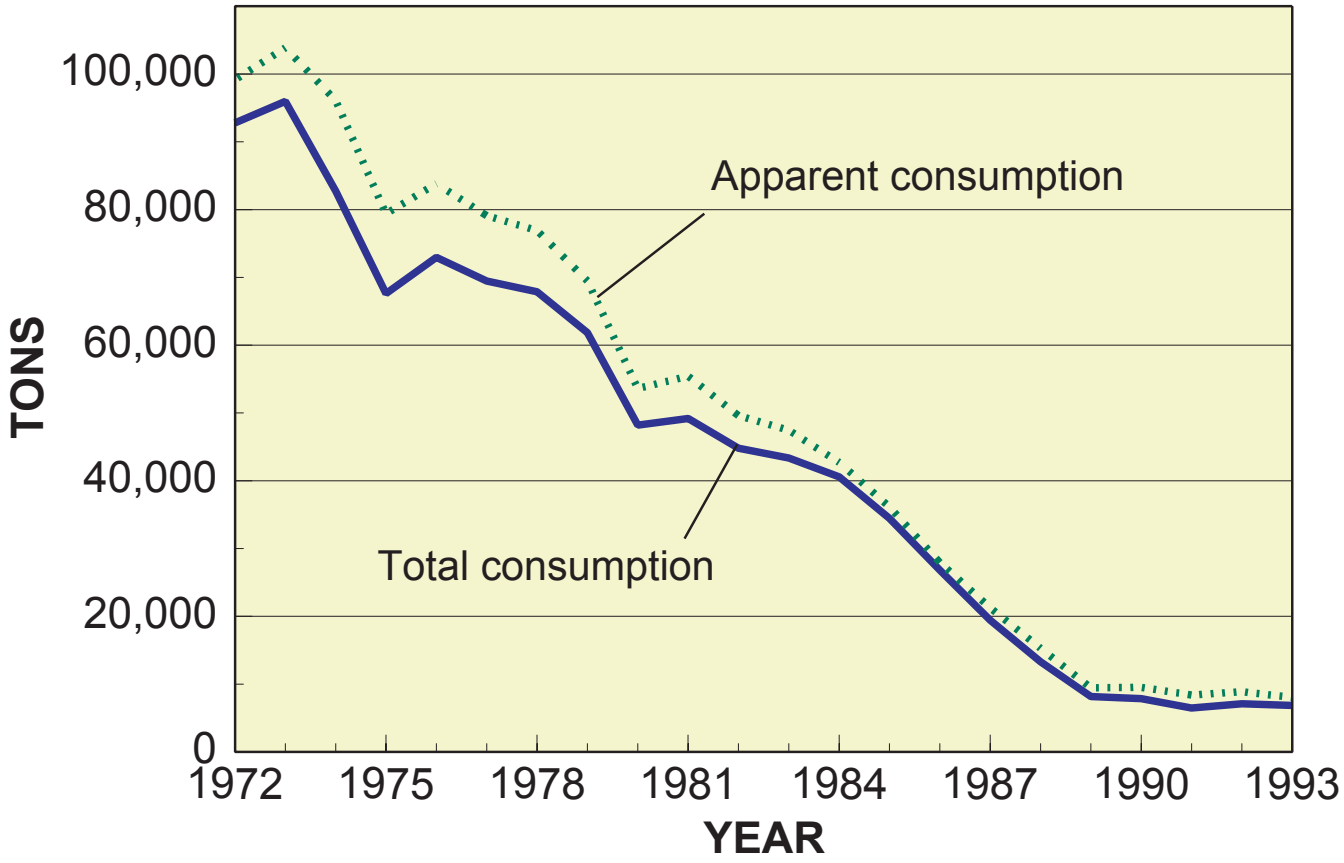
Figure 10. Lead consumption by the U.S. ammunition industry relative to industry output.

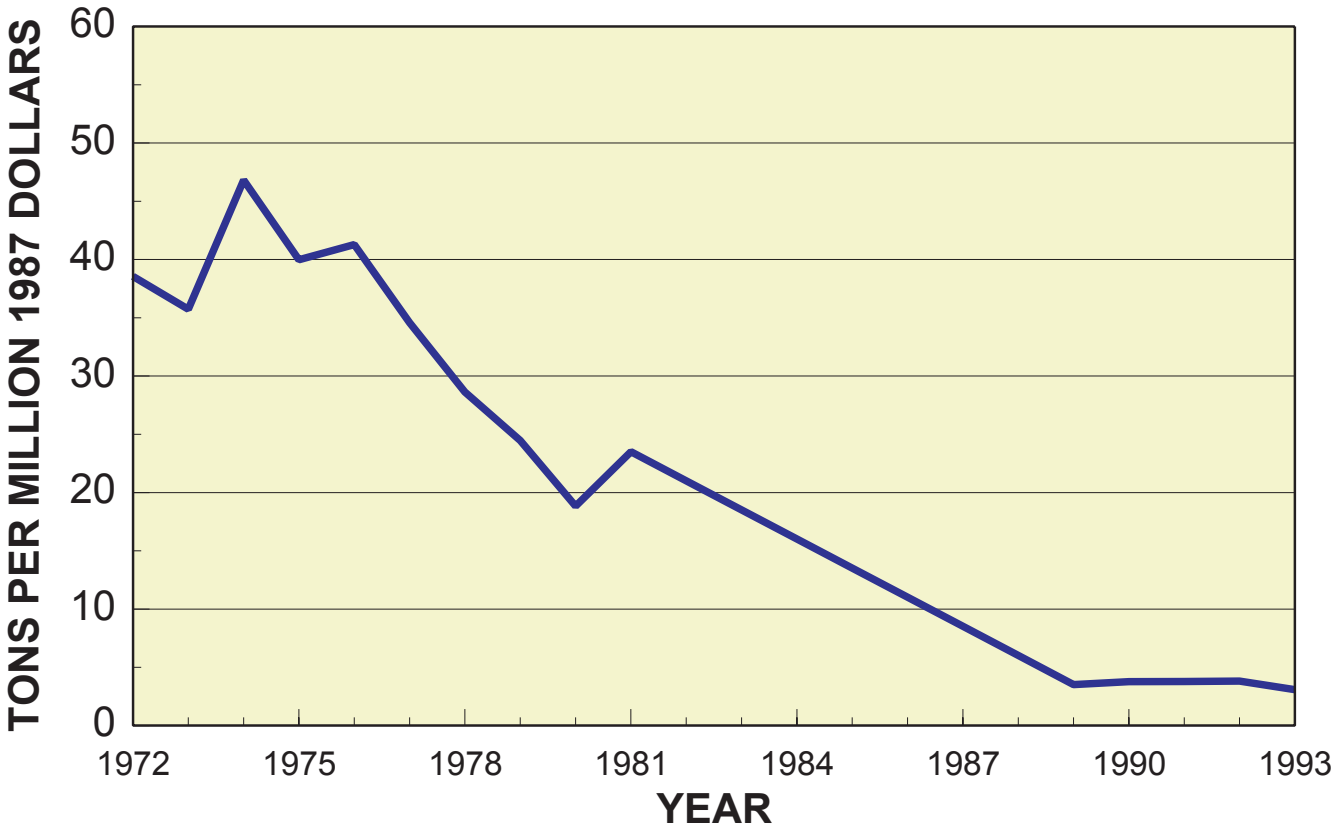
only 52 tons were needed per million dollars of output in terms of constant dollars. Many factors may have contributed to this decline; examples include environmental concerns and less military use.

Brass and Bronze Mills. Lead used to produce brass and bronze mill products was about 0.5 percent of total U.S. consumption of lead in 1993. Figure 11 shows the consumption of lead in brass and bronze mill products from 1972 through 1993. This U.S. sector remains a net exporter, albeit only slightly. Consequently estimated lead contained in imports of brass and bronze mill products is less than lead contained in exported products, so apparent consumption is higher than total consumption. The consumption of lead by the U.S. brass and bronze industry has also declined per real dollar of output as illustrated in figure 12. In 1972, the brass and bronze industry consumed nearly 38.6 tons per million dollars of output, but by 1993, this was reduced to almost 3.1 tons per million 1987 dollars of output as the industry has replaced lead with other metals, primarily bismuth. Health concerns have caused the reduction of lead used in this industry in many applications, such as the reduction of lead in faucets. As a result, total lead consumption by this industry dropped from approximately 93,000 tons in 1972 to just a little more than 6,900 tons in 1993.

Figure 11 (see page 13, top). Lead consumed in brass and bronze mill products.

Figure 12 (see page 13, bottom). Lead consumption by the U.S. brass and bronze industry relative to industry output.


100,000
80,000
60,000
40,000
20,000
0
TONS
Apparent consumption
Total consumption
1972
1975
1978
1981
1984
1987
1990
1993
YEAR


60
50
40
30
20
10
0
TONS PER MILLION 1987 DOLLARS
1972
1975
1978
1981
1984
1987
1990
1993
YEAR

Construction. Lead used in the construction industry was about 1.5 percent of total U.S. consumption in 1993. Lead has historically been used in many construction applications such as sound barriers, roofing, flashing, piping, caulking, waterproofing, and radiation shielding. The decline of lead use in construction has occurred because of environmental concerns about lead use in plumbing, soldering, and caulking. The combined consumption of lead by both the heavy construction (such as highways, bridges, pipelines, and dams) and building construction sectors for the period from 1972 through 1993 is shown in figure 13. Lead contained in net imports of construction products is small; therefore, there is little difference between apparent consumption and total consumption. Consumption of lead per million 1987 dollars of output for the two construction sectors (shown in fig. 14) also declined over the period. In 1972, heavy construction consumed nearly 1.3 tons of lead per million 1987 dollars of output. By 1993 consumption had declined to only 0.29 tons per million 1987 dollars of output. Similarly, lead consumption for building construction also declined, from 1.6 tons per million 1987 dollars of output in 1972 to 0.29 in 1993. Lead consumption by these two industries decreased from 147,000 tons in 1972 to less than 22,000 tons in 1993.

Gasoline Additives. Concerns over the environmental implications of releasing lead into the atmosphere resulted in governmental mandates which prohibited the addition of lead to gasoline. This caused lead consumption in gasoline to plummet from almost 98,000 tons in 1972 to zero in 1993. The consumption of lead in gasoline for the period from 1972 through 1993 is shown in figure 15. Figure 16 shows lead consumption in gasoline in terms of tons per million 1987

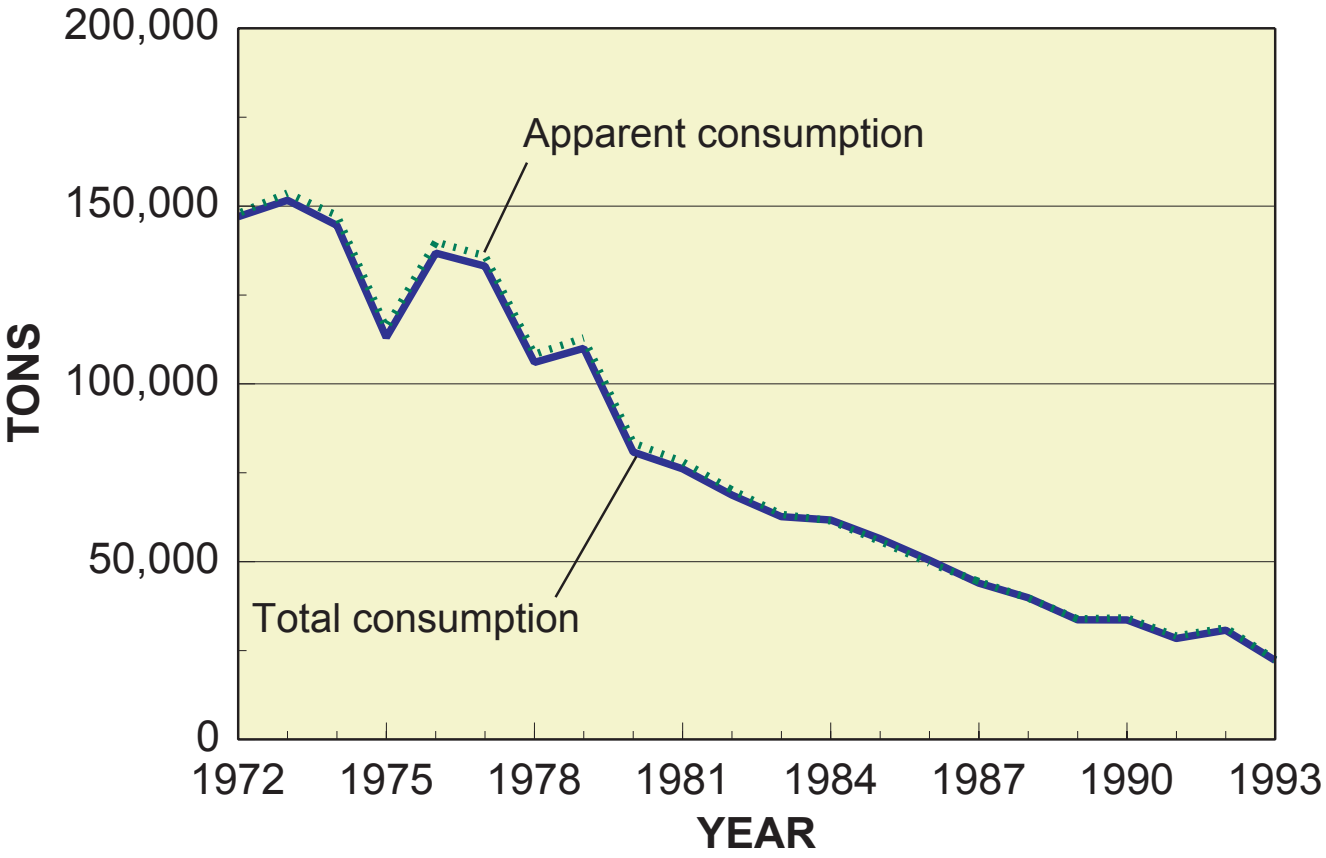
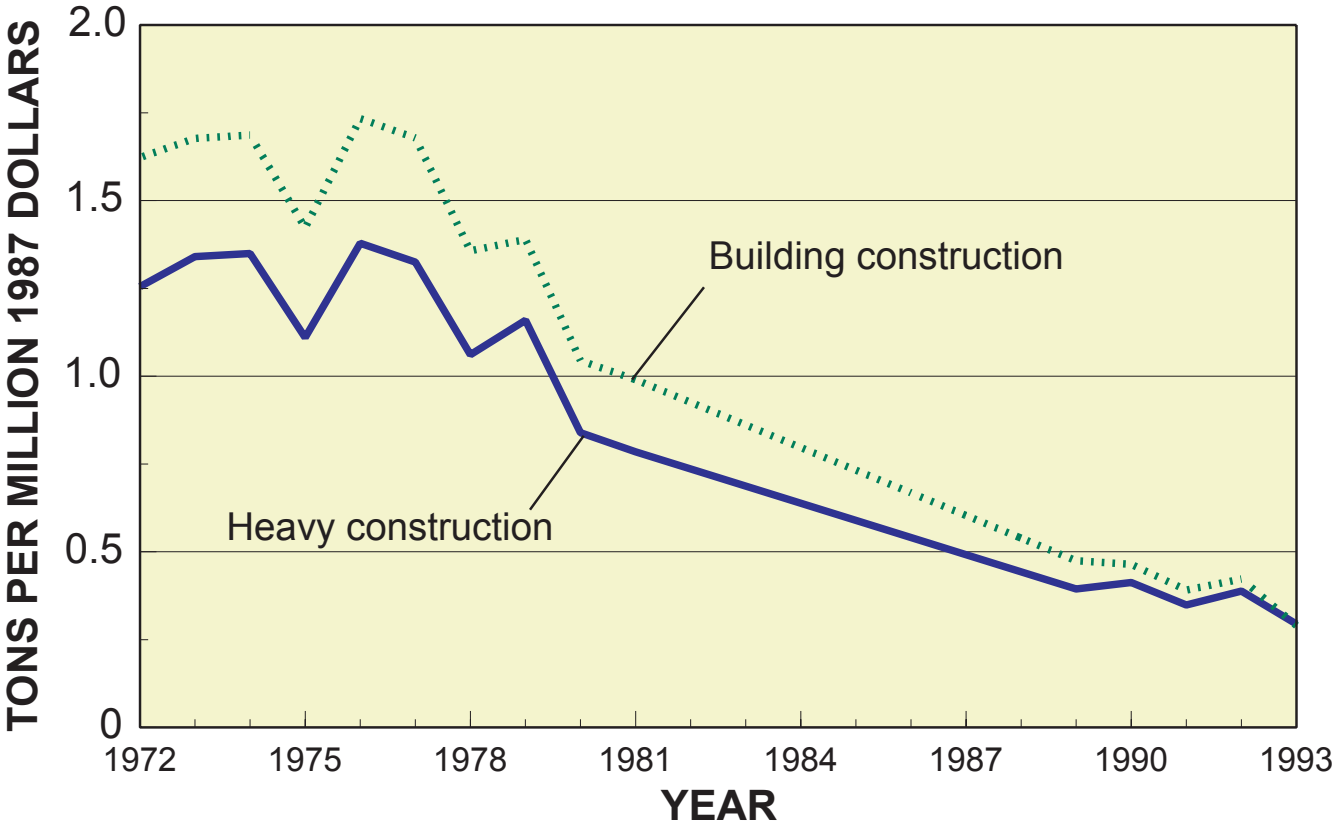
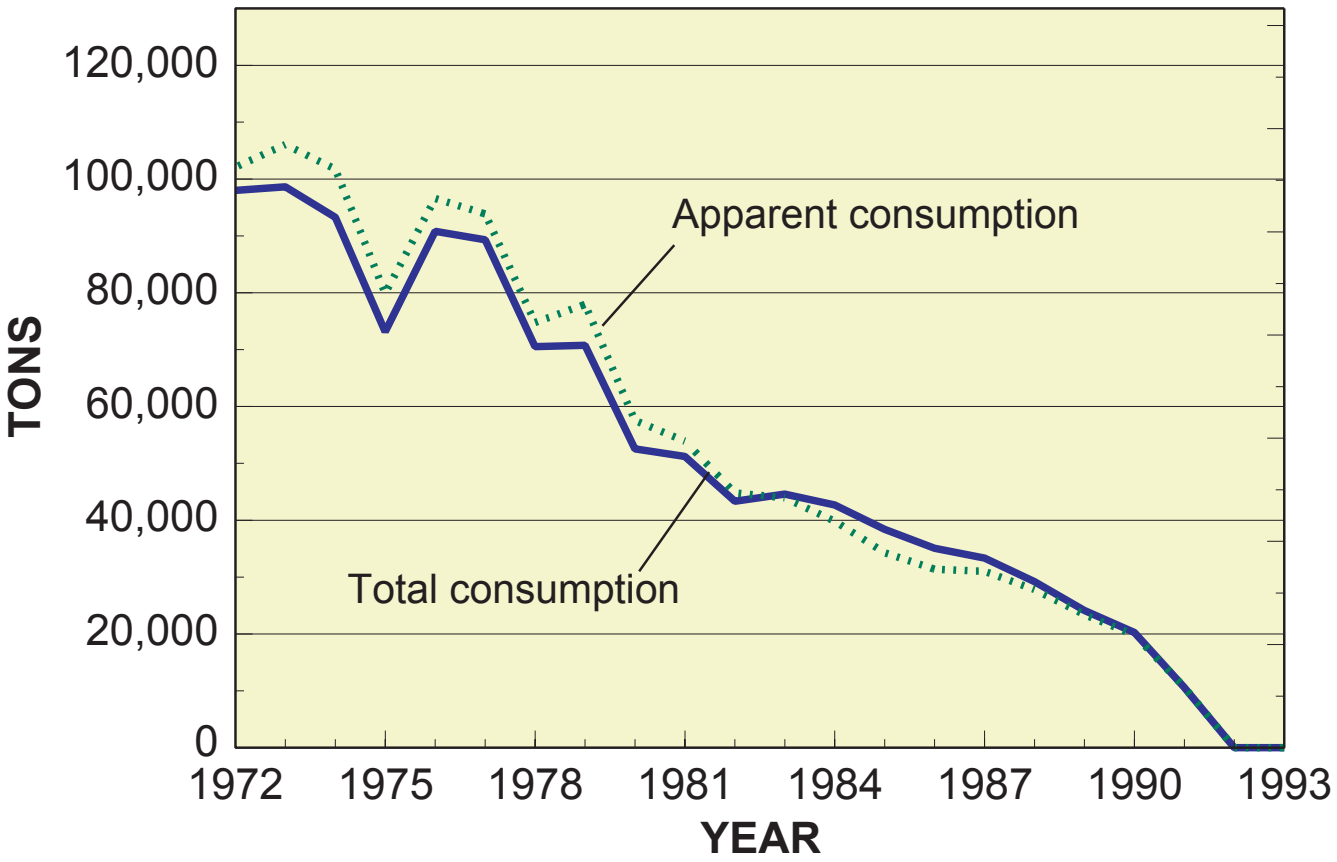


Figure 13. Lead consumed in construction.

Figure 14 (see page 15, top). Lead consumption by the U.S. construction industry relative to industry output.

Figure 15 (see page 15, bottom). Lead consumed in gasoline.


TONS PER MILLION 1987 DOLLARS
2.0
1.5
1.0
0.5
0
Building construction
Heavy construction
1972
1975
1978
1981
1984
1987
1990
1993
YEAR


TONS
120,000
100,000
80,000
60,000
40,000
20,000
0
Apparent consumption
Total consumption
1972
1975
1978
1981
1984
1987
1990
1993
YEAR

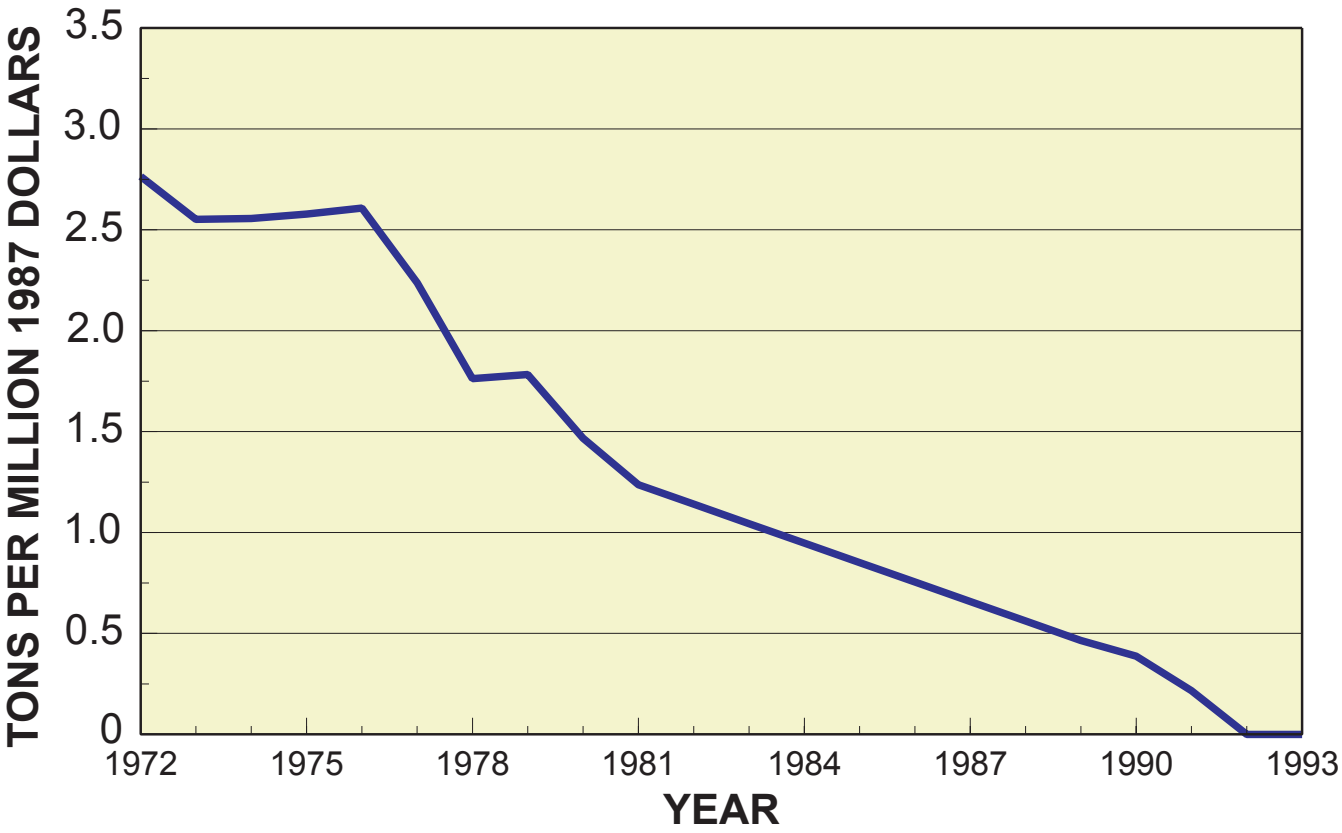


Figure 16. Lead consumption by the U.S. gasoline industry relative to industry output.

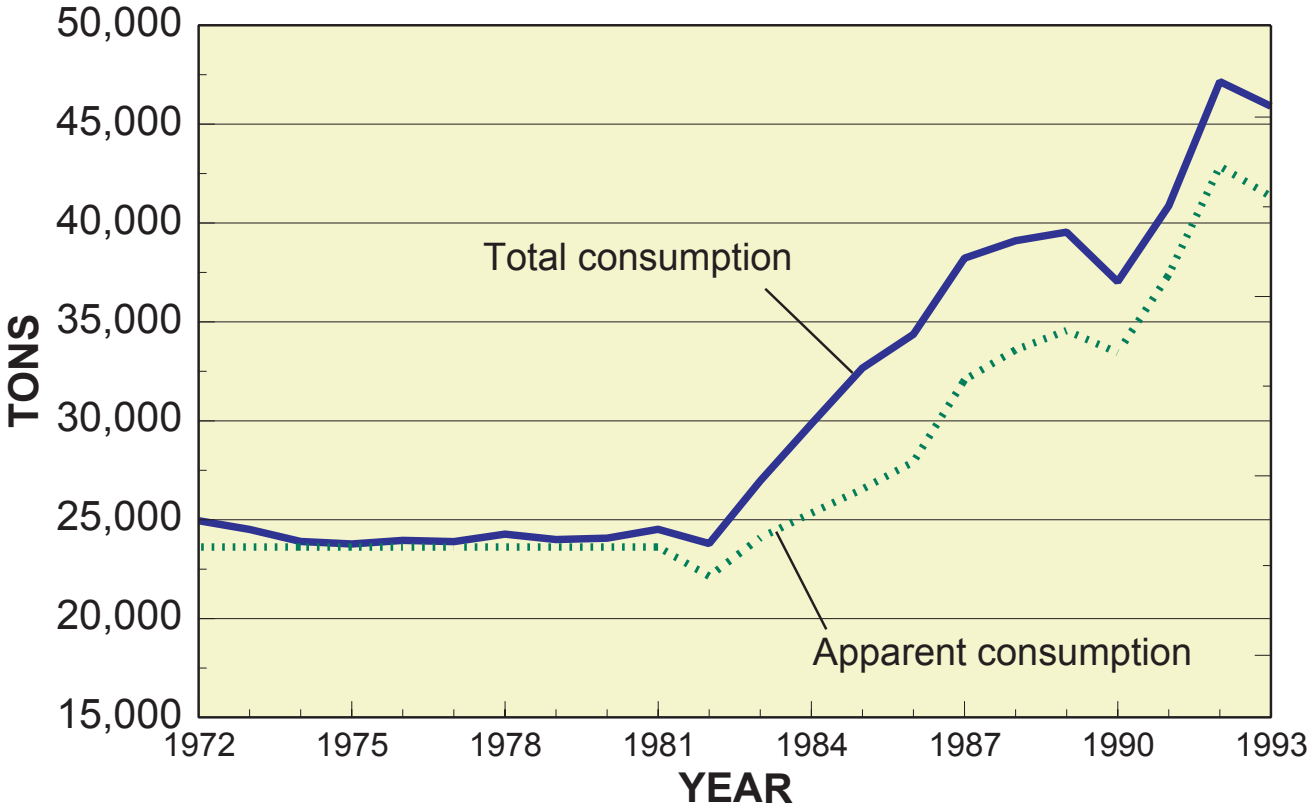
dollars of output. This was 2.8 tons per million dollars of output in 1972, declining to zero in 1993 (all on a constant-dollar basis).

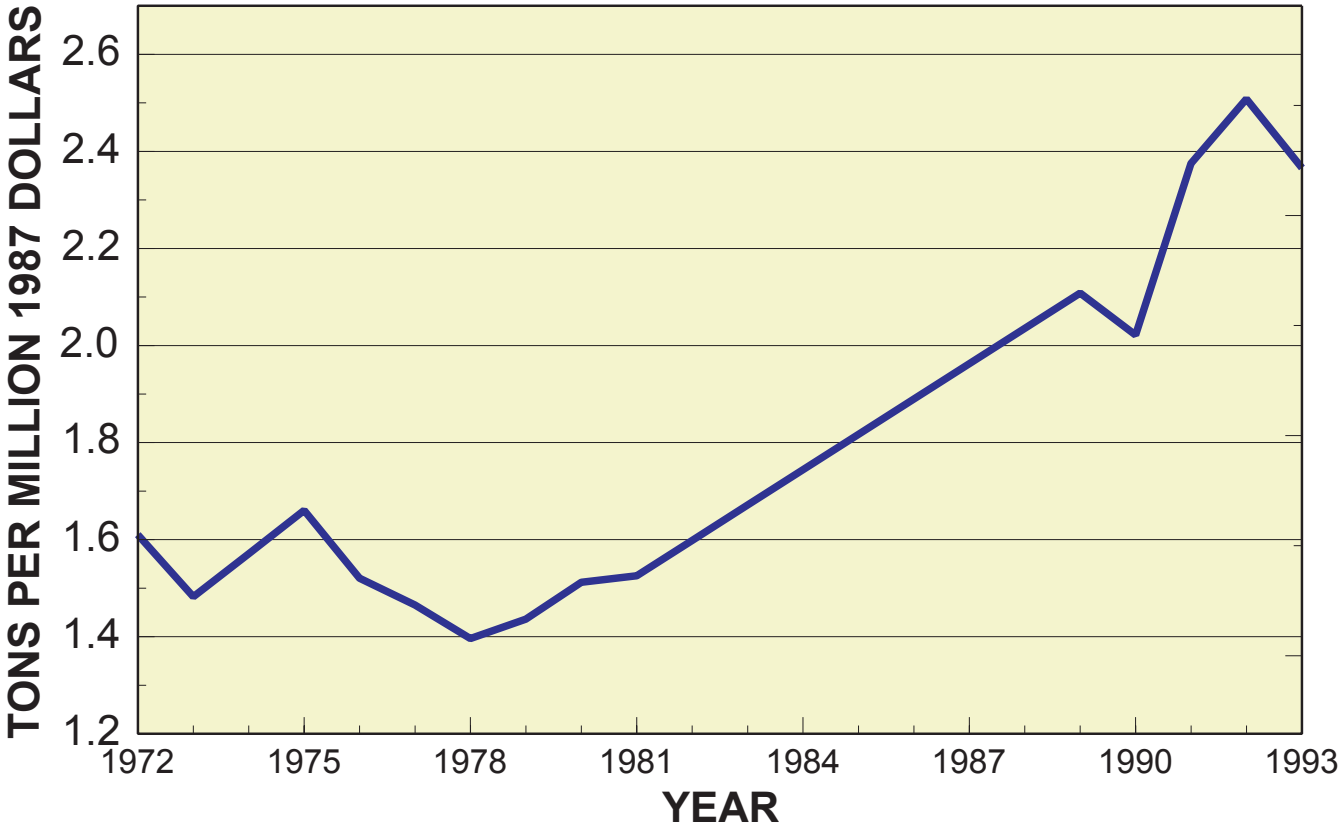
Glass and Ceramic Products. Lead used to produce glass and ceramic products was more than 3 percent of total U.S. consumption in 1993. Figure 17 shows the consumption of lead in glass and ceramic products from 1972 through 1993. Total consumption, which includes imports of lead in glass and ceramic products, remains greater than apparent consumption for the period. Output by this industry increased over the period from $14.7 billion in 1972 to $17.5 billion in 1993, all in constant 1987 dollars. Lead is an important ingredient in television and computer monitor screens because of its shielding properties. Both the amount of lead per screen and the number of screens being produced have increased. As a result, the consumption of lead per million dollars of output by this industry, as shown in figure 18, has increased from 1.6 tons in 1972 to nearly 2.4 tons in 1993. As a result, total consumption of lead by this industry has increased from nearly 25,000 tons in 1972 to 46,000 tons in 1993.

Industrial Inorganic Chemicals. Lead used in industrial inorganic chemicals was about 0.7 percent of total U.S. consumption in 1993. Lead is used to make pigments,

Figure 17 (see page 17, top). Lead consumed in glass and ceramic products.

Figure 18 (see page 17, bottom). Lead consumption by the U.S. glass and ceramic products industry relative to industry output.


50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
TONS
Total consumption
Apparent consumption
1972
1975
1978
1981
1984
1987
1990
1993
YEAR


TONS PER MILLION 1987 DOLLARS
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1972
1975
1978
1981
1984
1987
1990
1993
YEAR

additives, and other chemicals, which are then added to materials such as plastics to give them color or desirable characteristics. Figure 19 shows the consumption of lead by the industrial inorganic chemical industry for the period from 1972 through 1993. Total consumption, which includes imports of industrial inorganic chemicals, is shown to be always lower in this industry than apparent consumption, although in recent years they are much closer. The consumption of lead by the industrial inorganic chemical industry has also declined per million dollar of output, as shown in figure 20. In 1972, the industrial inorganic chemical industry consumed 3.2 tons per million 1987 dollars of output; by 1993, this was reduced to about 0.5 tons per million 1987 dollars of output. This reduction took place because lead additives to materials such as plastics are being replaced by less toxic materials. Total lead consumption dropped from approximately 53,000 tons in 1972 to a little more than 9,000 tons in 1993.

Lead-Acid Storage Batteries. Lead used to produce lead-acid storage batteries was more than 84 percent of total U.S. consumption in 1993. Figure 21 shows the consumption of lead in lead-acid storage batteries for the period from 1972 through 1993. The difference between total consumption and apparent consumption in the first part of this period is small. In more recent years the calculated total consumption of lead in batteries has grown because of an increase in imports of lead-acid batteries. The consumption of lead per 1987 dollar value of output by the lead-acid storage battery industry declined significantly over the period (fig. 22), thanks to improved technology requiring less lead per battery. In 1972, 384 tons of lead was consumed per million 1987 dollars of real output; however, by 1993 this amount

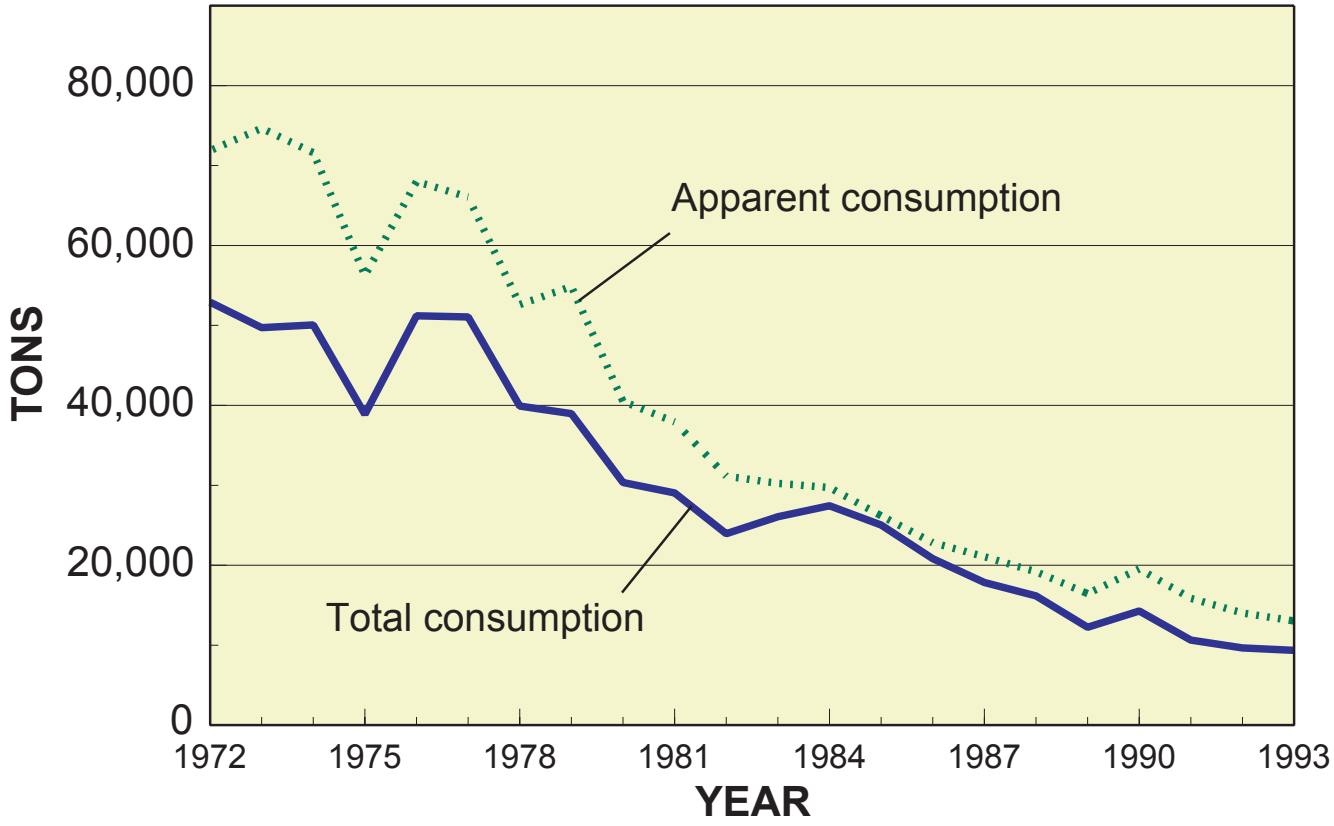


Figure 19. Lead consumed in industrial inorganic chemicals.

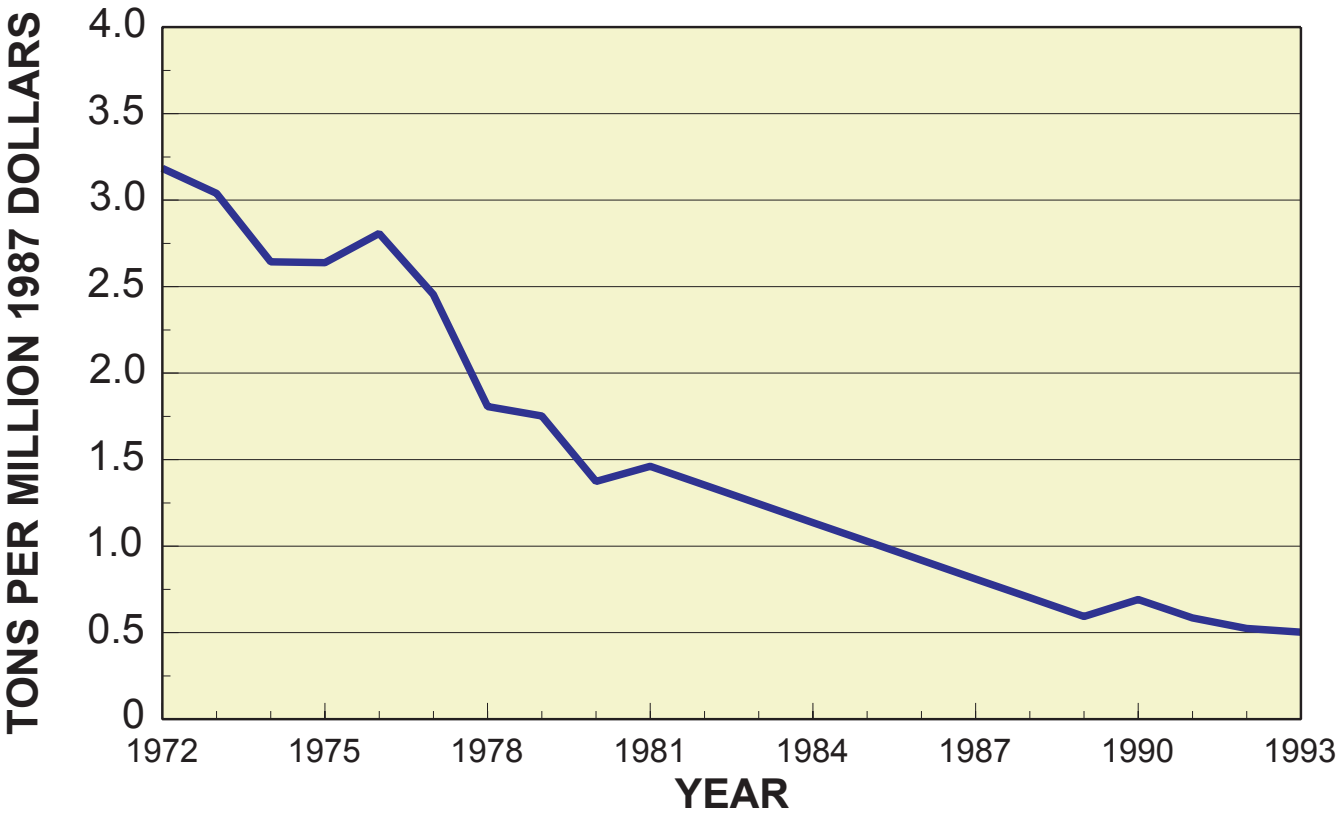
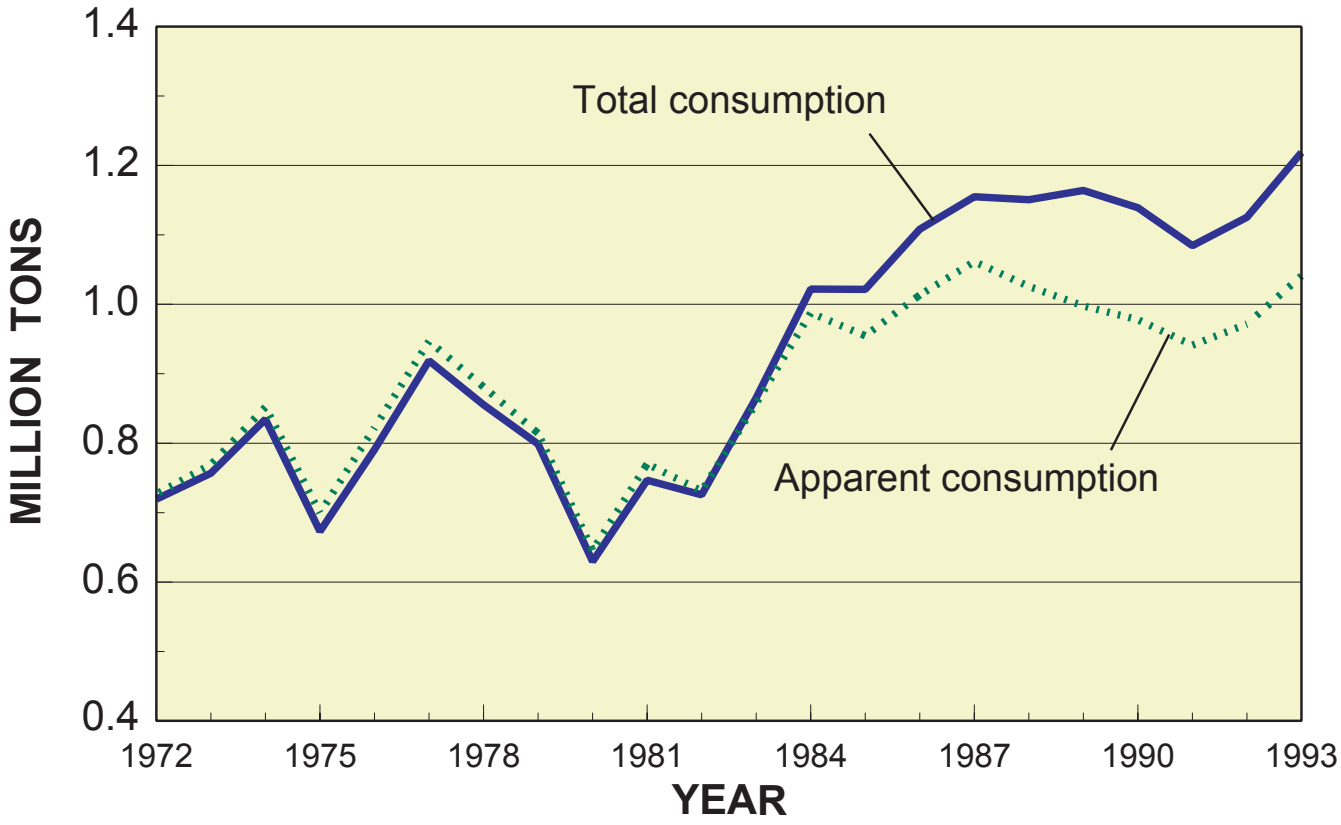
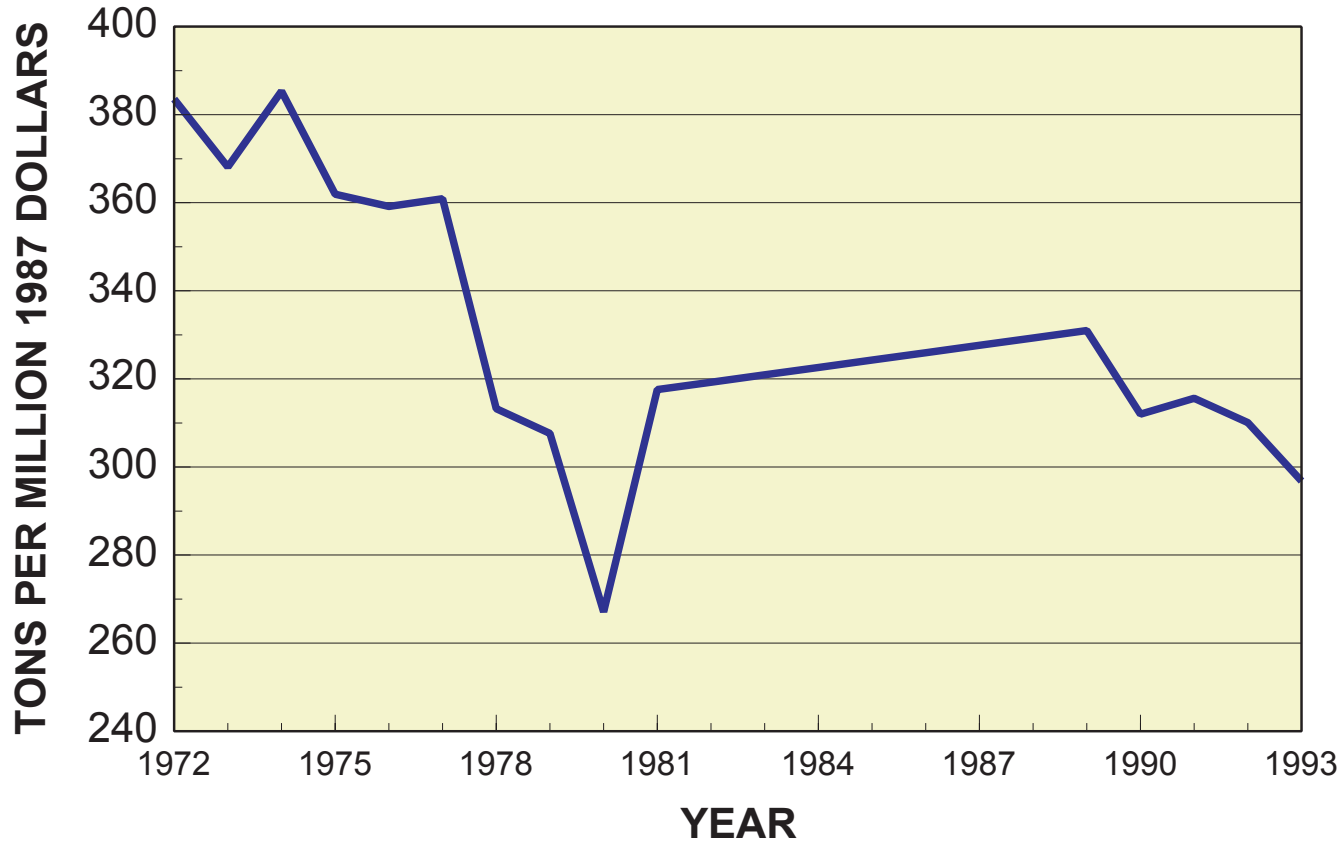


Figure 20. Lead consumption by the U.S. industrial inorganic chemicals industry relative to industry output.

Figure 21 (see page 20, top). Lead consumed in lead-acid batteries.

Figure 22 (see page 20, bottom). Lead consumption by the U.S. lead-acid battery industry relative to industry output.


1.4
1.2
1.0
0.8
0.6
0.4
MILLION TONS
Total consumption
Apparent consumption
1972
1975
1978
1981
1984
1987
1990
1993
YEAR


400
380
360
340
320
300
280
260
240
TONS PER MILLION 1987 DOLLARS
1972
1975
1978
1981
1984
1987
1990
1993
YEAR

was reduced to 297 tons per million 1987 dollars of real output, nearly a 23 percent decrease. During this same time period, however, the lead-acid storage battery industry's output increased. Therefore, even with a decrease in the consumption of lead per dollar value of output, lead consumption rose. It was 719 thousand tons in 1972, and by 1993 it had increased to 1,218 thousand tons.

Paints and Allied Products. Lead used by the paints and allied products industry was about 0.6 percent of total U.S. consumption in 1993. Figure 23 shows the consumption of lead by the paints and allied products industry for the period from 1972 through 1993. Lead contained in net imports does not play a large role. An environmental and health concern over lead-based paints resulted in the dramatic decrease in lead use in paints and allied products, from about 7.2 tons per million 1987 dollars of output by this industry in 1972 to less than 1 ton per million 1987 dollars of output by 1993. As a result, the quantity of lead consumed by the paint industry (fig. 24) declined from 55 thousand tons in 1972 to less than 9 thousand in 1993.

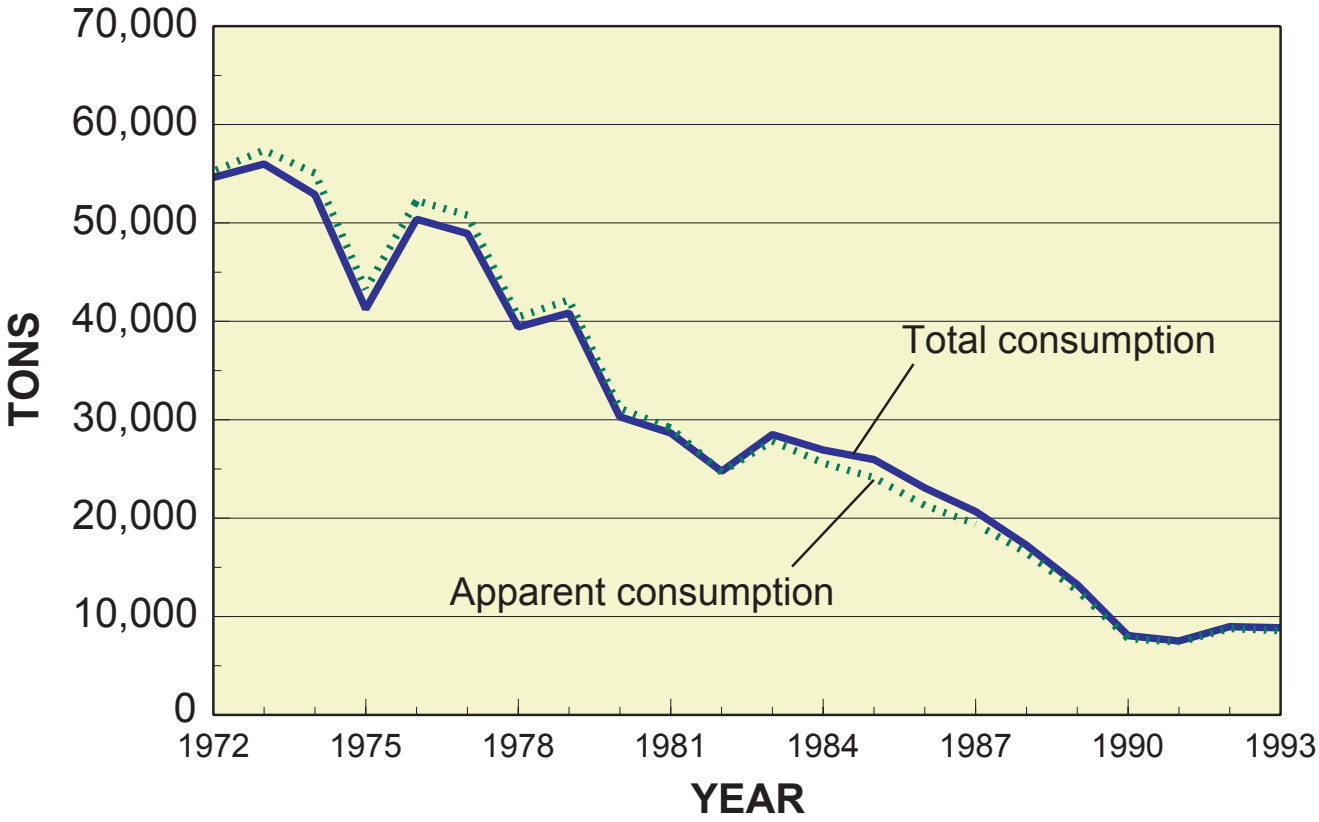


Figure 23. Lead consumed in paints.

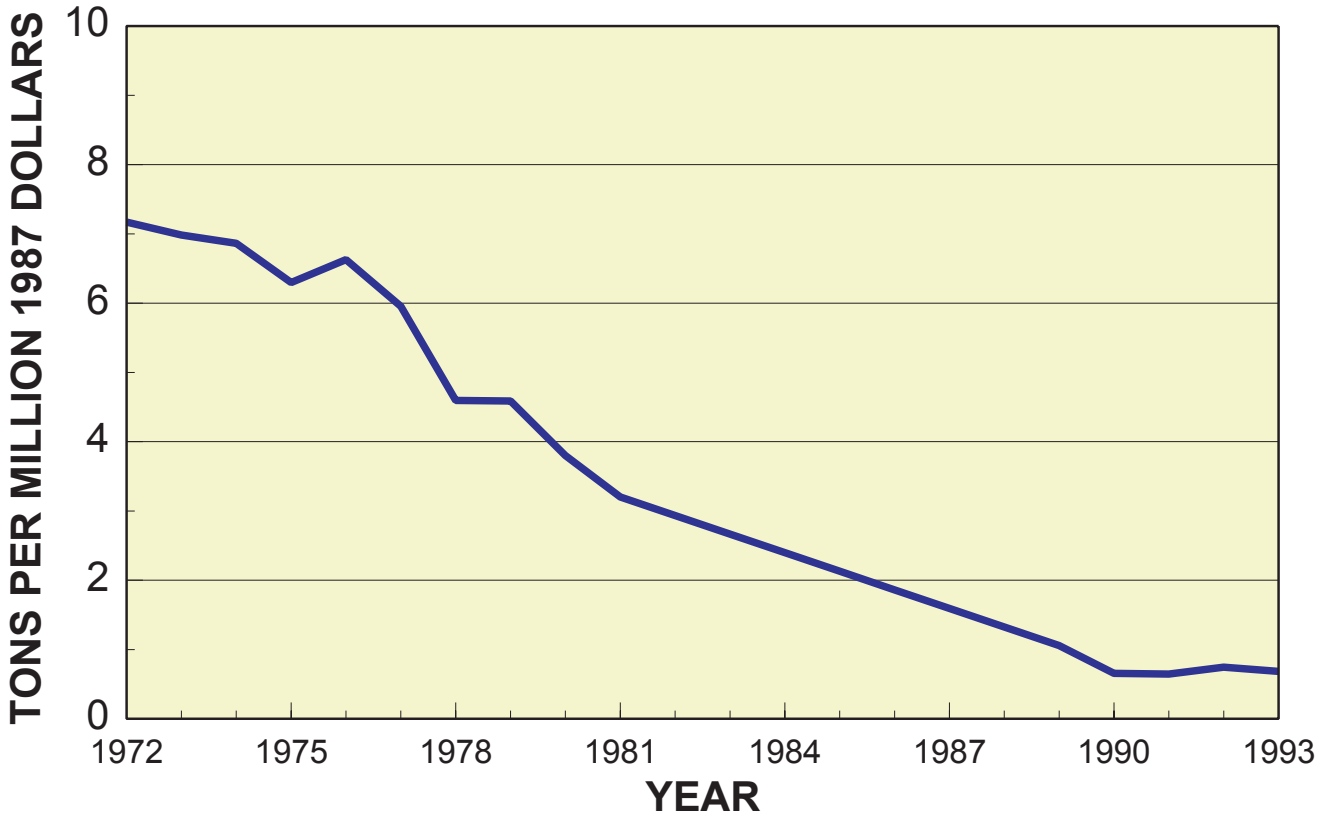


Figure 24. Lead consumption by the U.S. paint industry relative to industry output.