Raw materials and technology fuel U.S. economic growth

Construction materials, including aggregates, currently make up the greatest portion, by weight, of U.S. materials use. Photo shows Lafarge's Specification Aggregates Quarry in Golden, CO. (Photo courtesy of Lafarge.)

In 1900, the average U.S. citizen's average life span was 47 years. He traveled about 1,900 km (1,200 miles) in a lifetime and resided in a home with an icebox for food storage and oil or gas for lighting. He communicated by mail, telegraph and crude telephones with limited availability and range.

By 2000, the average citizen's life span was 77 years. He traveled an average of 19,000 km/a (12,000 miles/year) by automobile alone. He resided in a home with many electrical appliances, including refrigerators and electric lights. And he communicated almost instantaneously with any other part of the globe by several widely available means, including portable phones and e-mail.

Technology, the application of knowledge about the Earth's materials, their extraction and fabrication into products, helped create this change. Throughout the 20th century, the United States was a leader in technology. Automobiles, refrigerators, electric lighting, telephones and personal computers are only a few examples of the products invented and improved or further developed by American technology (National Academy of Engineering, 2000).

The United States is endowed with natural resources, a diverse, rapidly growing population, a dynamic economy and a location with ports on the world's two major oceans. So technology flourished in the United States as new and improved products were manufactured and made available to a growing population.

The interaction of technology and increasing material demand induced manufacturers to use materials efficiently to increase profit. As metals use increased, more scrap metals became available for recycling at the end of metal products' lifetimes.

Source reductions enabled the manufacturing of products that perform the same function with smaller material inputs. And materials substituted for one another as the functions of products were improved and product costs were decreased.

Materials Mountain

Changes in raw materials use in the United States between 1900 and 2000 illustrate the nature of materials demand and growth in the efficiency of materials use. Figure 1 is the "Materials Mountain." It shows the amount, by weight, of six categories of non-food, nonfuel materials demanded by U.S. industry throughout the 20th century. Nine classes of materials are shown graphically. Paper and recycled paper are split from wood and recycled metals are separately represented from primary metals. The upward trends in demand are evidence of growth and prosperity. The occasional downward trends reflect economic recessions and depressions.

New raw materials, new products, population growth and efficient materials use explain the shape of the areas for the nine raw material classes (from six material categories), which form the mountain.

The stone and sand and gravel category represents the largest ton-

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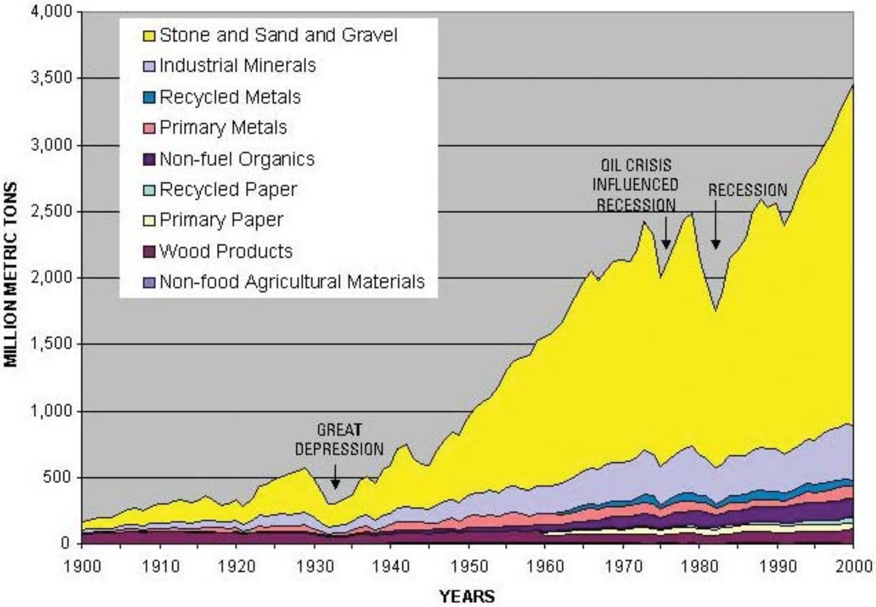
FIG. 1

Raw materials supplied to manufacturers in the United States (1900-2000), modified from Wagner (2001).



nage used throughout the 20th century. The noticeable increase in use from 1945 through the early 1970s resulted from the construction of the interstate highway system and the postwar construction boom. More than 80% of these materials are used in cement concrete, bituminous (asphalt) concrete and the loose aggregate associated with roads, buildings and railroad beds. The large use of these materials is explained by population and economic growth in an increasingly urbanized nation that relies on automobiles and trucks for transportation.

Figure 1 illustrates the importance of stone and sand and gravel to the U.S. economy. But the size of this category's contribution overwhelms the graphical representation of the other categories because it compresses the scale at which the other categories are represented. Removing the stone and sand and gravel category in Fig. 2 decompresses the weight scale for all the other material categories. It brings into view nonfood agricultural materials, which represent an insignificant quantity on a weight basis (Barsotti and Morse, 2000).

Figure 2 shows a decompressed weight scale (the y-axis). It allows the viewer to more accurately estimate the quantity of material in a given year or span of years because Fig. 2 is a stacked area chart (as is Fig. 1). Stacked area charts represent the material categories' relative weights as bands of varying width framed by a bottom line and top line.

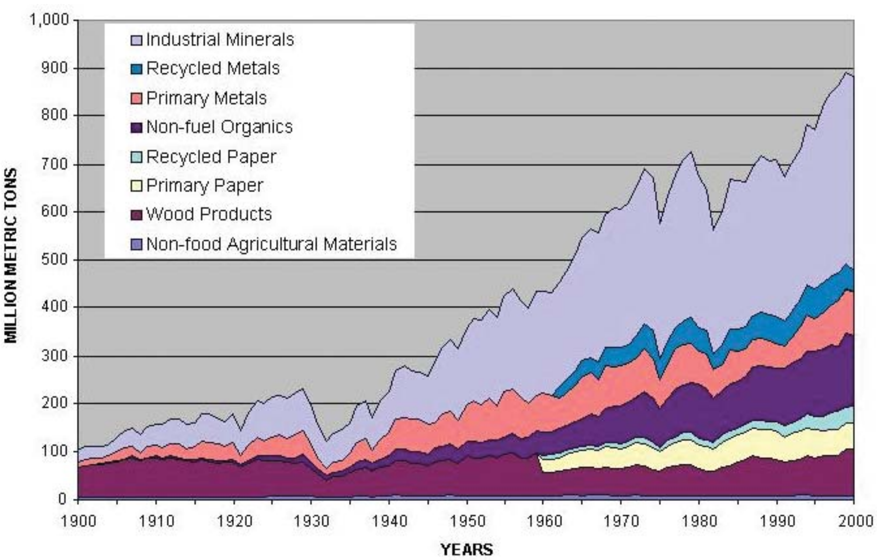
Estimation of a material category's weight amount in any given year or span of years requires an estimate of bandwidth made by subtracting a material category's bottom line weight value from the top line weight value. In Fig. 2, it is possible to visually estimate that the recycled paper supply has grown from about a fifth of the total wood supply in 1962 (the year the data starts to be collected) to about a third in 2000. The ease in visualizing these time-relative changes in y-axis quantities is an advantage of an area chart presentation.

A disadvantage is the scale compression in Fig. 1 that necessitated the removal of the stone and sand and gravel category, which precludes viewing all of the data. Furthermore, material categories cannot be compared for their individual responses to depression and recession. This is because the bands that represent material categories are stacked on one another so that the top line in any band is the sum of all the bands below it. This makes any dip in the top line of a material category the sum of all the dips below that category. A semilogarithmic plot of these data overcomes these disadvantages.

On a semilogarithmic graph, the slopes of the curves are a measure of the growth rate of each material category during the 20th century. In addition, the vertical movements in these curves are proportional to the absolute amount of material. This is demonstrated in Fig. 3. It compares total material supply in a semi-logarithmic plot and a normal, arithmetic plot. The visual representation of the Great Depression on the semilogarithmic plot is significantly greater than all other economic downturns,. This is a reversal

FIG. 2

Raw materials supplied to manufacturers in the United States excluding stone and sand and gravel.



in appearance from the arithmetic plot in which the recession during the early 1980s is visually the largest.

The early 1980s recession caused the largest decline in material supply during the 20th century. But, relative to the total amount of materials supplied in 1979, it represents a 30% decline vs. a 47% decline (from 1929 to 1932) during the Great Depression.

The semilogarithmic representation of declines during economic downturns in Fig. 3 puts into perspective the relative total amounts of materials supplied during the 20th century. Applying this graphing technique to the six material categories that constitute total supply allows the visualization of two important rates-of-change relations between and within the categories in Fig. 4.

Advances in manufacturing technology have reduced the amount of manufacturing scrap and made recycling more efficient. Photo shows stainless steel "turnings," drummed ferrochrome fines, trimmings and punchouts. (Photo courtesy of the U.S. Geological Survey.)

Rate of change

By visually ranking the slopes of the curves in Fig. 4, it is apparent that nonfuel organic materials exhibited the greatest rate of growth during the 20th century. This was followed by stone and sand and gravel; industrial minerals; metals; wood and nonfood agricultural materials.

Furthermore, the rate of change during economic downturns shows that demand for the material categories responds differently to economic variation. The demand for metals is the most sensitive to economic recessions, while the demand for nonfuel organics and agricultural materials are the least sensitive. The demands for wood, stone and sand and gravel, and industrial minerals appear to be intermediate in their responses to economic downturns.

Metals are a large component of durable goods, such as automobiles, washing machines and industrial machinery. Nonfuel organics and agricultural materials are a large component of nondurable goods, such as packaging, clothing and toys. The use of durable goods depends, in part, on interest rates, which tend to follow economic cycles. Consumer confidence and unemployment are influenced by economic downturn. They, too, affect the use of durable goods. Use of nondurable goods depends more on satisfying basic necessities and reflects population growth to a greater extent than factors like interest rates and consumer confidence.

Efficient material use strategies

Metal goods have been recycled since humans first started forming metal items. This is because the energy saved by melting scrap metal is significantly less than that required to extract and purify virgin metal. In 1900, large metal goods or durables, such as industrial machinery, were recycled because of their energy-intensity and the resultant cost savings.

In the latter part of the 20th century, nondurable goods started to be recycled at significant rates because the cost of disposal increased. Growth in population and technology led to more production of nondurable goods and, at the same time, less available land for disposal sites. Recognition of the environmental impacts of past bad practices resulted in legislation that regulated disposal and encouraged recycling.

Almost simultaneously with this increase in environmental awareness, an energy crisis occurred in the

FIG. 3

Total supply of materials to U.S. manufacturers during the 20th century.

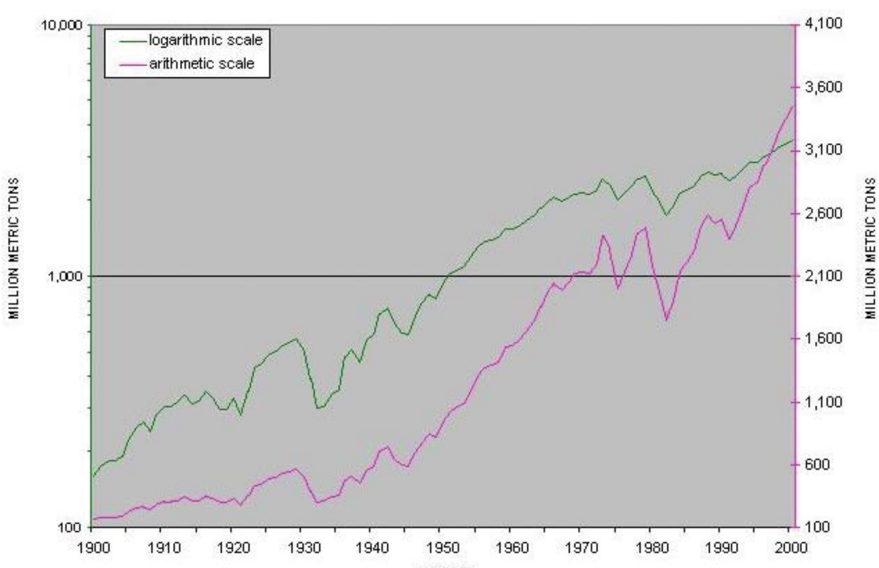
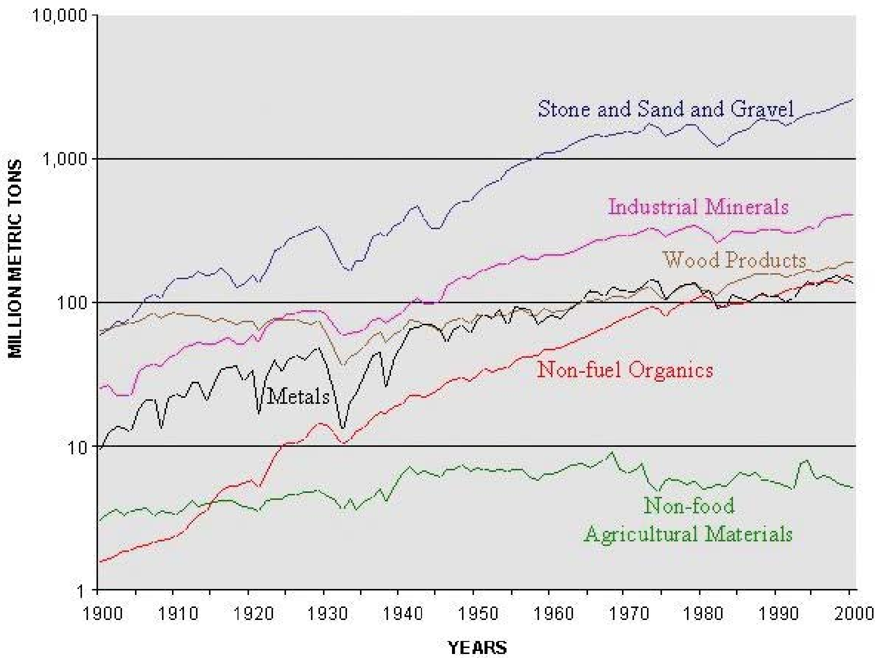


FIG. 4

Raw materials supplied to manufacturers in the United States (1900-2000).



United States during 1974, based on an oil shortage. Legislation was passed to encourage recycling for energy conservation. Since then, other regulatory measures were passed to protect the stratospheric ozone layer, increase fuel efficiency in automobiles, remove heavy metals from the environment and protect water resources from contamination. These regulations have led to source reductions and material substitutions in products and manufacturing processes.

The recycling, source reductions and material substitutions were originally driven by performance of function, manufacturing cost and the energy needed to process metals. They are now affected by considerations of overall energy consumption and environmental impact. And as the 21st century begins, the link between materials, energy and the environment becomes more significant. Global warming and its potential for catastrophic climate change have influenced some firms, nations and even individual consumers to change their patterns of material and energy consumption.

Materials cycle

A new technological trend is developing where scientific theory and engineering practice are used to examine technology itself. One method is is the materials flow cycle (Fig. 5). This method takes an overview — a systems view — of the material flows and processes of the nonfood, nonfuel portion of the U.S. economy.

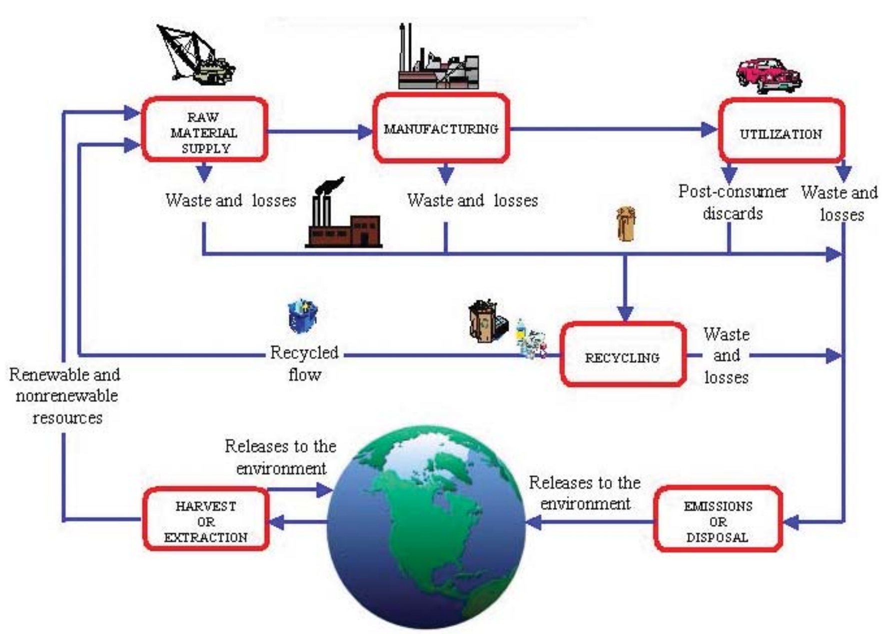
Materials flowing through the processes of the materials flow cycle (rounded red rectangles) provide a pattern for estimating the energy use and environmental impact of these flows. Past changes in material flow patterns demonstrate changing material use resulting from technological progress and energy or environmentally inspired regulation. A gain in controlling material loss, energy conservation or environmental impact in one process may be accompanied by losses or gains in other processes. The systems view may be used to examine the overall effects of changes in technology. Whether inspired by a consideration of manufacturing cost or social cost (the sum of private cost and external, or environmental, cost), technological changes cause new patterns in flow of materials through the materials flow cycle. Data on material flows and processes are required to connect past material flow patterns with future projections.

In November 1998, the U.S. Geological Survey (U.S.G.S.) held a workshop to discuss material and energy flows (Brown, Matos and Sullivan, 2000). A common concern expressed by workshop participants was the need to make data more accessible.

To help accomplish this goal, there is an ongoing effort to publish U.S.G.S. data on raw material use in an electronic format. These data (Kelly et al., 2002) are available online at http://minerals.usgs.gov/minerals/. Select "Historical Statistics" under "Popular Topics." Recycled materials and extracted materials are listed, along with imports, exports, world production and the unit value of raw material supply

FIG. 5

Materials flow cycle.



(raw material supply is called apparent consumption in the published data).

Unit value of raw materials in deflated dollars has declined for most materials throughout the 20th century in spite of the growth in world population and products. Several factors made this possible. They include technological progress, efficient material-use strategies, and location of mineral deposits. Global production data are reported when available, because many raw materials used in U.S. industry have moved from domestic to global sources.

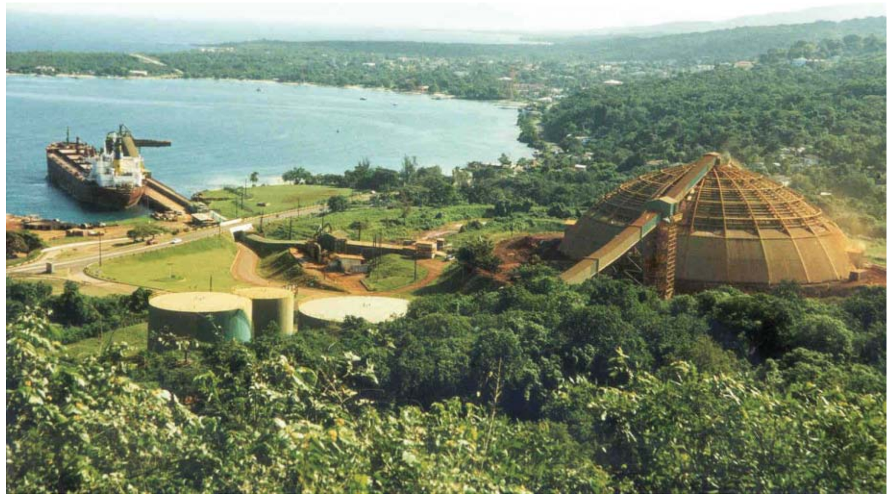
Summary

During the 20th century, U.S. citizens lived in a rapidly changing world. Health and life span, travel, communication, domestic convenience, work and leisure time underwent revolutionary changes. At the same time, growth in waste materials and environmental emissions accompanied the gains in lifestyle.

Recognition that technology causes problems that diminish some of the lifestyle gains occurred mainly in the latter third of the century. As the 21st century begins, technology is being called on to help solve the energy and environmental problems caused by the flow of materials through a global economy.

A systems view of materials, energy and environmental impact using the materials flow cycle is a powerful tool for performing these analyses. The U.S.G.S. data on U.S. use and global production of raw materials are a logical framework to help collect and analyze all of the data necessary to perform a materials flow analysis. ■

The United States increasingly depends on imports to meet the country's need for materials. The United States is 100% dependent on imports of bauxite, through ocean transport, to produce alumina. Photo shows the Discovery Bay port in Jamaica. (Photo courtesy of Parris Lyew-Ayee, Jamaica Bauxite Institute.)



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