



COVER The effective surface temperature variation of the sun between 1983 and 1987 after removing the effect of bright solar faculae from the data. The temperature is calculated on the basis of solar limb data. The red regions are about 0.2% brighter, or 3°C hotter, than the blue areas. Starting in the upper left and moving down and then down in the right column, the images correspond to the sun in the summers of 1983, 1984, 1985, and 1987. See page 908. [J. R. Kuhn, Michigan State University, East Lansing, MI 48824; K. G. Libbrecht, Big Bear Solar Observatory, California Institute of Technology, Pasadena, CA 91125; and R. H. Dicke, Princeton University, Princeton, NJ 08544]

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Improved Efficiency of U.S. Copper Production

During the first two-thirds of this century, U.S. companies controlled most of the world's reserves of copper and the United States was the leading producer of the metal. But in the past two decades, U.S. companies have experienced traumatic blows, including nationalization of their profitable foreign holdings, competition from low-cost producers elsewhere, and impact of environmental regulations. For some years during the 1980s, operating losses of the companies were so large that it seemed possible that the U.S. copper industry would disappear. Such a development would have been a cause for concern. Copper has many uses and will have an increasing role as electricity is employed more intensively here and worldwide.

In part the problem of costs was due to failure of management to install state-of-the-art equipment in the huge open-pit mines that produce 85 percent of this nation's copper. In part the problem of costs was exacerbated by a slow decline in the grade of U.S. ore, which was and is considerably lower than that of foreign competitors. The financial and competitive problems of the copper industry were exacerbated by environmental regulations. While producers in most other countries continued to pollute, those in the United States were required to cut emissions of sulfur dioxide by 90 percent. As a result, substantial costs were incurred to achieve compliance, and some smelters were abandoned.

The period 1984 to 1986 was particularly trying as the producer price of copper hovered around 65 cents per pound. In terms of constant dollars, this was the lowest price since the great depression of the 1930s. Nevertheless, some companies did not give up on copper. Instead, they analyzed what needed to be done to be profitable even if the price of copper remained low. Looked at one way, the task of extracting each day the 0.8 percent copper from 77,000 tons of hard rock is enormous. But in principle, it is fairly simple. Boulders of the rock are blasted loose, transported to a mill, and ground into a fine powder. The powder is suspended in big vats that contain a detergent that sticks selectively to the copper values (mainly sulfides). Air bubbles rising in the vat bring to the surface a foam that contains most of the copper.

Major copper companies have found ways of reducing their costs. Phelps Dodge, the largest domestic producer (about 500,000 tons a year), achieved savings in a multiplicity of ways. It transferred its headquarters from New York to Phoenix and cut by half its white-collar staff. It will improve the efficiency of its transportation of rock by use of computer monitoring and by installing an in-pit crusher at its Morenci, Arizona, mine. This will permit cheaper transportation of rock to the mill on a moving belt. Phelps Dodge has improved the efficiency of its copper concentration process by employing analytic instrumentation, including x-ray fluorescence. The most effective move at Phelps Dodge has been to install equipment that permits inexpensive (less than 30 cents per pound) production of pure copper from leachates of wastes and tailings. Soon a third of its production will come from this source. The copper in the leachate is extracted by kerosene that contains a copper-binding organic chemical. The copper is later stripped from the kerosene by 1.5 molar sulfuric acid and then electroplated.

The mine at Bingham Canyon, Utah, is the largest man-made hole on Earth. It is shaped like a saucer, 2.5 miles in diameter and a half mile deep. Mining was stopped in March 1985 because of high costs and outmoded equipment. But by investing \$400 million, British Petroleum, the owner, is achieving a cost reduction in production of copper of about 20 cents per pound. A 1000-car railroad has been replaced by a moving belt, and pipelines are being used to transport ore concentrates and tailings. The complex will annually produce 200,000 tons of copper, 300,000 ounces of gold, 2 million ounces of silver, and 12 million pounds of molybdenum.

At the moment, the price of copper is above \$1 per pound, and essentially all producers are making a profit. History teaches that in time there will be new mines elsewhere, overproduction, and low world prices. But at least some of the U.S. production will have costs that will be among the lowest anywhere. We will probably continue to import about 25 percent of our copper for consumption, but expanded imports of copper will not add a further burden to our trade deficit.—PHILIP H. ABELSON