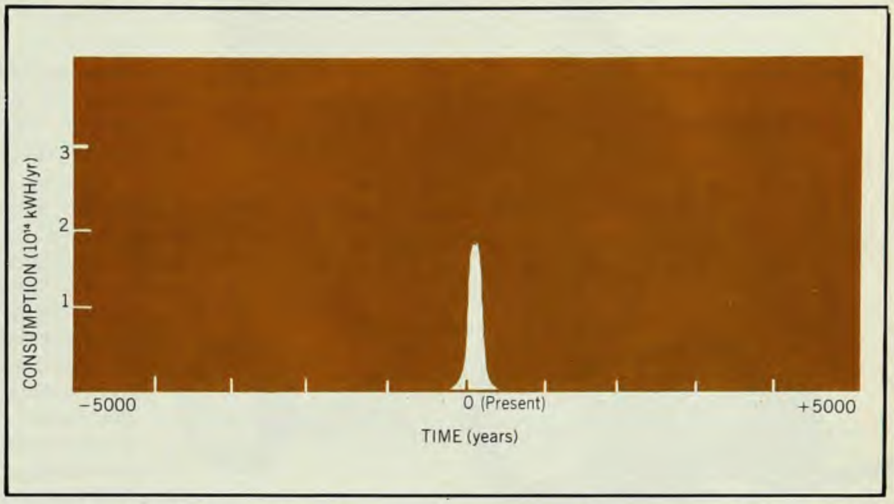
Coal: no superabundance for US



The rise and fall of the world's rate of consumption of fossil-fuel resources is like the flame of one match in the long night—a delta function in the darkness.

I wish to call attention to a very simple and striking aspect of the energy crisis. M. King Hubbert has given a distant look (see figure) at the rise and fall of the consumption of the Earth's fossil-fuel resources.[1] Since it is clear that our enormous agricultural production is totally dependent on artificial fertilizers and on fuel to power mechanized equipment, we may define modern agriculture to be "the use of land to convert fossil fuel (petroleum) into food." We then note that the rise and fall of world food production and hence of world population can be expected to follow the curve in the figure.

The devastating consequences of the growing crisis in petroleum is causing massive efforts to be made to shift as much as possible of our domestic energy consumption from petroleum to coal. Two estimates of the magnitude of US reserves of coal are cited by Hubbert:

$$R_1 = 0.39 \times 10^{12} \text{ metric tons}$$

$$R_2 = 1.49 \times 10^{12} \text{ metric tons}$$

Our 1972 rate of consumption of coal was

$$C_0 = 5 \times 10^8 \text{ metric tons per year}$$

This rate of consumption has remained approximately constant since 1920; but for the 50 years between 1860 and 1910 the rate of consumption grew at a rate of 6.69% per year.

The length of time T that a quantity R of a finite resource will last when the present consumption rate is C_0 and the consumption is changing according to the exponential growth curve $C = C_0 \exp(kt)$ is

$$T = \frac{1}{k} \ln\left(\frac{kR}{C_0} + 1\right) \qquad (1)$$

The results of calculating the times T for various values of k and for the quoted values of C_0, R_1 and R_2 are given in the table. These figures must be contrasted with the impressions given by the great energy companies, which advertise that we have a "superabundance" of coal whose rate of consumption we must vastly increase if we are to achieve "self-sufficiency."

"Coal, the only fuel in which America is totally self-sufficient."[2]

If we put our coal consumption on the same increase (6.69% per year) that occurred for the 50 years following the Civil War, the larger estimate of US coal reserves will be gone in 80 years! If we restrict our rate of increase of coal consumption to the rate at which world consumption of coal is increasing (3.03% per year) the larger estimate will last only 150 years! If we want US coal to last through our nation's second 200 years our rate of increase of coal consumption can not exceed 2% per year! In each of these cases it is interesting to speculate what life will be like the day after the reserves run out.

The most interesting aspect of the table is that it shows how the coal (or any finite non-renewable resource) may be made to last forever! If we set the argument of the logarithm of equation 1 equal to zero, the time T will equal infinity. This gives $k = -C_0/R$, which, for R_2, is a decrease of 0.0336 percent per year. *United States coal would last forever if we let our consumption decrease at a rate of 3.3% per century. This is the ultimate self-sufficiency! It would provide adequate time for us to develop alternate energy sources.* Alternatively, if we put our coal consumption on an annual increase of 10% then we have barely 50 years in which to develop new sources of energy.

We see many public figures and many representatives of large energy companies speaking and writing about "energy self-sufficiency" and "energy independence." Although these people speak with authority on the complex aspects of the energy situation, I have seen no evidence to suggest that any of these experts understand the simple and fundamental arithmetic of the problem about which they speak with such great self-confidence.

I hope that all members of the physics community will use every means at our disposal to educate our business and government leaders to the magnitude and long-range implications of the problem.

It has been predicted that if there are

Life expectancy of US coal reserves, R_1 and R_2

Annual growth in consumption (%)	Years R_1 will last	Years R_2 will last
30	18.2	22.7
20	25.3	32.0
10	43.7	57.0
6.69	59.4	79.2
5	73.8	100
3.03	105	149
2	140	205
1	217	342
0	780	2980
−0.010	812	3538
−0.020	848	4531
−0.030	888	7481
−0.03356	904	infinity
−0.05	988	
−0.10	1514	
−0.11	1744	
−0.12	2290	
−0.1282	infinity	

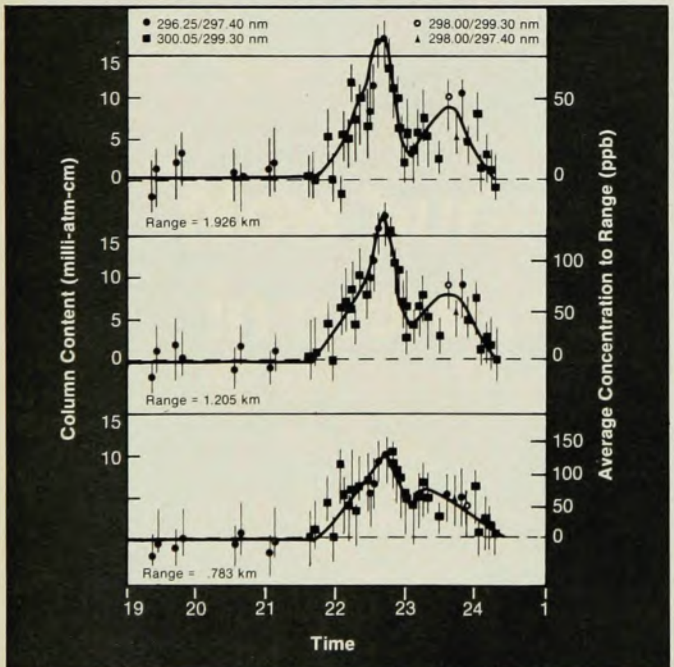
REMOTE SENSING OF ATMOSPHERIC SO_2

The second in our series of CMX-4 applications reports on remote sensing of atmospheric sulphur dioxide and other pollutant gases by NASA Langley Research Center, Hampton, Virginia.

Pictured at left is NASA's mobile lidar system in which a Chromatix CMX-4 tunable UV laser is used as the radiation source for differential absorption and scattering measurements. Each measurement was taken with a wavelength pair from the tunable laser corresponding to a maximum and minimum of the SO_2 absorption spectrum. As part of the atmospheric studies, quantitative measurements of sulphur dioxide from a local steam generating plant were made. Shown at left is the time history of atmospheric sulphur dioxide concentration taken along a measurement path to three ranges. At 2100 hours, the wind direction shifted from out of the west to out of the south, and finally at 2400 hours from out of the southwest. At 2245 hours, the steam plant began a scheduled variation in sulphur dioxide emission.

For complete details on this interesting study, write Chromatix for a copy of "Remote Sensing of Atmospheric SO_2 Using the Differential Absorption Lidar Technique," a paper by J.M. Hoell, Jr. and W.R. Wade of NASA Langley and R.T. Thompson, Jr. of Old Dominion University.

NO. 2 OF A SERIES



Time history plots of atmospheric SO_2 concentration.

chromatix

1145 Terra Bella Avenue
Mountain View, CA 94043
Phone: (415) 969-1070
Telex: 910-379-6440

In Europe:
D6903 Neckargemünd 2
Unterestrasse 45a
West Germany
Phone: (06223) 7061/62
Telex: 461691

THE CMX-4 AT WORK

Circle No. 11 on Reader Service Card

paleontologists ten million years from now they will characterize our period (the present) as the "age of extinction."

References

1. "US Energy Resources, a Review as of 1972, Part I"; Serial No. 93-40 (92-75) prepared by M. King Hubbert, Office of Energy Resources, US Geological Survey at the request of Henry M. Jackson, Chairman, Committee on Interior and Insular Affairs, US Senate, June 1974. US Government Printing Office 1974, (31-8200).
2. American Electrical Power Company, Inc. advertising in *Newsweek*, 3 Nov., 1975; page 67.
3. J. I. Shonle, *Environmental Applications of General Physics*, Addison Wesley, Reading, Mass. (1975); page 377.

ALBERT A. BARTLETT
University of Colorado
Boulder, Colorado

More on civil defense

The "debate" on civil defense by Arthur Broyles and Eugene Wigner versus Sidney Drell (April, page 45) ignored the major role that fire will play in any nuclear war, be it large or small. The tendency of the physicist to assign the most familiar effect the greatest importance was apparent in this article. Thus, the electromagnetic pulse, thermal radiation, blast and fallout were given major roles, whereas fire was relegated to two short sentences in the section on shelter design.

The effectiveness of the incendiary air raids on Japan and Germany in which firestorms developed far exceeded that from the high-explosive air raids in terms of damage and casualties.[1,2,3] Even in the attacks of Nagasaki and Hiroshima, between 50 and 65 percent of the deaths and casualties are attributable to fire. There were 68 000 killed at Hiroshima and 38 000 killed at Nagasaki. The interesting comparison can be made, that a firestorm developed at Hiroshima and not at Nagasaki. However, even in Nagasaki, fire played an important role in inflicting damage and casualties.

As a further basis for comparison, the great Tokyo air raid of 9–10 March 1945 killed 83 793, the Dresden fire raids of 13–14 February 1945 created a firestorm in which 135 000 died, and the Hamburg fire raids from 24 July to 3 August 1943 generated firestorms that killed more than 43 000. These fires created firestorm winds[1,3] over areas up to 16 km^2. The Dresden firestorms were the most severe, and they probably most nearly approximate the fire that will develop from the large-area ignitions generated by a thermonuclear weapon. In this raid, the shelter ventilation systems, in many cases, collapsed and there is evidence that the intense fire whirls associated with the firestorm generated pressure differential fluctuations that caused injected lethal concentrations of carbon monoxide into some of the shelters.

Theoretical studies[4,5,6] of the fires generated by a five-megaton thermonuclear weapon, clearly indicate that almost all buildings from ground zero out to 8 km will be destroyed by fire. Many of these will start as a result of events other than thermal radiation. The rate of postulated destruction decreases to near zero at a range of 17.5 km; however, these studies largely ignore the spread of fire due to fire fronts and firebrands. These studies also show that the use of fallout shelters in large public buildings will result in the death by fire of large numbers of people, if the shelters are not especially designed to withstand the burning of the building. Even in this case, if there is a full-fledged firestorm development, the probability of survival is small. In the large, experimental fires of Project Flambeau, some were designed to produce firestorm-firewhirls. The areas in which they occurred were scoured clean, down to rocks the size of pebbles (about 1 cm) and all combustibles were burned off flush to the ground. It is possible to generate such large firewhirls by igniting 27 hectares or more[7] simultaneously with a fuel loading of dry fuel greater than about 35 kg/m^2.

It has been indicated that as much as 10% of the United States would be destroyed by fire, even in the most modest nuclear exchange. Some areas are more vulnerable than others; for instance a modest nuclear attack in Southern California during a Santa Ana wind would effectively destroy much of the area.

It is probable that nuclear weapons will be used again against civilian populations. It behooves the planners of strategy to make realistic analyses of the impact of even limited use of nuclear weapons and to provide for the protection and preservation of the population. Otherwise, the destruction of our major cities by bomb and fire is highly probable.

References

1. D. Irving, *The Destruction of Dresden*, Ballantine, New York, (1965); pages 219–223.
2. S. Katsumoto, (written by S. Iwanami), *The Great Tokyo Air Raid*, Tanaha Shoji, Tokyo (1975); page 190.
3. C. F. Miller, *Fire Fighting Operations in Hamburg Germany During World War II*, OCD Contract DAHC 20-70-C-0307, USR Research Co., San Mateo, California (1971); page 107.
4. H. J. Avise, *Development of a Shelter Blast and Fire Vulnerability Data System*, Contract No. DAHC20-70-C0385, System Sciences Inc., Bethesda, Maryland 20014, November 1971, page 39.
5. A. N. Takata, F. Salzberg, *Development and Application of a Complete Fire-Spread Model*, Contract No. 0222867C1498, IIT Research Institute, Chicago, Illinois, 60616, (1968); Summary, pages 1, 2, 3.