ENERGY

from opulence to sufficiency

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From Opulence to Sufficiency

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BOOK

*To you, reader, in whose hands lies the opportunity to steer our nation to a path of moderation. As moderation was the cornerstone of Hilton's Shangri-La (*Lost Horizon*), so moderation in energy usage, as well as in all our activities, may prove to be the key to a viable future for our society.*

Published in 1980 by Praeger Publishers
CBS Educational and Professional Publishing
A Division of CBS, Inc.
521 Fifth Avenue, New York, New York 10017 U.S.A.

0123456789 056 987654321
BRBR

Library of Congress Cataloging in Publication Data

Krenz, Jerrold H. date
Energy, from opulence to sufficiency.

Bibliography: p.
Includes index.
1. Power resources–United States. 2. Energy conservation–United States. I. Title.
TJ163.25.U6K73 333.7 79-15059
ISBN 0-03-057001-8

Printed in the United States of America

Preface

Judging from frequently expressed views of the energy crisis, most individuals would prefer to return to the days of plentiful supplies of low-priced fuels. Unfortunately, this is not a valid option. "But surely," many argue, "if we use our ingenuity, alternative sources of energy will be found, and gasoline wars (or their equivalents) will return." It is often overlooked that our past technological successes have been dependent on abundant and cheap resources. Because gluts of fuels, rather than scarcities, have dominated the past, they tend to color our expectations for the future.

Extricating ourselves from the present dilemma will very likely require all the ingenuity that we can command albeit that we now need to devise solutions that do not depend upon plentiful resources. In the case of energy, we need to adapt both our technology and our societal habits to doing more with less. Resource shortages, excessively polluted air, and economic limitations all tend to point in the same direction—to the need of more effective utilization of energy. Reducing energy consumption in the United States, if we make the appropriate commitments, may not be as difficult as generally assumed. Our present patterns of energy usage, the result of cheap fuels and little concern for environmental effects, are very wasteful.

As the title of the first chapter states, there is a crisis of rising expectations. Almost simultaneously with the 1973-1974 oil embargo, U.S.

production of petroleum started to decline. Consumption, however, continued to increase. Concurrently, energy-using activities have resulted in excessive levels of harmful atmospheric pollutants. Historic growth rates in energy consumption have tended to influence unduly the projections of energy consumption in the United States. Because of the depletion of domestic reserves of oil and natural gas as well as export limitations imposed by the Organization of Petroleum Exporting Countries (OPEC), it now appears that these projections will be unrealizable. However, more effective utilization, that is, accomplishing the same task with fewer energy inputs, is economically viable.

Chapter II deals with the important technical aspects of energy conversion and utilization. Not only are the quantities used to express energy and power discussed (as well as the difference between these two terms), but also the equally important concept of energy quality is addressed. The generation and usage of electrical energy are discussed, emphasizing the importance of distinguishing between different forms of energy (heat and electricity in this case). The chapter concludes with a brief treatment of important thermodynamic principles.

The next chapter deals with environmental limitations, both global and local, that constrain energy usage. Expectations of exponential growth, that is, an increase by a constant percentage each year, are shown to be unrealistic. No matter how great the reserves of a resource may be, exponential growth in consumption leads to the depletion of the resource in a surprisingly short time. The chapter concludes with a discussion of a nineteenth-century projection by the British economist Jevons which was not fulfilled. Like many of today's planners, Jevons felt that national progress was dependent on continued growth in energy consumption.

Chapter IV, a treatment of domestic fuel reserves, touches on many of the problems associated with their extraction and usage. Domestic reserves of both crude oil and natural gas, according to most accepted estimates, are shown to be insufficient for expanded production of these fuels. Increased usage of coal, however, is possible.

More effective energy utilization, the subject of Chapter V, is very likely to be the next large-scale energy transition because of the increased costs of all fuels. Energy per se has tended all too frequently to be endowed with a value of its own. By considering the tasks for which energy is used, substantial reductions in energy usage can be economically achieved, as is shown in Chapter V. Energy usage is discussed for each sector, household and commercial, transportation, and industrial. Sufficient examples are included to substantiate the conclusion that a 50% reduction in energy usage can probably be achieved with investments no greater than those that would otherwise be used to expand energy production.

Chapters VI and VII deal with nonfossil fuel sources of energy, which at present supply little or no energy inputs but which in time might supply significant quantities. Nuclear energy, fission, has its advocates and adversaries, many of whom are emotionally entrenched in their own positions. The author views fission-produced energy as a Faustian bargain: we can have plentiful supplies of energy but at the cost of an unprecedented waste disposal problem. Proponents of nuclear energy argue that the waste problem *will* be solved. However, unless a breeder reactor is developed, or an energy-producing controlled-fusion reaction is achieved, nuclear energy will be limited by the availability of uranium. Radiation resulting from the release of radioactive isotopes and possibilities of major reactor accidents are also discussed.

Nonnuclear sources of energy, discussed in Chapter VII, are shown to be considerably more benign. With the exception of solar space and water heating, most of these are yet to be developed. Therefore, unless unforeseen technological breakthroughs occur, energy produced by these technologies is likely to be expensive, and hence more effective utilization will be necessary. Furthermore, the potential contribution of alternative sources is very likely to be considerably smaller than many of their proponents suggest.

The concluding chapter attempts to synthesize the concepts developed individually in the earlier chapters. As often is the case for seemingly complex problems, appreciation of a few frequently overlooked key concepts can be sufficient for developing a viable national energy policy.

This book is an outgrowth of my earlier technical book *Energy: Conversion and Utilization*. A technical background, however, is not necessary to follow the arguments of *Energy: From Opulence to Sufficiency*, which draws on several disciplines to develop a holistic view of energy-related problems. By focusing on interdisciplinary aspects, technological, environmental, economic, and social, more effective utilization emerges as not simply an attractive possibility, but as the cornerstone for a sustainable future.

I am grateful to many colleagues at the University of Colorado who provided useful suggestions, in particular to Dwight Nicholson (now at the University of Iowa) and Elizabeth Moen, who patiently reviewed the entire manuscript providing numerous useful comments. David Bartlett gave a most helpful critical review of the chapter on nuclear energy. Other suggestions were provided by Walter Jessel of IBM (former president of the Colorado Mountain Club) and Susan Carpenter of the Rocky Mountain Center for the Environment. I deeply appreciate the help and encouragement of Frank Kreith of the Solar Energy Research Institute (formerly a colleague at the University of Colorado). Nevertheless, I fully accept responsibility for any errors or misjudgment that may remain.

The credit afforded by a mere acknowledgment is quite insufficient for the contribution of my wife, Maria. In addition to editing and typing numerous drafts of the manuscript, she critically reviewed the text, insisting throughout that arguments be as clear, concise, and readable as possible. She is responsible for deleting many of the obtuse discussions, often overburdened with jargon, that appeared in early drafts. While we have worked together on other manuscripts as well, a recognition on the title page of her contribution to this book is lacking only because of her modesty.

Contents

Chapter I

The "Energy Crisis": A Crisis of Rising Expectations

The frequently referred to energy crisis is often perceived as being simply an energy shortage, that is, a demand for energy greater than that currently available. Supply, to the extent that it is regarded as insufficient, is only part of the present dilemma. Energy-consuming activities that convert fuels to heat and useful work are frequently accompanied by undesirable as well as unhealthy side effects. The combustion of fossil fuels produces atmospheric pollutants that have substantially degraded urban-industrial environments throughout the world. Hence, the industrial benefits that have accrued through increased energy usage are tending to be negated by the effects of increased pollution.

Perceived shortages and insufficient supplies raise the question of quantity. How much energy is sufficient? How great must energy inputs be to provide the well-being or life-style that we desire? Present energy use in the United States is very large—excessive is probably a more descriptive term. Perceived needs are often predicated on the assumption that more effective energy utilization is not possible. However, increased efficiency in the usage of energy is not only possible, but from a pollution aspect it is desirable. Furthermore, it is economically viable. Energy usage patterns that have evolved have been based on low-priced, readily available supplies. The domestic portion of these supplies is no longer plentiful, a result of the depletion that our high level of usage has precipitated.

Our perception of the future also exacerbates the energy situation: energy needs are assumed to increase at a yearly rate considerably in excess of foreseeable increases in population. Envisioned future shortages are not shortages in the sense that consumption would be reduced from that at present, even though this level may readily be shown to be excessive, but shortages in the sense that increases in the rate of consumption could not be achieved. Furthermore, extrapolations of "need" for the remainder of this century tend not to be based on long-term historical data that suggest only modest increases but on the unprecedented increases that occurred over the decade prior to 1972. Economic hopes also seem to be tied to economic growth that occurred over this unique decade.

Electrical generating capacity, however, has, throughout the twentieth century, been doubling every decade. In the last few years environmentally imposed constraints have tended to reduce the desired expansion by utilities. Again, the supply-demand conflict for electricity can be mitigated either by increasing supply, the historically relied-upon approach, or by using electricity more effectively. Increased prices for electrical energy, the result of higher fuel prices and skyrocketing utility construction costs, suggest that investments to improve the efficiency of using electricity are appropriate.

The underlying reasons for the energy crisis are numerous and are in dispute among experts, but a more or less agreed-upon conclusion is that the era of cheap energy supplies in the United States is over. It is in this light that the energy crisis will be examined. Although we have a crisis, it is a crisis in the sense that we as a nation do not quite know how to proceed. Furthermore, it is not a crisis for which a long-term solution can be achieved by simply increasing supplies.

More effective utilization will be necessary, both of the fossil fuels on which we depend almost wholly for energy and of inputs that will be obtained through new technologies, such as solar energy.

A SIGN OF TROUBLE: DETERIORATING AIR QUALITY

Fossil fuels (coal, petroleum, and natural gas) provide 93% of the energy inputs for the United States while water power and nuclear energy provide the remaining 7% [1]. Even if the rather optimistic projections by proponents of nuclear energy are realized (projections that appear very unlikely to be fulfilled), fossil fuels will continue to be the dominant energy source for the remainder of this century. The process of obtaining energy from the combustion of fossil fuels, however, results in many undesirable and frequently hazardous atmospheric pollutants.

Incomplete combustion produces carbon monoxide, an odorless, colorless gas, that owing to its reaction with the hemoglobin of the blood is extremely harmful. From 1940 to 1970 the emissions of carbon monoxide in the United States increased by 150% [2]. Hydrocarbon emissions, that is, products formed by the incomplete combustion of petroleum fuels, increased by 120% over this same period. Both of these pollutants are primarily results of the internal-combustion engine on which nearly all forms of transportation depend. Excessively high combustion temperatures also result in nitrogen oxides, the emissions of which increased 190% during the 1940–1970 interval. Approximately one-half of these emissions are from vehicles, the other half from electric power plants. Sulfur oxide emissions result from the combustion of fuels containing sulfur impurities (coal and petroleum) that are used primarily for the production of electric power. These emissions increased by 60% from 1940 to 1970. In 1970 the yearly per capita emissions of carbon monoxide totaled approximately 1000 lb, while the emissions of each of the other pollutants were 200–300 lb. Affluence and effluence have not been unrelated.

The continued deterioration in air quality resulting from increased emissions of pollutants prompted federal legislative activities culminating in the passage of the Clean Air Act (PL 91-604), which was signed by President Nixon on the last day of 1970. The Environmental Protection Agency, established earlier in 1970, was given the responsibility of implementing the provisions of the Clean Air Act.

To achieve acceptable levels of atmospheric pollutants, levels that would not be unduly injurious to public health and safety, national ambient air quality standards have been established. These ambient standards, designed to provide guidelines for enforcement decisions, drew on the results of federally sponsored research conducted prior to the enactment of the 1970 Clean Air Act. The act also established a set of emission standards, that is, a limit on the quantity of pollutants that could be emitted by various sources. The goal for reduced emissions was to be achieved in a gradual fashion according to an established time schedule. Implementation of the Clean Air Act has resulted in a small but not insignificant improvement in air quality.

Motor vehicles with reduced emissions are slowly replacing older, more polluting vehicles. Full compliance of vehicle emission standards was to have been achieved by 1977 models. However, because of pressures exerted by the automobile industry, the implementation of the original standards has been delayed. Industry claims that the standards cannot be achieved with currently available technology. This response needs to be qualified. Although the initially proposed emissions standards, determined on a per mile basis, can readily be achieved with moderate-sized vehicles, this was not the case for the oversized, overpowered automobiles that the U.S. manufacturers produced. The achievement of cleaner urban air is being needlessly delayed. Many electric power plants, the other significant source of air pollutants in highly urbanized areas, have shifted from coal to less polluting but scarcer fuels.

The Clean Air Act also takes into consideration that unfavorable weather conditions can result in a protracted accumulation of pollutants that could lead to some form of disaster. In 1952 a pollution disaster in London resulted in 4000 deaths. Since then, the soft coal that was used in home furnaces and fireplaces and that produced the "killer smog" has been replaced by alternative but less abundant fuels. In the United States, Donora, Pennsylvania, experienced an extended temperature inversion in October 1948. The air inversion trapped the emissions of the steel mills as well as the smelter and coke plants of the valley in which Donora is located. Within 5 days, more than 40% of the town's 14,000 residents became ill, and 20 pollution-related deaths occurred [3].

Federal criteria have been set for dealing with these potentially dangerous intermittent high ambient levels of atmospheric pollutants. Three pollution levels, each of which requires explicit actions by the communities affected, have been established. The most serious level, emergency, would require the curtailment of all but essential activities, including all motor vehicle usage except that approved by the police. Severe air pollution episodes would, if appropriate actions were enforced, drastically affect energy-related activities.

In 1970 the average level of sulfur oxides for New York City was three times that considered acceptable for human health [4]. Furthermore, sootfall, a substantial portion attributable to electric power plants, was estimated in 1965 to be 60 tons per square mile (mi^2) each month; in 1 year this amounts to an accumulation of approximately $\frac{1}{4}$ kilogram per square meter (kg/m^2) [5]. Particulate emissions (soot) and sulfur oxides react synergistically resulting in a greater health hazard than if either is present alone. The sulfur oxides react with water vapor and form sulfuric acid, which is then carried into the lungs by the particulates. London's killer smog was the consequence of this effect.

Regulations to prevent the deterioration of air quality below the established standards have affected the availability of electric power. As a result of the high pollutant levels, the construction of new fossil fuel-using power plants in or near New York City is no longer feasible. As early as 1969 shortages of electric power developed [6]. Electric generating capacity was insufficient to provide for the air conditioning demanded on hot stifling afternoons. The voltage was lowered in so-called brownouts to reduce everyone's power consumption rather than totally curtail electricity in selected areas. In 1969 a shortage resulted from an unanticipated series of equipment failures, but in subsequent hot summers the desired peak demand for electric power continued to exceed generating capacity.

Utilities, owing to their franchise, are required to anticipate increases in demand and to expand their generating capacity accordingly. Demand, however, was not only anticipated, it was actively stimulated. Prior to 1971 Consolidated Edison, the utility supplying electric power for New York City, and other utilities throughout the United States, engaged in promotional advertising urging customers to use more electrical energy. The year 1971 marked a significant turning point for a utility: Consolidated Edison switched to advertisements urging the conservation of electric power! [7]

Air pollution in New York City is the result of almost all urban activities. Besides the electric power plants, automobile emissions are a significant source of foul air. While automobile-produced smog is now commonplace in all large cities, it was Los Angeles that first became well known for it. Smog, at least the U.S. variety, is caused by a series of complex chemical reactions involving the hydrocarbon and nitrogen oxides emitted by the internal-combustion engine used in automobiles and trucks. Smog, consisting of a collection of oxidized hydrocarbons formed in the presence of sunlight, represents a severe health hazard and also injures vegetation. Transportation in the Los Angeles valley, an air basin with frequent temperature inversions that trap effluents, is dominated by the privately owned automobile. Car usage has been encouraged by the construction of one of the most complex freeway systems in existence. Alternative modes of transportation are almost nonexistent.

Because of the persistently poor air quality of the region, there has been no construction of fossil fuel-using electric power plants for the past several years. Furthermore, the use of nuclear power in the region has been considered by many to be unduly risky, because of the numerous earthquake faults along the coastline—the most desirable location from the point of view of obtaining cooling water for power plants.

Rather than curtail increased usage of electrical power, southern California has "solved" its electrical needs by, in effect, exporting the pollution. Utility companies supplying electricity for the area are involved in the ownership and construction of gigantic coal-fueled power plants located in Nevada, Utah, Arizona, and New Mexico. The city of Los Angeles, for example, has a 20% interest in the Mohave plant near Bullhead City, Nevada, and a 21% interest in the Navajo plant near Page, Arizona.* Southern California Edison owns 56% of the Mohave plant and 48% of the largest units of the Four Corners plant in Fruitland, New Mexico† [8]. In addition, Southern California Edison along with San Diego Gas and Electric Company and Arizona Public Service were partners in the proposed Kaiparowits plant in southern Utah. This plant, the construction of which has been cancelled, would have been the largest electric power plant in the world and would have resulted in a significant deterioration of air quality of the region. Bryce Canyon, Glen Canyon, and other areas administered by the National Parks system would have been adversely affected. The completed plan would even have had a significant impact on the air quality of the Grand Canyon. It is probable that the withdrawal of the California participants was prompted by the threat of a major lawsuit by the Sierra Club Legal Defense Fund [9].

*Their share of the generating capacity for these two plants is approximately 800 megawatts (MW).

†Their share is 1700 MW.

Los Angeles, owing to its out-of-state electric power plants and to its strict emission controls for automobiles (California has standards that are stricter than federal standards), has been able to achieve a small improvement in air quality. High smog levels, unfortunately, are no longer limited to the Los Angeles and New York megalopolises—smaller cities are equally affected. Even Denver, which had long been noted for its pristine air affording a spectacular view of the Continental Divide, has not been spared.

DOMESTIC FUELS: NO LONGER CHEAP AND ABUNDANT

Even before the Arab oil embargo (October 1973 to March 1974), the maldistribution of gasoline supplies had resulted in several temporary and localized shortages. The lines of cars at gas stations across the country during the embargo demonstrated not only the U.S. dependence on imports but also the inability of the nation to adjust to fluctuation in energy supplies. By January 1974, petroleum imports were 2.7 million barrels per day (bbl/day) less than that anticipated [10]. The key term relative to the 2.7 million barrel shortage is *anticipated*. Petroleum consumption, as indicated in Figure 1-1, had been rapidly increasing at a yearly rate of 4.2% during the decade prior to the embargo [1, 11, 12]. The shortage of 1974 resulted in a level of

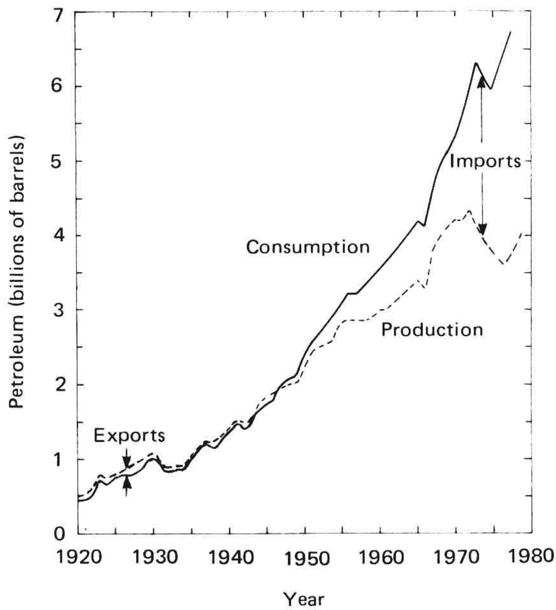

Figure 1-1 U.S. yearly petroleum consumption and production [1, 11, 12].

petroleum consumption comparable to that of 1970, a year not noted for either shortages or a degree of frugality. Increases in petroleum usage have been readily accepted, but we were quite unable in the few months of the embargo to adjust to a decrease, even though that decrease resulted in a level of usage that we were quite comfortable with a few years previously.

As indicated in Figure 1-1, domestic production of petroleum products has not increased as rapidly as consumption. Domestic production of petroleum, obtained from crude oil and natural gas liquids produced by gas wells, reached a peak in 1972 and has since declined. Notwithstanding, prior to 1975 the United States was the largest producer of petroleum in the world (the USSR moved into the lead in 1975). Prior to 1966 U.S. petroleum production exceeded that of the entire Middle East* [13]. However, in addition to being the largest producer of petroleum, the United States is the largest consumer. Imports in 1973, even with the embargo that occurred during the last quarter, were twice those of 1969 and four times those of 1959. An earlier Arab embargo, attempted and soon abandoned following the Arab-Israeli war of June 1967, had little effect on the United States. Had it not been for the 1973-1974 embargo and the subsequent quadrupling of prices and production limitations by the Organization of Petroleum Exporting Countries (OPEC), U.S. imports would have probably continued to increase steadily. A later embargo would have resulted in a much greater disruption.

Increased consumption of petroleum has been primarily the result of increases in transportation and the substitution of petroleum for coal in producing electric power. Present refinery capacity is also considerably less than petroleum demand (about 30% less); hence fully refined petroleum products are imported. The hesitation of refiners to increase capacity may reflect the warnings offered by many experts that U.S. petroleum reserves are insufficient to warrant expansion.

Following the 1973-1974 oil embargo, the OPEC nations reacted to the steadily increasing demand for petroleum by the United States as well as other nations by drastically increasing their prices. By the middle of 1978, the cost to U.S. refineries of imported crude petroleum was $14.50/bbl [1], whereas immediately prior to the embargo it was $4.50 and a year before that as low as $3.00 [14]. Prior to the embargo, U.S. petroleum consumption and hence imports were expected to continue to grow. The National Petroleum Council in 1972, for example, judged that growth rates for energy consumption until 1985 would not be significantly less than the 4.2% per year (yr) that occurred before the embargo [15]. The oil company executives, however, did not envision the substantial price increases and production limitations that OPEC was able to effect.

As a consequence of the oil embargo, construction of the Alaskan pipeline

*The significant petroleum producing countries of the Middle East are Iran, Iraq, Kuwait, Oman, United Arab Emirates, and Saudi Arabia.

for transporting oil from the northern regions of Alaska was not only initiated but was put on a crash schedule. The pipeline's initial capacity of 1.2 million bbl/day meets only about 7% of 1978 petroleum consumption (a capacity of 2 million bbl/day is anticipated for 1980). The pipeline's cost in 1969 was estimated at $1.5 billion; by 1976 its cost had risen to $7.7 billion [16]. The difficulty of constructing a pipeline across the harsh Alaskan terrain was drastically underestimated. In addition to the cost of constructing the pipeline, $3.5 billion has been spent on the wells and associated equipment. Although the quantity of oil provided by the pipeline will obviously be significant, it will reduce imports by only 20% (one-third when full capacity is achieved), providing consumption does not increase and other domestic production does not decline.

During 1974 natural gas consumers also experienced shortages. Production reached a peak in 1973. Inasmuch as natural gas is nearly free of impurities, it is the most desirable of fuels; it is used for everything except transportation. Nevertheless, its price has been much lower than that of other fuels. The maintenance of low prices through federal regulation of interstate rates has encouraged wasteful consumption, which has resulted in the unavailability of residential gas hookups in many localities and forced potential users to install alternative systems. Although increased prices could discourage waste, increased returns for producers might encourage an overexpansion of producing facilities, which would in turn result in an even more rapid depletion of gas reserves and speed up the day when all will be gone.

Importation of natural gas is possible. Approximately 5% of supplies in 1977 were imported from Canada and Mexico through pipelines. Natural gas can also be liquefied by cooling it to −260°F (−162°C) and then shipped in giant Thermos-bottlelike tankers. A rupture of a tanker, however, could produce a highly explosive cloud of gas. Ocean ports removed from population centers will be necessary if gas imports are to be increased.

Domestic production of both petroleum and natural gas depends on the amount of fuel remaining in the earth. The ultimately recoverable quantities of crude oil and natural gas (hydrocarbons) have in the past been assumed to be sufficient to justify increased production, but this may no longer be the case. Studies by M. King Hubbert, for example, suggest that the United States has already extracted approximately one-half of the usable hydrocarbons that were initially in place [17]. Because the fuels comprising the already recovered first half were probably the more accessible portion of the resource, the second half, which we are now using, is increasingly difficult and expensive to obtain. Expanding production would not only be costly but would require investments that may be of little value when the resource is depleted. Given present production rates, oil and gas reserves are sufficient for only the remainder of this century. A more moderate production rate is therefore desirable if hydrocarbon fuels are to be available in the next century.

Coal is much more plentiful than hydrocarbon fuels. The U.S. reserves of