Energy Conservation

Some challenges are proposed for science and technology.

G. A. Lincoln

As the energy crisis looms ever larger, energy conservation is beginning to receive increasing attention (*1, 2*). Energy conservation can make a substantial contribution in ameliorating or postponing the potential energy shortages faced by the United States over the next several decades. To realize this contribution, however, will require not only the political will to implement the necessary conservation measures but also the imagination and intellectual resources of the scientific community to develop new technologies to increase the efficiency of energy use.

This article is directed to provoking thought on how to attain economic, social, and other objectives while using less energy resources. Its purpose is not so much to answer questions of energy conservation as to raise them. The discussion is provocative in places, deliberately so. It is not intended to suggest any policy commitments on the part of the author or any of those whose advice and suggestions have contributed to the discussion. Rather, the objective is to enlist the interest of thinking people, and particularly the scientific community, in the energy conservation effort.

The history of civilization is, to a large extent, the story of man's progress in harnessing energy. Discovery of the controlled use of fire was certainly a major milestone in man's emerging domination of other forms of life. Development of the sail to utilize the energy of wind to propel watercraft opened up the rest of the world to curious and acquisitive societies around the Mediterranean basin. Windmills and watermills represented early attempts to harness energy sources for direct work. The industrial revolution, one of the great landmarks of our present culture, consisted essentially of the large-scale replacement of muscle power by controlled mechanical energy derived, in turn, from thermal energy.

A less noted, but equally significant, impact of the industrial revolution was the general introduction of available energy when and where it was needed. In previous ages man used energy largely when and where it was found: he sailed when the wind blew, he forged his metals by the forests where firewood was plentiful. With the advent of combustion engines, however, man was freed to travel without (or even against) the wind, and at speeds which animals could not match. He could transmit large amounts of controlled mechanical power throughout a mill by use of shafts and pulleys. And finally, the understanding of electricity completed the revolution by permitting not only mechanical power but also information to be made available far from the originating source.

First wood, and then coal was used to satisfy the increasing demands for manageable sources of thermal energy. Both served the purpose admirably. But both wood and coal presented certain problems. Then came the discovery of oil and gas and how to use them with greatly increased versatility and flexibility in conversion of fuel to thermal energy. The internal combustion engine arrived and flourished, automatically fired boilers became the norm, and our modern mechanized society was at hand.

Increases in the convenience and economy of harnessed energy have led to additional applications, which in turn have increased the demand and, coming full circle, fostered further technological advances in the convenience and economy of harnessing energy. The use of energy in the United States today is not only growing but accelerating. With only 5 percent of the world's population, this nation already consumes about one-third of the world's energy production. And the current annual appetite for about 70×10^{15} British thermal units (Btu) is projected to double within 20 years to 140 quadrillion Btu (that is, from 1.7×10^{19} to 3.5×10^{19} calories) (*3*). Unfortunately, the finding and production of domestic energy supplies is not keeping pace with this rapidly growing demand. Thus, careful attention must now be addressed to the adequacy of our remaining domestic energy resources. More than 10 percent of our present requirements are met by importing foreign oil (about 4.6×10^6 barrels per day). Even the more conservative projections indicate that the level of imports of oil, and also of some gas in liquefied form, must increase a great deal within the next decade alone to compensate for the projected shortfall of available domestic fuels. This situation suggests serious problems both for the national security and for the balance of payments.

Furthermore, recent practices and trends in methods of fuel extraction, energy conversion, and energy utilization have caused pollution problems affecting the nation's health and natural environment. Yet because of extensive interdependence among these important national concerns—problems related to energy and problems related to the environment—measures to alleviate one can easily aggravate another. For example, estimates derived from a recent study indicate that the removal of lead from gasoline for pollution control as presently planned will cause an increase of about 1 million barrels per day in our gasoline needs by 1975, thus worsening the nation's supply situation (*4*). Some of the state implementation plans to meet the requirements of the 1970 Clean Air Act (*5*) provide other examples of such conflicting demands. Several of these plans project a demand for quantities of fuels of low sulfur content (gas, oil, coal, nuclear power) which will simply not be available on the time schedule envisaged. In addition, the shifts in equipment and fuel types and the processing costs to

The author recently retired as director of the Office of Emergency Preparedness, Executive Office of the President, Washington, D.C. 20504.

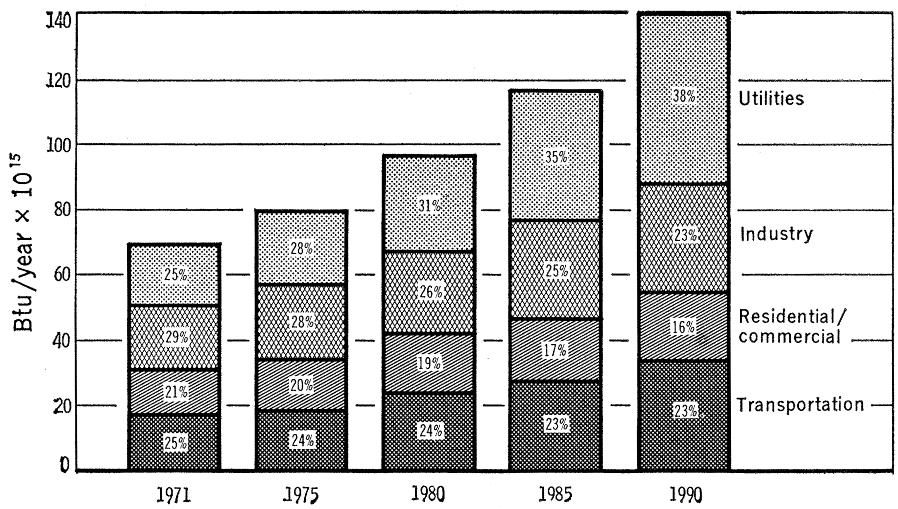

Fig. 1. Energy consumption in the United States by consuming sectors (6); 1 Btu $= 0.259$ cal; 10^{15} Btu $\cong 172 \times 10^{6}$ barrels of oil, 970×10^{9} cubic feet of natural gas, 41.7×10^{6} tons of coal.

manufacture such quality fuel can impose a severe economic penalty for the consumer. Shifts in types of fuel and their timing can have severe impacts on our industrial and economic structure; our foreign economic arrangements, including our balance of payments; our relations with other countries; and our own country's security. For energy security is now a critical component of our national security and overall foreign policy. Clearly, no one of these problems can be addressed apart from, or to the neglect of, the others; any reasonable solution must take all into account.

In order to lessen our potential dependence on foreign supply, we must increase our domestic energy supplies. Increased field exploration and extraction of oil and gas, including shale oil, are necessary. Measures should include expanded coal mining and the gasification and liquefaction of coal, more rapid introduction of electrical power generated from nuclear fuels, and greater emphasis on the development and exploitation of unconventional energy sources such as solar radiation and geothermal power. All of these will be undertaken as the demand for energy rises in relation to the supply, and fuel prices inevitably follow suit. But most of these measures take years, even decades, and even though successful, may leave a continuing energy gap. Certainly that energy gap is going to exist for a long while.

Although the increasing of energy supplies is essential, it is also important to reduce consumption or at least to ease its growth rate. This approach is intuitively appealing from the standpoint of assuaging those problems of environmental pollution which are related to energy consumption. Nevertheless, some of the potential approaches to reduced energy demand call for technology which, if available at all, is not yet advanced to an economically viable level. Equally or more difficult, some of the approaches may depend on fundamental changes in national attitudes toward living style, and even if the process of mass application of social incentives were well understood —which it is not—its ethical implications would require careful attention.

Energy conservation needs to be viewed both from the standpoint of the consumer and from the standpoint of broad national policy. The viewpoints are not necessarily conflicting, but at times may be. The useful but simplistic approach of achieving the same economic and social objectives with less energy needs to be combined with an approach of using the types of fuels which best further our national objectives while emphasizing the conservation of those fuels creating policy problems. For example, the consumption of oil is now beginning to pose policy problems. So also is the consumption of gas, since our domestic shortfall in production is made up by imported oil and gas. Hence, that conservation which holds back on consumption of oil and gas is most broadly useful. The most desirable way is through absolute reduction in consumption of energy from gas and oil. But just the substitution of more domestically available fuels, such as coal and nuclear fuel, is a plus in solving our energy problems and a logical component of an energy conservation endeavor.

Unfortunately, the concept of energy conservation through substitution of domestically more abundant fuels for the less abundant does run directly into the continuing friction, and sometimes direct confrontation, between environmental programs and energy utilization programs. Coal, for example, is abundant but often does not conform to environmental objectives. Coal now poses a challenge to science and technology of the same importance as that posed by oil and gas in the early period of their utilization for producing thermal energy.

The issue of energy conservation is an important and complex one. To provide the appropriate setting for its discussion, the general patterns of U.S. energy supply and demand will be outlined, and then the four major categories of energy consumption—transportation, residential/commercial, in-

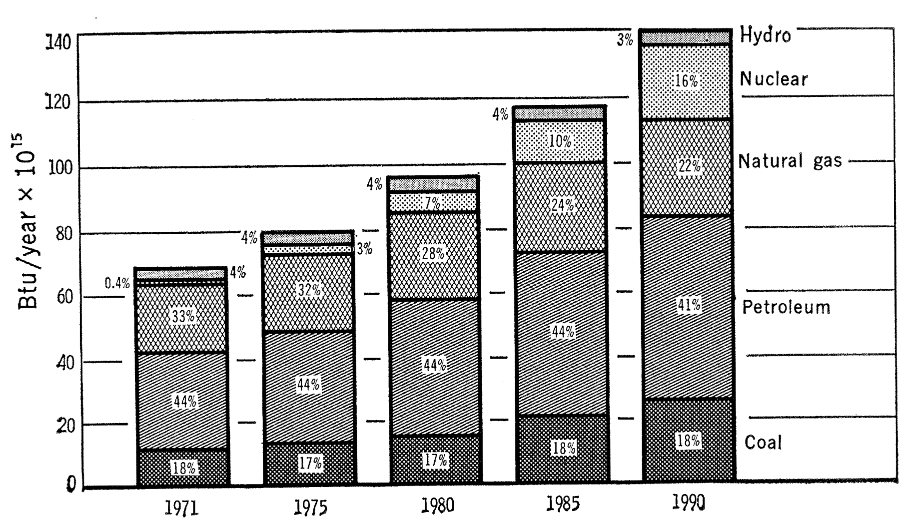

Fig. 2. Energy consumption in the United States by source (6). See Fig. 1 caption.

dustry, and electric utilities—will be examined somewhat more closely to reveal present trends and suggest possibilities for improved conservation. Finally, the complex problems of environmental pollution and economic investment will be introduced briefly.

Patterns of U.S. Energy Supply and Demand

The Bureau of Mines, Department of the Interior, has made careful projections of energy consumption by consuming sector (Fig. 1) and by source (Fig. 2) for the period 1971 to 1990 (*6*). The major projected change between now and 1990 in the consuming sector is a tripling in the energy used in generating electric power in order to meet increases in projected demand. Electrical generation is expected to increase by 72 percent from 1971 to 1980 and by 78 percent from 1980 to 1990. Transportation is expected to hold its current share of the market, with projected increases of 35 percent from 1971 to 1980 and 41 percent from 1980 to 1990. For the entire period 1971 to 1990, industrial use of fossil fuel is expected to increase by 53 percent and residential/commercial use by 41 percent. The major projected change in the sources of energy between now and 1990 is that nuclear power will significantly increase its proportionate contribution, but the consumption of fossil fuels will also increase a great deal. Projections to 1990 indicate that the sources of U.S. energy in that year will be distributed as follows: coal, 18 percent; petroleum, 41 percent; natural gas, 22 percent; nuclear power, 16 percent; hydropower, 3 percent.

In terms of dollar expenditures for energy, the patterns and trends differ considerably between intermediate demand and final demand. The final demand consists of purchases for end uses such as automobile fuel, residential heating, and exports, while the intermediate demand consists of industrial and commercial purchases to produce products and services for end consumers. Intermediate demand expenditures for energy are related very closely to the gross national product (GNP); the ratio of the two has varied less than a quarter of a percent over more than a decade. Although not correlated as closely with the GNP, the final demand for energy has grown substantially during the same period. About 85 percent

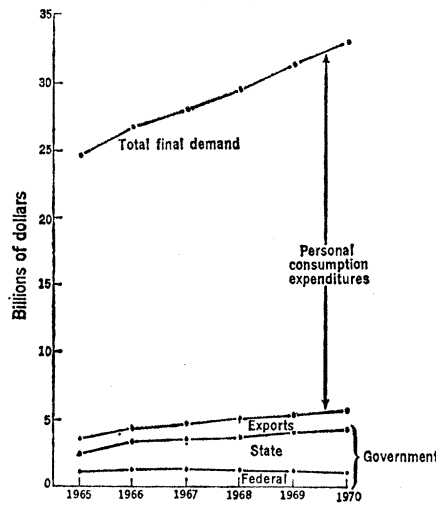

Fig. 3. Final demand expenditures for energy consumption according to the category of the consumer (*7*).

of the energy final demand during the last 5 years (Fig. 3) has consisted of personal consumption expenditures, which represent domestic consumption of fuel for such uses as private cars, home heating and air conditioning, and electric appliances (*7*).

Transportation

In 1970, transportation consumed 16.4×10^{15} Btu—one quarter of the total energy used in this country, a share which is expected to continue. Petroleum accounted for 96 percent of the fuel consumed for transportation in 1970. This amounted to 2,830,000,000 barrels of crude oil, or a rate of about 7,750,000 barrels per day (roughly equivalent to daily dissipation of a dozen 100,000-ton tanker loads). Automobiles are the leading consumer, using 55 percent of the transportation energy in 1970 (14 percent of total national energy consumption), with trucks second at 21 percent, and aircraft third at 7.5 percent. The remaining 16 percent is made up of rail, bus, waterway, pipeline, and other categories (*8*).

Major trends among transportation modes include railroads and waterways giving way to pipelines and trucks for intercity freight movement; buses and railroads giving way to aircraft and automobiles for intercity passenger traffic; and mass transit, especially buses and trains, giving way to private automobiles for urban passenger traffic.

As Table 1 shows, enormous differences exist in the energy efficiencies of these transportation modes (*9*). For passenger travel, airplanes are less efficient users of energy than automobiles, which are in turn less efficient than buses and railroads. For freight movement, airplanes are less energy efficient than trucks and considerably less efficient than pipelines, waterways, and railroads.

Energy efficiency within transportation modes also varies substantially and, unfortunately, has tended to decrease with time. The quest for ever-increasing speed and convenience has been succeeding at the cost of increased energy consumption. The low average occupancy of commuter cars combines with short distances traveled and traffic congestion to lower drastically the energy efficiency of the automobile. In

Table 1. Transportation propulsion efficiency (*22*). Conversions are: 1 foot ≅ 0.305 m; 1 mile = 1.609 km; 1 horsepower (hp) = 746 watts; 1 knot ≅ 1.85 km/hr.

Passenger		Freight	
Transport type	Passenger miles per gallon	Transport type	Cargo ton miles per gallon
Large jet plane (Boeing 747)	22	One-half of a Boeing 707 (160 tons, 30,000 hp)	8.3
Small jet plane (Boeing 704)	21	One-fourth of a Boeing 747 (360 tons, 60,000 hp)	11.4
Automobile (sedan)	32	Sixty 250-hp, 40-ton trucks	50.0
Cross-country train*	80	Fast 3000-ton, 40-car freight train	97.0
Commuter train†	100	Three 5000-ton, 100-car freight trains	250.0
Large bus (40 foot)	125	Inland barge tow, 60,000 gross tons	220.0
Small bus (35 foot)	126	Large pipeline, 100 miles, two pumps	500.0
Suburban train (two-deck)‡	200	100,000-ton supertanker, 15 knots	930.0

*One 150-ton locomotive and four 70-seat coaches plus diner lounge and baggage coach. †Ten 65-ton cars and two 150-ton 2000-hp diesel locomotives. ‡A ten-car gallery-car commuter train, 160 seats per car.

1971, for example, 55 percent of automobile energy consumption went for urban trips of 10 miles (16 km) or less, and 56 percent of all commuting was by automobiles containing only one occupant (*10*). Emission controls also contribute significantly to lower energy efficiency; those currently being installed and projected will result in an additional gasoline consumption by 1980 of the order of 2 million barrels per day.

A large number of factors, including government policy, social and environmental concerns, the low cost of energy, uncontrolled urban growth, and the demand for increased mobility and transportation service (speed, comfort, reliability, and convenience) have contributed to a continuing shift toward the use of less energy efficient modes and to a continuing decline in the energy efficiency of all transportation modes.

Furthermore, this discouraging trend shows every indication of persisting. Projections of growth in aircraft and automobile use show that these two modes alone will account for 22×10^{15} Btu in 1985, more than 73 percent of the total transportation energy consumption for that year.

Several actions could be taken over the short and midterm periods (within 3 years and within 10 years) to increase energy efficiency, improve the balance between transportation modes, and decrease total demand for transportation. Incentives for using smaller automobiles, subsidized mass transit, and improved traffic flow through traffic metering systems and priority bus lanes, would encourage greater use of more energy efficient transportation modes. Improved communications facilities, the development of urban clusters, and the construction of attractive walkways and bicycle paths will all help to reduce total transportation demand for energy.

Estimates indicate that the implementation of short and midterm conservation measures could result in savings of 15 to 25 percent of the projected transportation energy demand by the early 1980's (*11*). These estimates are predicated on the assumption that curtailment of passenger and freight movement is largely unacceptable, so that emphasis is placed not on restrictions but on approaches designed to improve energy efficiency relative to present standards. Even though many of the measures have been tried to some extent, experience is insufficient to allow a full analysis of the effects of all plausible actions. Nevertheless, these short and midterm estimates assume no significant advances in technology.

Over the long term, however, technology and urban design stand out as the areas of greatest promise in reducing transportation energy demands. For example, the development of practical hybrid energy storage systems, such as a system combining a gas turbine with electricity, could significantly increase the operating efficiency of urban automobiles (*12*). Similarly, the quest for solutions to urban social, economic, and environmental problems is yielding concepts that have important implications for transportation. For example, the development of urban clusters can reduce drastically the need for transportation. In general, transportation energy efficiency could be greatly increased by providing incentives to separate people from automobiles, for example, rapid transit trunk lines between clusters, moving walkways, and bicycle paths. Increased understanding and appropriate coordination in transportation and urban planning can yield enormous dividends not only for energy conservation but also for the environment, and for the health and mobility of the American people.

Many of these conservation measures have costs—economic, political, and social. Government, industry, and consumers, however, must come to grips with some of the difficult choices that will have to be made over the next several decades. For example, should the federal government institute financial disincentives to encourage the use of small automobiles, as through higher use taxes on large automobiles or taxes on engine size or automobile weight? The advantages of promoting the use of smaller automobiles are numerous—savings approaching 3 million barrels per day in 1985, reduced import costs, and less pollution. On the other hand, by forcing consumers to choices they may not desire, such measures may be highly unpopular. Moreover they could produce serious, adverse economic consequences for the automobile industry and related industries.

Another hard question concerns the extent to which the federal government should encourage or subsidize mass transit. With a much greater efficiency on a passenger-mile basis, effective mass transit systems would not only materially reduce fuel consumption but also significantly ameliorate our balance of payments and environmental and traffic problems. On the other hand, to make such systems effective would probably require restrictions on consumers in the form of bans on automobile use in the inner city or high parking taxes. Moreover, adequate efforts would require an enormous capital outlay, and mass transit would have to compete with other important social needs for these funds.

Transportation serves a number of national and social goals that must be balanced against the objective of energy conservation. Nevertheless, energy efficiency must be given proper emphasis in the design, development, and utilization of our transportation systems. Any truly practical program will require a blend of actions carefully balanced and timed to avoid disruption of needed traffic flows, upheavals in life styles, damage to industries dependent on transportation, and aggravation of problems concerning the international balance of payments.

Residential and Commercial Sectors

Private residences and commercial establishments account for about one-fifth of the total U.S. energy consumption. Space heating and cooling, water heating, refrigeration, and cooking represent somewhat more than 75 percent of the commercial energy use and more than 85 percent of the residential use (*13*). By far the largest portion of this is due to space heating and cooling.

By 1980 the annual energy requirement for household space heating and cooling is expected to reach about 11×10^{15} Btu, or about 63 percent of the total projected residential and commercial energy consumption.

Some reduction in residential energy consumption could be achieved through a nationwide educational program encouraging good energy conservation practices in the home. For example, the setting of all residential thermostats 2 degrees higher during summer and 2 degrees lower during winter could produce in 1980 energy savings of about 1.3×10^{15} Btu.

The National Bureau of Standards estimates that improvements in insulation and construction can reduce the energy consumed in heating and air conditioning by 40 to 50 percent from present norms. Improved insulation technology can be readily adopted in new homes. Unfortunately, the high cost of introducing such improvements into existing homes by present methods makes widespread introduction there less likely (except for storm windows). The discovery and development of inexpensive insulating techniques for reducing the energy loss from existing houses is therefore an urgent need. Furnaces of higher efficiency, with provision for easy periodic cleaning by the homeowner, can and should be developed also.

An important step was taken in 1971 with the revision to the minimum property standard of the Federal Housing Authority (FHA), which significantly tightened insulation requirements for single-family houses. Unfortunately, many apartment houses and single-family homes which were built under conventional loans do not meet desirable minimum standards. Further tightening of insulation requirements for single- and multiple-family homes, offices, and other buildings would provide an additional and important contribution in reducing unnecessary energy consumption.

Higher fuel costs may make economically feasible the wider use of common district heating, total energy systems, and heat pumps. More urban buildings could be heated and cooled by using the steam rejected by a central power generating station. Municipal waste could be burned in power plant boilers along with coal, thus reducing fossil fuel requirements for power generation by an estimated 8 percent (*14*) (and also helping in solid waste disposal). One consulting engineer has estimated that a saving of 15 to 20 percent can be achieved in the amount of energy normally used in office and commercial buildings by such energy conservation measures as using better insulation to recover the heat in winter and the cooling effect in summer from the building's exhaust air, recovering heat from lighting, reducing heating (or cooling) and lighting levels in corridors and certain other spaces, and reducing the amount of outdoor air drawn into the building (*15*).

All of this suggests that by 1990 the nation's overall space heating and cooling requirements could be reduced by perhaps 30 percent from the projected demand levels in that year. Even within 10 years a more modest 20 percent reduction (about 2×10^{15} Btu) should be possible, most of it through improved insulation. Additional energy savings in water heating, refrigerating, cooking, and lighting systems and in air conditioning equipment are also possible. But improved technology is necessary in most cases to make the introduction and operation of the improvements economically feasible.

Industry

Industrial energy consumption constituted about 29 percent of the total domestic energy consumption in 1971 (*16*). The primary metal industries, chemicals and allied products, and petroleum refining and related industries together accounted for more than half of that. Natural gas was the most rapidly growing and largest source of industrial energy used (46.5 percent), followed by coal (26.0 percent), petroleum (16.8 percent), and electricity (10.6 percent).

There will undoubtedly be a change in the relative amounts of the various energy sources used by industry in the future. Many gas pipelines are now having to curtail shipments or existing contracts as a result of the developing shortage of natural gas. Gas prices will increase, especially as the pipelines seek to turn to such expensive sources as liquefied natural gas and synthetic natural gas. Natural gas usage certainly cannot continue to increase its share of the industrial market, and most likely will be cut back.

Today, however, plans for new petrochemical complexes call for the use of heavy oil feedstocks, primarily naphtha, and a new regulation of the mandatory oil import program will assist petrochemical producers to acquire naphtha produced from imported oil. This should enable these producers to remain competitive with foreign producers who have traditionally used these feedstocks.

The major industrial sectors have all achieved a general decline in energy used per unit output over the last decade (*13*). Nevertheless, more rapid improvement could almost certainly be effected by focusing attention on energy conservation.

Given a sufficient incentive, industry as a whole could probably cut energy demand by 5 to 10 percent of projected demand by 1980, primarily by replacing old equipment, demanding more energy-conscious design, and increasing maintenance on boilers, heat exchangers, and so forth. Underpriced energy does not help in encouraging efficient energy use and results in inadequate exploration of avenues for improvement. Any deliberate economic incentive designed to cut energy demand would be made more effective by an accompanying "energy awareness" information program directed at trade associations, professional societies, equipment advertisers, and engineering design companies.

The general introduction of planning for the total life cycle in the use of resources, to include energy-conserving recycling or reusing, could also make noticeable contributions to energy conservation as well as conservation of other resources. Secondary recovery of materials is often less energy consuming than primary extraction and production; for many nonferrous metals, recycling energy requirements are only 20 percent or less of primary processing requirements. This approach is also a prime target for research and development.

Elimination of wasteful practices is of course important. Energy is a sufficiently large expense for the major industrial energy consumers that they already try to use it as economically as possible. Thus, wasteful practices are likely to be found primarily in marginal operators or in industries for which energy is a relatively minor expense.

Electric Utilities

Electric utilities represent the most rapidly growing consumer of energy among the four major groups. Their 1971 use of about 17×10^{15} Btu is projected to expand by a factor of almost 4 within 20 years, representing an increase from 25 to 38 percent of the growing national energy consumption. Thus, any improvements which can be achieved in the energy efficiency of electric power generation are of major importance.

Utilities already concentrate heavily on efficient use of fuel because it constitutes a major operating expense. Over the past quarter of a century, industry efficiency has improved by more than 30 percent; that is, the national average for energy input (in British thermal units) per kilowatt-hour output has declined from nearly 16,000 to about 11,000 (*17*). Nevertheless, efficiency has undergone a slight decline recently, a trend which the National Coal Association attributes partly to the heavy use of inefficient, old plants and peaking generators and partly to the use of more environmentally acceptable fuels with lower energy contents (*18*). An additional factor is the increasing installation of energy-consuming pollution control equipment.

It is sometimes argued that electrical power generation as a whole is a wasteful use of energy because of the large energy conversion losses involved (the overall conversion efficiency is about one-third). This alleged wastefulness must properly be measured against the alternative of direct fuel use. Except in some large industrial applications such as aluminum production, electrical power is distributed from large central generating plants to many small customers. Thus, the comparison is between one large energy consumer and many small ones. Aside from efficiencies due to the economics of size—which are substantial—the central generating plant generally offers much better equipment maintenance, a factor which bears directly on efficiency (a half-millimeter of soot in an oil burner can reduce its efficiency by 50 percent). Power distribution by electric transmission grids is generally more efficient than transportation of coal and oil by trucks (*14*), the usual method for small consumers. Furthermore, large electric power plants permit centralized pollution control, which is both more efficient and more easily monitored. On balance, it is not at all clear that electric power generation and distribution is as wasteful from an overall point of view as some of its detractors would claim.

Regardless of its relative efficiency, electrical power is increasingly in demand because of its cleanliness, convenience, and ease of control. An important question, then, is how to increase the energy efficiency of the centralized generation of electrical power by the utilities. Certainly, increased rates of replacement for obsolete equipment and reduced delays in bringing more efficient new plants on-stream would help. Accelerated introduction of nuclear plants would ameliorate substantially the demand on fossil fuels, whether from domestic or foreign sources. Smoothing the daily demand cycle in order to reduce heavy peak loads would significantly lessen the use of inefficient peaking generators.

The mechanisms for implementing these various measures are primarily economic, and perhaps also regulatory, in nature. But in electric power generation there are also long-term opportunities for significant improvements from new technology, some of it requiring extensive research and development. Historically, the electric utility industry has lacked an organized industry-wide research program. Equipment manufacturers have performed most of the research and development that has been carried out, and this has been limited. In recognition of this problem, the Electric Research Council, representing all segments of the electric utility industry, recently established a research corporation to be supported financially on a shared basis. This corporation is intended to address critical electric power problems at both applied and fundamental levels.

The more promising approaches to long-range improvement in the efficiency of generating electrical power include advanced power cycles, magnetohydrodynamics, various types of nuclear reactors, geothermal sources, cryogenic transmission, improved "waste heat" utilization, and total energy systems. The advanced power cycle, involving the combination of coal gasification with a gas turbine–steam turbine power plant, is currently under study by the Environmental Protection Agency. It promises improved flexibility in plant size and location, relatively low cost, and potentially high efficiency. Nevertheless, full benefits depend on the development of an efficient coal gasification process. Magnetohydrodynamic techniques offer greater efficiency as well as low maintenance and substantially reduced cooling requirements. The practical realization of any of several breeder reactor principles under study would reduce not only fossil fuel demands but also nuclear fuel demands—a factor of equal importance in the long run. Geothermal power already enjoys some limited use, but large-scale exploitation (which would make available a huge new energy source) awaits extensive investigation of several alternative approaches. Cryogenic transmission systems suggest exceedingly high distribution efficiencies but present difficult problems in practical realization beyond the laboratory scale. Various uses suggested for the waste heat dissipated from electrical power plants (two-thirds of the energy value of the fuel) include district heating for nearby residential or commercial installations, hothouse support for increased agricultural production, and prevention of ship channel freezing. All require considerable additional investigation.

A particularly appealing idea is the total energy system—an integrated package for electrical generation, air conditioning, water heating, steam generation, and any other energy functions required by a residential complex or shopping center. The greatest deterrent appears to be the problem of balancing demand among the various functions, but the potential is sufficiently promising that the National Bureau of Standards is conducting a carefully controlled experiment with a pilot total energy system in an apartment-shopping complex (*19*).

Some Thorny Issues—Pollution, Investment

Most energy sources can have significant environmental impacts, for example, strip mining and the disposal of heated water from power generating plants. But conversely, pollution controls have significant impacts on energy consumption. They can and do result in the additional use of energy, and may contribute to shortages of desired fuels. For example, motor vehicle exhaust systems have been proposed to reduce automobile pollution by over 90 percent; when implemented, they will introduce fuel penalties of 5 percent or more (under 1970 performance) for *each* technique needed to control different emissions; a fully equipped car will probably experience at least a 15 percent fuel penalty (*20*).

To meet environmental quality standards industry invested some \$9.3 billion in pollution control in 1970, and this investment rate is expected to double by 1975. The percentages of total annual capital expenditures invested in pollution control ranged from a high of 10 percent for the iron and steel industries down to 0 percent for the communications industry, with 2.6 percent for transportation and 3.8 percent for electric utilities (*21*). It is not clear, however, that all these investments produce energy-efficient pollution control systems. Firms whose energy costs are significant with respect to profits have probably installed efficient pollution controls. For other firms, federal standards may need to be considered.

Relating traditional profit incentives to efficient pollution control will be difficult until the principle of pollution control itself has become common practice. The capital investment and the institutional policies (such as environmental protection and licensing polices) take substantial time to implement on a regional or a national basis.

In some cases energy conservation is the fortuitous result of investment in other programs. For example, urban mass transit systems promoted to shorten commuter time and reduce highway costs also produce several times less pollutants per passenger mile than the automobile and reduce energy consumption considerably. But effective urban mass transit, for whatever goals, remains experimental in scope for lack of the capital necessary to modernize and integrate such systems as a substitute for the ubiquitous private automobile.

At any rate, environmental studies and programs should now have the included task of considering energy costs (and benefits). An explicit treatment should provide decision-makers with the tradeoffs which are the needed bases for thinking and actions by all of us.

We must begin to ask whether a slight relaxation in environmental standards, many of which may have been arbitrarily set with little thought to their full ramifications, could permit significant energy savings. For example, we should carefully examine the question of whether the nation's environment would be better served by obtaining emission reduction through policies designed to reduce automobile use and to increase mass transit use rather than by maintaining current strict emission standards which increase engine inefficiency (*1*). We also have to balance the extremely high costs which consumers are paying to obtain the last small increment of environmental protection against the potential energy and dollar savings from more energy efficient pollution control systems.

In summary, the close interdependence of these issues makes it essential that programs be coordinated in meeting where possible the objectives of both pollution control and energy conservation. The needed objectives include making pollution control systems more energy efficient and encouraging greater energy conservation by choice of those options (applications) which limit both energy consumption and pollution.

Improvements to energy conservation could also have significant implications for the national economy. Capital investment in the U.S. energy industry has been projected at $566 billion (in 1971 dollars) for the period 1971 to 1985. This enormous capital investment requirement raises several potentially serious problems with respect to all areas of our economy. The amount of money available for capital investment is rather inflexible—it depends strongly on the rate of savings, which tends to be very stable. An increase in capital needs for one sector, that is, the energy industry, could significantly affect the money market through increased interest rates. Hence, if conservation can reduce energy consumption, the sizable capital requirement in this area would also be lessened. One estimate indicates that the savings in energy consumption, as a result of conservation measures, could lead to potential savings of $97 billion or 17 percent of the projected capital investment of $566 billion during the 15-year period from 1971 to 1985 (*11*).

Summary

We can no longer afford to ignore the serious potential consequences of our lavish use of energy. Continuation of the present rate of increase, particularly with the trend to imported fuels, will lead in short order to a level of dependency on imports which is disturbing for both the national security and the balance of payments.

The inevitable rise in the price of energy will presumably lead to some increases in the domestic energy supply. But our reserves, particularly in the preferred forms of petroleum, gas, and even low-sulfur coal, are finite. Thus, the energy problem must also be attacked from the standpoint of energy conservation. The forthcoming rise in fuel prices will, of course, make more attractive some forms of conservation which at present are economically marginal. Nevertheless, consumers, industry, and government will have to make difficult choices in the years ahead: between greater convenience and lower energy bills, between the high capital costs of energy conservation measures and the long-term dollar savings from increased energy efficiency, and between environmental protection and the availability of needed energy supplies.

Existing capabilities and technology, on which short- and midterm improvements must be based, appear to offer substantial possibilities for reducing U.S. energy consumption within the next decade (*11*). Long-term solutions to the energy problem, however, will depend to a considerable extent on the continuing appearance of new technological capabilities for increased efficiency of energy utilization and increased integration of energy applications. The capacity for continuing technological advances is, of course, dependent in turn on a strong relevant scientific base.

A word of caution is necessary. Recent experience has shown that technological advances alone will not solve the problem. The problem spans not only the traditional physical and engineering sciences but also those sciences which deal with human attitudes and actions, that is, the social sciences, and includes a more fundamental understanding of underlying economic principles. The challenge to all sectors of American science should be clear.

References and Notes

1. P. H. Abelson, *Science* **178**, 355 (1972).
A. L. Hammond, *ibid.*, p. 1079.
3. Energy industries generally employ the British thermal unit (Btu) as a common denominator among the various specialized fuel and energy units of measure. Approximate conversion factors between the major measures are: 1 barrel of oil = 5.8×10^6 Btu = 1.5×10^9 cal; 1000 cubic feet of gas = 1.0×10^6 Btu = 2.5×10^8 cal; 1 ton of bituminous coal = 2.5×10^7 Btu = 6.3×10^9 cal; 1 kilowatt-hour of electricity = 3.4×10^3 Btu = 9.6×10^5 cal.
4. "An economic analysis of proposed schedules for removal of lead additives from gasoline," a study prepared by Bonnor and Moore Associates, Inc., Houston, Texas, for the Environmental Protection Agency in June 1971. They estimate that lead removal would cause a 12 percent increase in gasoline consumption. Since refinery output is approximately 50 percent gasoline, and 1975 crude runs are estimated by the National Petroleum Council [Committee on U.S. Energy Outlook, *U.S. Energy Outlook* (National Petroleum Council, Washington, D.C., 1971), vol. 1, p. 27] at 18.4 million barrels per day, the resulting increase in gasoline would be approximately $0.5 \times 0.12 \times 18.4 = 1.1$ million barrels per day in 1975.
5. Public Law 91-604.
6. Bureau of Mines, ***U.S. Energy Through the Year 2000*** (Department of the Interior, Washington, D.C., December 1972). For the purposes of this article, electric energy is accounted for solely in the electric utility sector and is not distributed to the other sectors. In addition to extrapolating current trends in energy consumption, the Bureau of Mines projections assume continued improvements in the efficiency of fossil fuel plants, improved insulation in new home construction based on raised FHA standards, and a continued increase in the proportion of steel produced by the more energy-efficient basic oxygen furnace process.
7. A. A. Schulman, ***DITT Data Estimates and Input-Output Review*** (OEP Report IST-103, Office of Emergency Preparedness, Executive Office of the President, Washington, D.C.,

1972). Values are derived by the use of the demand impact transformation tables (DITT).
8. E. Hirst, *Energy Consumption for Transportation in the U.S.* (Report ORNL-NSF-EP-15, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1972).
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11. Office of Emergency Preparedness, *The Potential for Energy Conservation: A Staff Study* (Government Printing Office, Washington, D.C., 1972).
12. W. E. Fraize and R. K. Lay, *A Survey of Propulsion Systems for Low Emission Urban Vehicles* (Report No. M70-45, MITRE Corporation, McLean, Va., September 1970). Hybrid energy storage systems allow constant maximum efficiency load to be placed on the engine, for example, by combining a heat engine, storage batteries, and electric drive.
13. "Patterns of energy consumption in the United States," a study prepared by Stanford Research Institute, Menlo Park, Calif., for the Office of Science and Technology in 1972.
14. Federal Power Commission, *The 1970 National Power Survey* (Government Printing Office, Washington, D.C., 1971).
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19. Department of Commerce, *The Application of Total Energy Systems to Housing Developments* (Department of Commerce, Washington, D.C., March 1972).
20. Environmental Protection Agency, *The Economics of Clean Air* (Environmental Protection Agency, Washington, D.C., February 1972).
21. Council on Environmental Quality, *Second Annual Report* (Government Printing Office, Washington, D.C., August 1971).
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23. I thank Robert H. Kupperman of the Office of Emergency Preparedness, chairman of the interagency working group on energy conservation. This article draws heavily from the findings of that group's report. I am also grateful to Felix Ginsburg, Frederick McGoldrick, and Richard Wilcox for their review and thoughtful observations and to Philip Essley and Robert Shepherd for their critical reading of the article.

NEWS AND COMMENT

Division of Biologics Standards: Reaping the Whirlwind

On 27 October 1963, a Philadelphia housewife named Mary Jane Griffin swallowed a sugar cube impregnated with live poliovirus vaccine. The vaccine, it was to appear, came from a production lot in which the virus had changed back into a virulent form. A month later, Mrs. Griffin awoke from a coma to find herself in an iron lung, with a priest administering the last rites.

She survived, but the polio has left her confined to a wheelchair and almost totally paralyzed in all four limbs. The most active movement she can manage is to bend her right arm at the elbow, but only enough to touch her nose, not to reach her head or comb her hair. Her left shoulder, unless the nurses dressing her are careful, is easily pulled out of its socket, causing severe pain. Her diaphragm is two-thirds paralyzed; she has learned to breathe again, but she cannot cough. Otherwise, she is healthy in mind and body and has the normal life expectancy of a 50-year-old woman—another 28 years.

Last November, deciding a case that had taken 7 years to prepare, a Philadelphia judge awarded Mrs. Griffin and her husband just over $2 million in damages against the United States government. (The government is still deciding whether to appeal the ruling.) Mrs. Griffin's disease, the judge ruled, "was caused by the negligence of the Division of Biologics Standards [DBS]," the government agency that regulates vaccines. The DBS's own test results indicated that the lot from which Mrs. Griffin's dose was derived exceeded the legally established safety limit for neurovirulence.

Significantly, a quite separate inquiry into DBS affairs has also found evidence that agency officials ignored their own regulations. The General Accounting Office, the investigatory arm of Congress, recently published a report on the DBS's supervision of adenovirus vaccine, concluding on the basis of the agency's own records that about half the vaccine lots the DBS approved were less potent than required by regulation.

The DBS, formerly a part of the National Institutes of Health, is now the Bureau of Biologics of the Food and Drug Administration. The agency was transferred to the FDA last July, following criticisms of its scientific and regulatory management (*Science*, 3 and 17 March 1972). The polio and adenovirus cases concern events that are now ancient history. But they are indicative, and maybe representative, of a period of regulatory management which came to an end only last year, and the full repercussions of which may not yet be evident.

The Griffin decision is also important because of others similar to it. About 100 other cases occurred, and more than 20 people filed claims against the manufacturer. Most were lost or settled for small sums. A principal reason for their lack of success, according to Mrs. Griffin's attorneys, was testimony by DBS officials to the effect that the vaccines had passed the DBS safety tests. But polio vaccine victims seeking to reopen or initiate claims now would run into difficulty with the statute of limitations.

The unique feature of the Griffin case is that Mrs. Griffin's attorneys brought suit against the government as well as against the manufacturer and were thus able to obtain a court order compelling the DBS to release all its relevant files. From the files they were able to construct a case that the DBS had violated its own rules for dealing with the vaccine in several important instances. Their suit, brought under the Federal Tort Claims Act, represents the first time that the government has been held liable for the release of a biological product. Mrs. Griffin's attorneys, Avram G. Adler and Stanley P. Kops, of the Philadelphia firm Freedman, Borowsky, and Lorry, say they spent some 7 years preparing the case.

Mrs. Griffin's contraction of polio from Sabin type III vaccine could not have come as a total surprise to those knowledgeable in the field. Several cases associated with the vaccine occurred soon after it was introduced, and the Surgeon General's committee on polio decided at a meeting in September 1962 to recommend that adults not take the type III vaccine unless they were at special risk. In December 1962, by a 6 : 4 vote, the committee reversed