The Durand Lecture for Public Service

# Mobilization of Energy and Space Technology

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## I. Introduction: The Early Years in Space

WORLD War II was a global conflict involving not only armies, navies, and air forces, but also crash developments of a wide variety of high-technology systems ranging from electronic sensors, to computers, servomechanisms, fire control, subsonic aircraft, guided bombs, and, finally, nuclear weapons. Although the United States and its allies had achieved superiority in the technical areas mentioned, the Germans had advanced more rapidly in the field of rockets, bringing both the V-1 buzz bomb and the V-2 supersonic rocket into operation prior to the war's end. Soon after World War II, the Peenemunde rocket team headed by Wernher von Braun was ensconced at White Sands, NM, using the V-2 technology and hardware to gather scientific information from the upper atmosphere and in the process to acquaint U.S. civilians and military engineers with the major technical advances made by the Germans in this new field. Laboratories were established on many campuses to conduct studies on pumps, injectors, and nozzles for rocket engines, on supersonic aerodynamics for missiles, and on plasma physics for vehicles re-entering the atmosphere. In the early 1950s, the potential progression from aircraft to missiles to Earth-orbital spacecraft was becoming more apparent and inevitable. The possibility of space travel was evaluated in graduate seminars on a number of campuses and university lecturers found that their speeches could be enlivened by talk of manned rockets and space stations.

During this same period, the Soviet Union also benefited from an influx of engineers and technicians from Germany, although this was not immediately apparent. What was all too obvious was the rapid assimilation by the Soviets of U.S. classified research and development on nuclear materials. The United States' exclusive province at war's end rapidly became a scientific and technical battlefield, engaging the major resources and top talents of both countries.

It is hard to remember or even imagine today the impact of Russia's Sputnik in 1957 as it orbited overhead. But by reflecting on our technical preeminence at the end of World War II and then the rapid erosion of our nuclear superiority, one can better understand the shock that ultimately resulted when the Soviets were the first into space. They appeared to have both the nuclear weapons and their delivery systems in operation. Many technical people felt that the U.S. had squandered time, resources, and opportunities, but the public's and world's view was even more ominous. In this larger arena, the Soviets appeared ahead in science and technology and it was feared that the democracies of the West might never again be in first place because of their decentralized form of government.

Some in the Eisenhower administration attempted to belittle Sputnik by scoffing at the value of a grapefruit-sized vehicle passing overhead. However, President Eisenhower saw the need for credibility and also recognized the necessity for closer ties between government and the technical community. Consequently, he appointed James R. Killian, President of the Massachusetts Institute of Technology, as his science advisor.[1] Killian found that governmental expertise for space research and exploration existed in a number of governmental organizations. He recommended a merger of this talent, which soon led to the formation of the National Aeronautics and Space Administration (NASA), an agency dedicated to a civilian space program for the benefit of all mankind.

During this same period, the U.S. suffered through the repeated launch failures of the Vanguard rocket, a modest research effort started prior to the launching of Sputnik as part of the International Geophysical Year (commenced July 1, 1957). However, the U.S. technical capability was par tially redeemed by the successful orbiting of Explorer I, a Jet Propulsion Laboratory satellite, launched by the Army team headed by von Braun.

Nevertheless, many were increasingly dissatisfied with the U.S. space program as the Soviets launched a series of Earth- and lunar-orbiting spacecraft in rapid succession. The orbiting of Vostok with Cosmonaut Gagarin aboard was the ultimate catalyst that led to a re-evaluation of U.S. space goals and to President John F. Kennedy's special message to Congress, "Now is the time to take longer strides ... before the decade is out, of landing a man on the moon and returning him safely to the Earth."

The battle was joined and the result is well known: Apollo 11 was launched July 16, 1969, and four days later Eagle landed on the moon with Neil Armstrong and Edwin Aldrin

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aboard. After a brief walk on the lunar surface, they rejoined Michael Collins (who had remained aboard the reentry capsule) in orbit around the moon. After a safe splashdown in the Pacific Ocean, the astronauts were greeted by President Richard M. Nixon as they came aboard the aircraft carriet Hornet. In his welcoming remarks Nixon was quoted as saying, "This is the greatest week in the history of the world since the creation." The President's genuine feeling of elation was held by many, certainly all those participating in the Apollo Project.

More people watched the mission live on television than any previous world event. It was obvious to all that the U.S. was not only preeminent in space, but also a leader in science and technology.

## II. Mobilization of U.S. Space Technology

A much more complex and complete version of the space program is portrayed in a recent book by McDougall.[2] He uses a large canvas to embroider a picture of space developments on several levels. As *The New York Times Book Review* of April 7, 1985, stated, "It is a narrative history of space activity, a political analysis of what caused Sputnik I and what Sputnik I caused, [and] an exposition of the contradictions inherent in the Soviet socialist system and the American free-enterprise system."

The book is good reading, especially for those who were intimately involved in the space activities of the 1950s and 1960s. The history has been carefully researched and written with detailed documentation. The underlying themes are provocative, elusive, and worth addressing. McDougall states, "What was more the space program grew on its own movers and shakers until it outgrew the space race itself and seemed a model for a society without limits, an ebullient and liberal technology—not Space Age communism but Space Age America."

The book has a hero, President Dwight D. Eisenhower, and a variety of villains, including Presidents Kennedy and Lyndon Johnson and James E. Webb, Administrator of NASA from 1961–1968. McDougall observes that in the late 1950s the principle of limited government still clung to life. However, in the 1960s, he alleges that NASA became a "juggernaut of politicians and engineers." As a result of NASA's successes, he claims, the American resistance to technocracy (government-controlled technology) evaporated. The success of the Apollo Project made government-ordered innovations look "easy" and "American," so that governmental technology initiatives could be moved from space to domestic needs. According to McDougall, the United States lost sight of the fundamental question, whether a society shaped by state planning and spending is in consonance with American freedom. In the end, he concludes, "NASA's destiny was to serve as a prototype for reallocation of national power for social and political goals."

In the chapter, "Big Operator, James Webb's Space Age America," McDougall quotes from a letter that Webb wrote Lee A. DuBridge, President of the California Institute of Technology, in which Webb attempted to interest DuBridge in the use of NASA-derived technology for "urban development, water resources, energy, communications, management, and life sciences."

The purpose of this paper is to explore energy developments since 1973 and to raise the issue of the appropriate role for government and the lessons that can be learned in this field from the Apollo Project. In the next section, the government agencies established for energy research and development are compared with NASA and, in subsequent sections, the results of an energy study by the author are correlated with a variety of legislative actions. Then, the roles of the government and the private sector in energy supply and demand are examined so that the interaction and capability of U.S. institutions dealing with contemporary issues can be evaluated.

## III. The U.S. Reaction to the Oil Embargo

In 1973, OPEC (Organization of Petroleum Exporting Countries) imposed an embargo on oil shipments to the United States and other Western countries. The U.S. had been an exporter of oil until the late 1960s. In the early 1970s, consumption of oil in the U.S. had outrun domestic production so that the oil embargo had a major impact on the national economy. On the recommendation of President Richard M. Nixon, the Congress passed the Energy Reorganization Act of 1974 that established two new government agencies, the Energy Research and Development Administration (ERDA) and the Federal Energy Administration (FEA). Whereas the FEA was responsible for temporary issues including fuel allocation in the event of serious energy shortfalls, ERDA provided focus for new approaches, analogous to NASA's research and development role in space exploration.

During the next five years, there was a substantial increase in research and development on oil and gas resources, coal conversion, shale retorting, solar applications, and nuclear fuels. The study of energy efficiency was intensified and investigations of energy-related issues was initiated. Some of these activities were supported solely by the government, some by industry, and some were joint endeavors.

Although the national situation was never again as traumatic as during the oil embargo, dislocations in oil supplies occurred each time OPEC increased oil prices. The harsh winter of 1976 also caused a heavy drain on fuel oil and natural gas, often causing government curtailment of fuel for transportation and industry. By 1977, the multifaceted and enduring nature of energy issues was more generally understood. Since the government would be involved for an extended period, ERDA and FEA were folded into a Department of Energy (DOE) formed to oversee the totality of the government's mission in the scientific, engineering, social, economic, and political aspects of energy. In the eyes of some, the DOE was responsible for part of the growing technocracy that threatened individual freedom.

That part of DOE responsible for new approaches (formerly ERDA) had a research and development budget comparable to NASA's. Part of this budget supported fundamental investigations in university, industry, and government laboratories. The investigations were directed toward new and improved technology. The government participated directly, not only in support of these investigations, but in proof-of-concept testing in experimental and prototype plants. The construction and testing of these plants was conducted jointly with industry on a cost-shared basis, with the profits (if any) going to each on a pro-rata basis. The purpose of these plants was to develop new technology across a wide spectrum ranging from turbine-powered automobiles to electric-power generation using breeder reactors. The management of these projects benefited directly from NASA's experience and, as in NASA, no major opposition was voiced because of government involvement. Only the potential or imagined risks and benefits of particular technologies caused major controversy.

Considerable controversy, however, arose over government loan and price guarantees. In order to test the feasibility of full-scale operations, President Gerald Ford requested an authorization of $6 billion in loan guarantees to be used by municipalities and private ventures for the conversion of waste and coal to electrical power and pipeline gas. The Senate approved the bill by an overwhelming margin, but the bill was defeated by a 2-to-1 margin in the House. The House defeat resulted from the coalition of two disparate groups, one concerned lest there be an alliance between big business and big government and the other wanting free enterprise to be unshackled to solve the energy crisis. Ultimately, a bill was passed in support of governmental guarantees to industry through the formation of the Synthetic Fuels Corporation, recommended to Congress by President James Carter in 1978. A 14,000 ton/day coal-gasification plant was constructed with private capital in Beulah, ND, initially with DOE support. The government guaranteed loans of up to $2 billion covering 75% of the cost. The plant produced pipeline-quality gas, but with falling oil prices the synthetic gas could not compete in the market place and failed to receive continuing governmental support from either DOE or the Synthetic Fuels Corporation. After two years of operation, the plant proved to be technically viable, but may be mothballed without gaining full value of the data and experience from the public and private investment.

In the pursuit of long-term options for alternate fuels and for new energy-saving technologies, it does not appear that the government is using energy technology to create social change and a liberal technocracy. However, the government has means for influencing the use of energy other than direct participation. Highway speed limits, automotive efficiency, electrical appliance regulations, oil and gas price controls, and tax credits for solar installations, house insulation, and oil-well depletion have an impact on the exploration and consumption of fuel. The effectiveness of such government controls and their impact on existing institutions and personal freedom will be examined in the remainder of this paper.

## IV. The U.S. Energy System

During the oil embargo in late 1973 and early 1974, there was brave talk of an Apollo-like effort that would give the U.S. "energy independence" by 1976. Politicians were saying that if the U.S. could fly men to the moon, the U.S. could solve the energy crisis by the 200th anniversary of our independence. Such absurd statements would not have been expressed if the complexity and scope of the nation's energy system had been better understood. This country's energy system is normally conceived in terms of domestic and foreign oil and gas, with tankers bringing oil to storage depots and pipelines serving as conduits for the gas and some domestic oil. Local service brings the refined oil to gasoline stations and into homes and apartments. Regional utility stations convert fossil and nuclear fuels into electricity for transmission to cities, towns, and manufacturing centers. This concept, which many could further embroider by addition of refineries, railroads, trucks, buses, and commercial buildings, does not account for the magnitude and variety of the demands on the system; see Fig. 1.

#### Transportation Systems

The transportation systems include highway traffic (passenger vehicles, trucks, and buses), aircraft, ships, trains, and pipelines. Transportation provides point-to-point service for passengers and freight and the demand can be measured in passenger miles and ton-miles. Pipelines carry oil and natural gas and their use varies with the total amount of oil and natural gas requested by the consumers. With the exception of the small amounts of electricity used by railroads and subways, transportation is fueled by petroleum products and natural gas and in 1984 accounted for 26.8% of the total energy use in the U.S.

#### Residential and Commercial Sector

The residential and commercial sector encompasses buildings for housing, wholesale and retail businesses, health and educational institutions, and government office space. The demand for energy results from the need to heat and cool these buildings, to provide lighting, hot water, and air circulation, to permit cooking, and to supply elevator service in multistoried structures. The energy demands for this sector are related to the number of residential units and the square feet of commercial space and amounted to 35.5% of the total use in 1984.

#### Industry

Industry can be divided into manufacturing, which accounts for 60% of the industrial demand, and mining, construction, and agriculture, which account for the remaining 40%. Manufacturing is defined by standard industrial classification codes, 10 of which exert over 90% of the total demand. These are, in the order of usage: chemical and allied products; petroleum products; primary metals; paper products; stone, clay, and glass; food and kindred products; fabricated metals; machinery products; transportation equipment; and textile products. In the case of petrochemicals, the energy demand includes the requirement for oil and gas feedstock. In most cases, the demand can be measured in terms of product quantity, i.e., gallons of alcohol, barrels of oil, tons of steel, number of automobiles and trucks produced. In 1984, U.S. industrial consumption was 37.7% of the total.

#### Electrical Power Generation

Electrical power generators are operated by utilities to convert a variety of fuels into high-voltage electricity for transmission to end users. The demand for electricity is

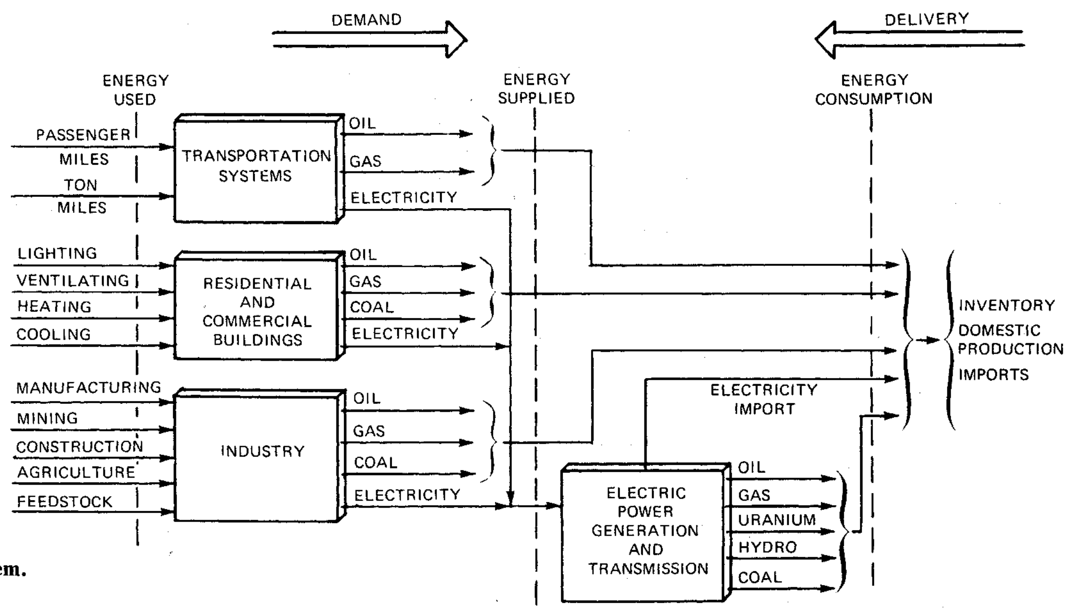


Fig. 1 National energy system.

seasonal and also fluctuates throughout the day. Individual utilities must be prepared for wide variations in demand by investing in capacity considerably greater than the average. This capability is provided in part by different types of equipment. The base load or nearly steady load is satisfied by large fossil-burning combustors and nuclear reactors, both of which supply steam to turbine generators. For the peak loads occurring in the late afternoon and early evenings in the winter months, oil and gas turbines can be quickly brought on-line. Of course, each utility does not operate singly; rather, the utility transmission lines are interconnected into grids that permit instant buying and selling of electricity between companies and regions. On occasion, the demand can exceed the total capacity of the system, in which case brownouts and even total blackouts occur, as happened along the East Coast in the mid-1960s and early 1970s. Renewable sources for power generation amount to about 10% of the total. Hydroelectric dominates the renewables, but several small geothermal and solar plants are now connected to the West Coast grid.

If the total consumption of energy in the United States was matched by domestic production, the U.S. would be energy independent. Postwar economic growth caused the country to shift from being a net exporter of energy to a net importer in the late 1960s. There was no immediate way, short of economic chaos, to reduce oil imports substantially, either by conserving fuel or by increasing domestic production. Both require major investments of time and resources. Figure 1 also includes fuel held in inventory. Some inventory results from oil or gas in transit in pipelines, tank cars, trucks, tankers, and depots. In order to have more substantial resources in the face of future embargos, the government is storing fuel in the salt domes along the Gulf Coast. These strategic oil reserves can be withdrawn at a rate of $1 \times 10^6$ barrels/day to augment domestic sources if world events preclude the shipment of foreign oil for protracted periods.

ERDA brought together the Atomic Energy Commission, the Office of Coal Research, and most of the other research elements of government involved in consumption and power generation. Federal legislation required ERDA to develop a comprehensive plan for energy research, development, and demonstration and to update the plan on an annual basis. The first plan[3] was submitted to the president and the Congress in June 1975.

The heart of the plan was the Energy Reference System, which showed the quantity of each energy source, the efficiencies of fuel transportation, conversion to electricity, and transmission, as well as the amount of fuel for each end use. Projections could then be made into the future by making assumptions about end-use growth, the increase in electricity use, the effect of a nuclear moratorium, etc. The Brookhaven National Laboratory was responsible for these analyses, which were kept current through 1979 (the studies were discontinued by the Reagan administration). However, excellent energy data are still collected by the Energy Information Administration of the Department of Energy (DOE/EIA). These data are updated monthly and are summarized in a Monthly Energy Review.[4] This information is the basis for the comparative data in this paper.

The computer model used in this paper attempts to provide the linkages from disaggregated user demands to aggregated supply and consumption. In some cases, the linkages are known; for example, the miles driven annually by the automotive fleet and the fleet fuel efficiency, measured in miles per gallon. In this paper, fleet "mileage" will be considered synonymous with "fleet fuel efficiency." The gallons of gasoline used can be readily calculated from a knowledge of miles driven and mileage and, in turn, knowing the energy content of gasoline, the energy requirement for the automotive fleet can be computed in quads. (A Btu is a British thermal unit and a quad is $10^{15}$ Btu. There are $5.253 \times 10^6$ Btu in a barrel of gasoline. Hence, a quad of energy is contained in $190.4 \times 10^6$ [$10^3/5.253$] barrels of gasoline.) Where disaggregated data are available, the sources will be referenced and when major assumptions are made, they will be indicated. The three energy users and the electric power utilities are discussed in the following four sections and then a range of potential demands and their impact on overall consumption in the year 2000 is presented in the summary and conclusions.

## V. Transportation

### Passenger Vehicles

The DOE/EIA Monthly Energy Reviews include passenger-vehicle mileage, but not the miles traveled by the passenger car fleet nor the total amount of the resulting fuel consumed. This information is contained in material prepared by the Oak Ridge National Laboratory in June 1984.[5] These data are plotted in Fig. 2 and show that passenger vehicles were driven fewer miles in 1974 than in 1973, because of the gasoline shortages resulting from the oil embargo. Passenger vehicles (automobiles, motorcycles, vans) were driven more miles each year following 1974 until the total reached a level of $1,170 \times 10^9$ in 1978. The increasingly high cost of gasoline, coupled with a recession in the early 1980s, then caused automobile drivers to reduce the miles driven, with a low in 1981.

*Savings and Growth*

In order to compare the effects of price, fuel shortages, and new technology on different modes of transportation, it is convenient to define the terms growth, savings, and conservation. The miles driven $M$ is assumed to be an exponential function of time in the form,

$$M = M_{73} \times [1 + G_M]^T \tag{1}$$

where $M_{73}$ is the number of miles driven in 1973, $G_M$ the growth in miles driven, and $T$ the time in years (equal to zero in 1973).

The annual growth $G_M$ from the pre-embargo year of 1973 (the embargo was imposed in October 1973) to the 1978 maximum was 2.9%. Equation (1) is shown as a solid curve in Fig. 2 and is presumed to represent the passenger miles that would have been driven had there been no oil embargo in 1973–1974 and no dislocation of prices and the economy in the early 1980s.

Owners of passenger vehicles were aware of prices and the economy, causing them to drive fewer miles to save fuel and out-of-pocket expenses. The mileage driven with savings included can be written in the form

$$M = M_{73} \times [1 - C_{ms}] \times [1 + G_M]^T \tag{2}$$

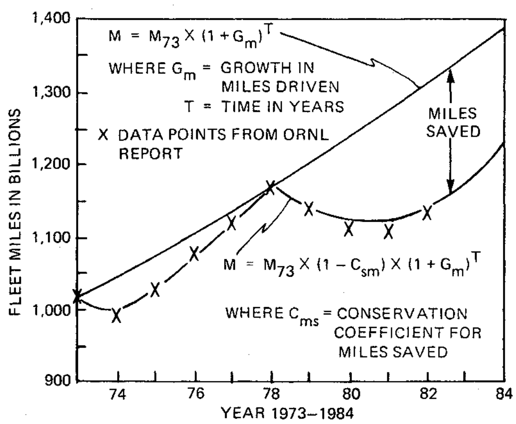


**Fig. 2 Passenger vehicle miles.**

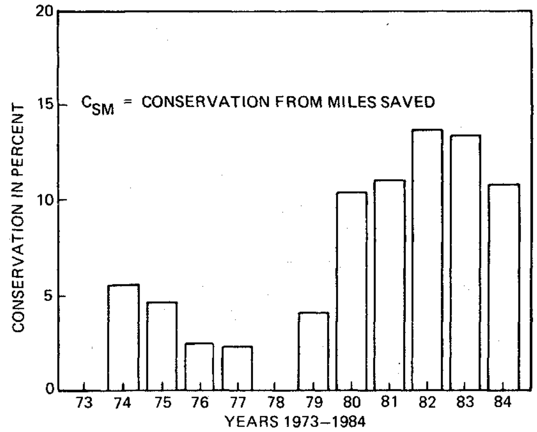


**Fig. 3 Savings in vehicle miles.**

The term $C_{ms}$ represents the conservation in miles driven, the belt-tightening form of conservation. The second solid curve in Fig. 1 (the miles driven generated by the energy model) matches the data reasonably well for 1973-1982. Data on miles driven are not available for 1983 and 1984. The conservation due to saving is shown in Fig. 3 in percent. The saving peaked at 5.6% in 1974 at the height of the oil embargo and at 13.8% in 1982 due to economic factors.

*Efficiency*

During the six-year period 1967-1973, passenger-car mileage dropped from 13.9 to 13.1 mpg as a result of governmental regulations on automotive emissions. With the onset of the oil embargo, mileage improved, at first slowly and then dramatically in 1978. The early increase initiated by the automobile manufacturers in anticipation of customer demands resulted from modest improvements in engine performance and reduction in car weight. Legislation enacted in 1977 mandated corporate average fuel economy commencing in 1980. Companies manufacturing automobiles in the United States were required to produce each year a fleet of cars with an average mileage greater than levels specified by the government. The level increased from 20 mpg in 1980 to 26 mpg in 1983 and is to remain above 27.5 mpg in 1985 and subsequent years. Automotive use of gasoline will be reduced nearly 50% due to these improvements in fleet efficiency. As can be readily imagined, this legislation was passed only after considerable lobbying and debate and remains controversial to this day, but the results have been significant, as can be seen from Fig. 4. The energy model assumes that the mileage increased linearly from 1973 to 1978 at a rate of 1.4% and that thereafter the mileage was a function of the sales rate and mileage of new vehicles, the attrition rate of the old vehicles, and the size of the entire fleet. The model assumes that, for the past six years, $10\times10^6$ vehicles have been sold annually, the new vehicles operate on the average at 22 mpg, vehicle life expectancy is 6.8 years, and there were $125\times10^6$ registered vehicles in 1973. Figure 4 shows that the fleet mileage in actuality fell a few percent short of the expected level in 1983. Only Chrysler complied with the mandated fleet fuel economy of 27 mpg in 1984. It remains to be seen whether the government will keep industry's "feet to the fire" in subsequent years. If industry produces vehicles that meet the mandated goals, the forced reduction in energy demand resulting from improved energy efficiency has profound national significance.

*Conservation*

The amount of fuel supplied to passenger vehicles can be calculated each year from knowledge of the miles driven and the fleet mileage. The energy supplied is shown in Fig. 5 in quads. The solid curve results from the energy model and the

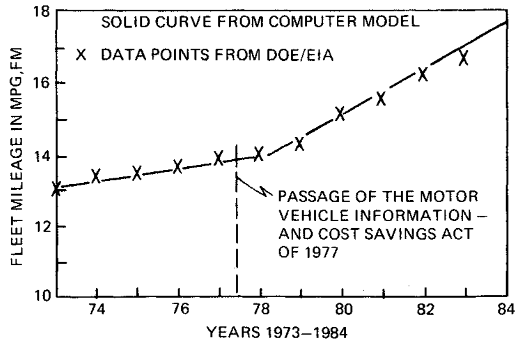


**Fig. 4 Mileage of passenger vehicle fleet.**

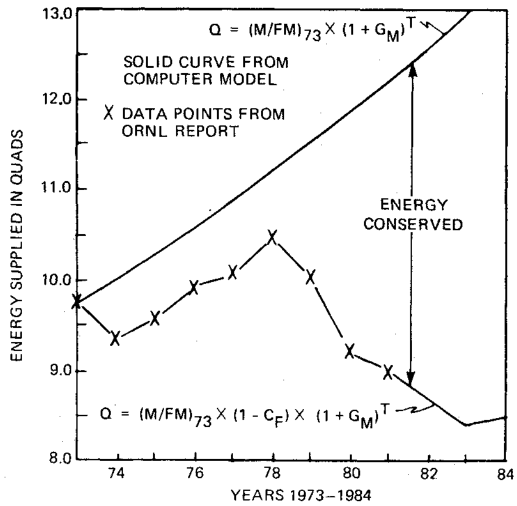


**Fig. 5 Energy supplied to passenger vehicle fleet.**

individual plots are from the data in the Oak Ridge National Laboratory report, which has not provided energy information beyond 1981. The amount of fuel for passenger vehicles dropped in 1974 due to the oil embargo and then increased to a maximum in 1978. Energy use increased at an annual rate of 1.4% during this five-year period, even though the growth in miles driven was 2.9%. The difference resulted from the improvements in automobile fuel efficiency.

Of course, total fleet conservation $C_F$ for passenger vehicles depends upon both the savings achieved in driving, as well as improvements in vehicle efficiency. The sum total is plotted in Fig. 6 where the savings are those already shown in Fig. 3 and the total is the amount required in the expression

$$Q=\frac{\text{miles driven}}{\text{fleet mileage}}=\frac{M}{FM}$$

$$=\left(\frac{M}{FM}\right)_{73}\times(1-C_F)\times(1+G_m)^T \tag{3}$$

for $Q$, the energy used by passenger vehicles each year to match the published data. The difference between the total fleet conservation $C_F$ and the conservation resulting from fewer miles driven $C_{sm}$ is the conservation efficiency $C_{\text{eff}}$ or

$$C_F=C_{sm}+C_{\text{eff}} \tag{4}$$

If present trends hold for automobile sales and attrition, there will be over $145\times10^6$ passenger vehicles in the year 2000. If improvements in automobile fuel efficiency meet present regulations and if the savings continue at 11%, only

330,000 additional barrels per day will be required in the year 2000 than in 1984. However, if savings drop to 5.5% and the fleet mileage levels off at 22 mpg, an additional $1.6 \times 10^6$ barrels of gasoline will be required per day. It should be noted, however, that if the mileage continues at the 1984 level, $7.4 \times 10^6$ barrels per day of gasoline will be required to energize the fleet, $2.8 \times 10^6$ barrels per day more than in 1984.

### Light and Heavy Trucks

There is more complete data on passenger vehicles than any other form of transportation. The report by the Oak Ridge National Laboratory provides information on the fuel supplied to each mode, but provides no information on the number of miles traveled in each category, excepting trucks. Trucks are split into two size categories. Lightweight trucks experienced over twice the growth rate in fuel than did heavy-duty trucks, due in part to their increasing numbers. However, the data for truck miles were aggregated and, consequently, it was not possible to differentiate between the mileage of each type. The combined mileage increased at an annual rate of 2.5%, slightly less than the mileage increase of passenger vehicles. By using aggregated data, the total energy used by trucks and the miles driven closely match the data from the Oak Ridge report.

### Aircraft

Commercial aircraft carry passengers and freight. Passenger mileage can be increased by use of higher load factors (percent of passenger capacity), improved handling of air traffic, more efficient propulsion systems, and cleaner aerodynamic design. The most significant near-term change has resulted from airline deregulation. Communities with less travel have suffered from a reduction in home-port traffic, but by concentrating on the heavily traveled routes, aircraft are flying closer to their maximum passenger capacity and hence 25 passenger-miles/gallon is being achieved. Feeder lines with smaller aircraft appear to be operating effectively into less densely traveled cities. The amount of cargo carried by both regular commercial airlines and those devoted exclusively to freight has increased dramatically in the past three decades, but appears to have leveled off recently. In this model, cargo aircraft are assumed to use 10% of the fuel required for commercial air.

Two other categories of aircraft transportation were included in this study: general aviation and military air. Executive and other private aircraft, along with military missions, are assumed to require 25% of the total energy used in air travel. Modern fighters and bombers require so much fuel for operations that pilot and crew training make extensive use of flight simulation. (Training for lunar missions had to be conducted under simulated conditions. Visual, audio, and motion simulations developed for the Apollo program have greatly benefited training for commercial and military pilots.) This development, originally developed for the Apollo project, not only saves fuel, but permits training for engine outages on takeoff, control failures, and other procedures too dangerous for trainees in actual flight.

### Comparison of Transportation Modes

For the purpose of this study, the fuel use of the other transportation modes was also taken from the Oak Ridge National Laboratory report. Fuel use by most modes dropped during the oil embargo increased to a maximum in 1968, and fell in subsequent years. The exceptions are railroads and buses that operated at nearly constant levels of diesel fuel and pipelines that required less fuel as the consumption of natural gas attenuated.

For those modes that followed the same pattern of growth until 1978 and then declined, fuel use in 1978 was compared with 1973 to determine growth and, in other years, the percent conservation required to match the data was determined. It should be noted that this procedure does not account for improvements in transportation efficiency and, hence, the increase in miles traveled may be greater than the growth rates indicated.

Energy use by the different modes of transportation is compared in Fig. 7. Passenger vehicle use that accounted for over 50% of the fuel used for transportation in 1973 fell below 45% in 1984, while the truck and bus use of fuel increased from 24% to nearly 29% during the same period. Total highway energy use has remained more nearly constant, dropping from nearly 77% in 1973 to 73% in 1984. Although the energy model indicates that the amount of fuel used in air travel increased at a lower rate (2.5%) than other modes, improvements in fuel efficiency not recognized in the model have probably hidden larger passenger and ton-mile increases. Note that the percentage use of energy by aircraft over the 11-year period has grown from 10 to 11%.

Ship growth in energy use was dramatic during the 1970s. Shipping includes inland and intercoastal waterway and transoceanic transportation. Tankers from the Middle East refuel after unloading crude in the United States, but tankers with higher-grade oil arriving from refineries in other parts of the world may use their own distillate for the return. Imports of oil increased 5.7% annually in 1973–1978 and have since decreased at a rate of 10.3%. For this reason, it seems unlikely that the growth in ship use of fuel grew at 11% beyond 1979. A growth rate of 3% was assumed from 1980 on.

### Transportation Conservation

Total fuel conservation for transportation was calculated by prorating the conservation in each mode according to the

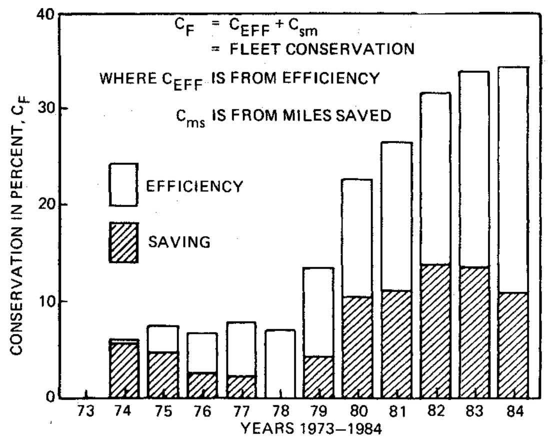


**Fig. 6 Conservation of passenger vehicle fleet.**

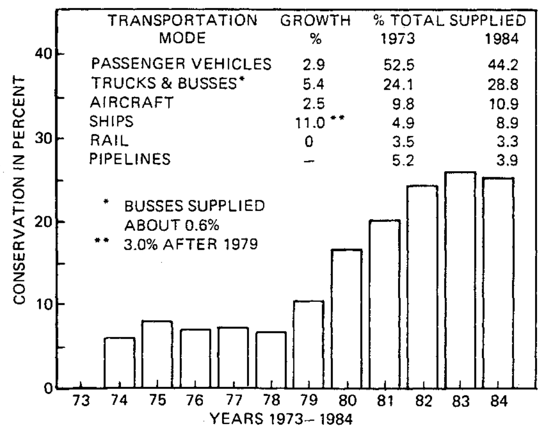


**Fig. 7 Conservation of all transportation modes.**

amount of energy used. Since over 70% of U.S. transportation is on the highways, the composite conservation tends to reflect the conservation of passenger vehicles and trucks. For example, the composite figure of 25.2% for 1984 is only slightly less than the combined conservation of all highway vehicles of 31.5%. Fuel conservation for all modes of transportation was fairly constant in 1974-1978 and then increased at over 4% per year the next four years, before leveling off at nearly 25%.

Clearly, future energy use for transportation depends heavily on highway traffic[6] and its efficiency. The flexibility of movement that the U.S. now enjoys is intimately related to the structure of the highway system. Buses, rapid transit, and rails combined consume less than 4% of the total energy used by the transportation system. If the presently mandated fuel economies are continued until the year 2000, highway traffic fuel consumption will be 30% greater than today, compared to a 90% increase if the fleet efficiencies remain at the present level. But strong pressures are building for "junking the fuel standards. Let the marketplace rule," to quote *USA Today,* May 23, 1985. In less-than-convincing logic, the *USA Today* editorial notes that Chrysler meets the standard, but Ford and General Motors say their family-sized cars are so popular that the fleets they build will not meet the 27.5 mpg target. The editorial continues, "The government doesn't dictate how much electricity a manufacturer can use or how many diesel rigs a trucker can put on the road. Why should it dictate the efficiency of an auto engine?"

There is more emotion than clear thinking in many of these arguments, including this quote. The government has not dictated how many cars, nor the size of the cars, that a family can own and operate. However, if Senator Howard Metzenbaum's (D-Ohio) views had prevailed, the government would mandate small cars for everybody and the freedom of choice would be lost.

The *USA Today* editorial adds, "That doesn't mean that consumers and car companies can be complacent about conservation or foolish about fuel. If another oil shock hits and it could, then car makers and consumers must be ready for it." The editorial writer does not seem to understand that "being ready" hinges on the fuel efficiency of the highway fleet at the time of crisis. It took 7 years from the time the legislation was enacted (11 years from the embargo) to increase the fleet fuel efficiency to its 1984 level. The battle will be joined over this fundamental issue of highway vehicle fuel-efficiency regulation. Can the principle of limited government satisfy national energy needs? That is the central issue of this paper.

## VI. Residential and Commercial

As was indicated in the discussion of the national energy system shown in Fig. 1, buildings are divided into those used as residences (single family, multifamily, and mobile) and those used commercially (apartments, hospitals, hotels, schools, office buildings, government buildings, and shopping centers). Somewhat arbitrarily, buildings are considered apartments when they house over five families. The energy demand for residential buildings is normally related to the number of homes and to the amount of floor space for commercial buildings. Commercial buildings use 42% of the energy demand in this sector, but are supplied only 36%. Commercial buildings utilize relatively more electricity than fossil fuel and the efficiency of their electrical equipment is higher, thus accounting for the difference between use and supply.

### Demand Categories

The DOE Energy Reference System, described in Sec. IV, split the energy demand into four categories: space heat, air conditioning, miscellaneous heat, and miscellaneous electric. "Miscellaneous heat" includes hot-water heaters and stoves

**Table 1 Energy use in residential and commercial buildings, %**

| Type | Residential | Commercial |
|---|---|---|
| Space heat | 55 | 34 |
| Air conditioning | 7 | 31 |
| Misc. heat | 23 | 14 |
| Misc. electric | 15 | 21 |
| Total | 100 | 100 |

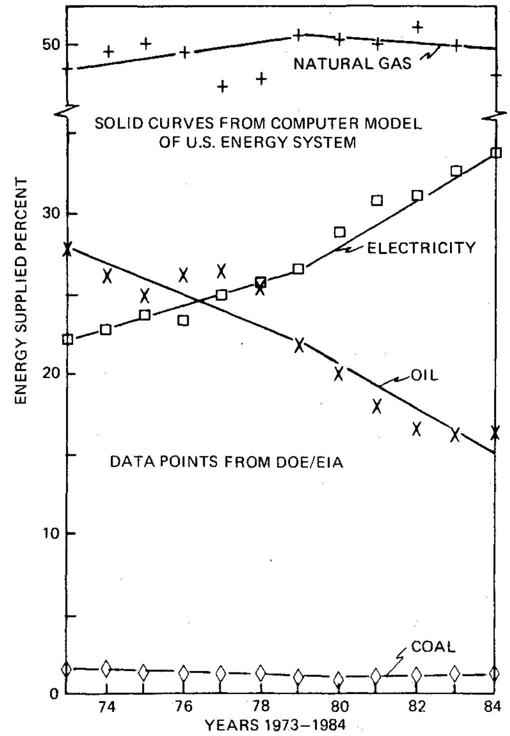


**Fig. 8 Fossil fuels and electricity supplied to residential and commercial buildings.**

and "miscellaneous electric" includes lights, refrigerators, elevators, and circulating fans when not part of the heating and air-conditioning systems. The percentage use of energy in these categories can be seen in Table 1.

It can be seen that residential buildings use substantially more energy for heating than do commercial buildings, whereas commercial buildings use more energy for air conditioning. Statistical data have been obtained by the architectural and engineering communities on the energy requirements for each of the categories in Table 1. The Btu requirements are available for the residential buildings (in terms of the number of residences) and for the commercial buildings (in terms of square feet of work area). Using these data, the energy requirements for each category can be determined from a knowledge of the number of residences and the total area of the commercial buildings.

### Number of Homes

The number of new homes under construction is always strongly influenced by mortgage rates. During the last 11 years, the number has gone from a high of $2 \times 10^6$ in 1973 to less than $1.1 \times 10^6$ in 1981 and is currently at about $1.7 \times 10^6$. On the basis of the current $80 \times 10^6$ homes, this is an increase of 1.4–2.5%. In order to determine the net growth rate, building attrition would also have to be known. The average net growth rate is probably less than 1.5% and, for the purpose of this study, was assumed equal to the 1.0% growth in energy between the peak years of 1973 and 1978.

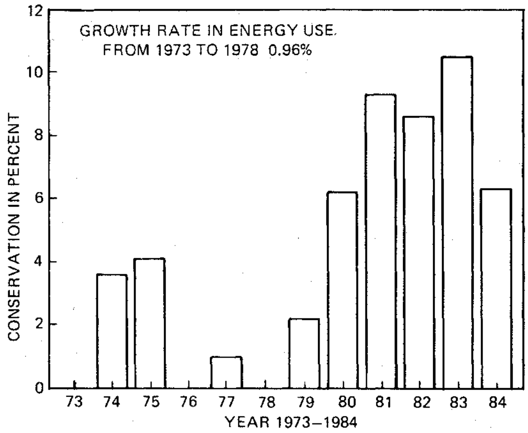


**Fig. 9 Conservation of energy in residential and commercial buildings.**

### Energy Efficiency and Fuel Substitution

In order to calculate the energy supplied to the building sector, the allocation of fuels must be determined in each category, as well as the conversion efficiency of the furnaces, air conditioners, hot-water heaters, refrigerators, and other appliances. The values of these quantities used in the Brookhaven energy reference system for 1979 were used in this study.

Homeowners and real-estate developers have been sensitive to fuel costs and potential shortages in their selection of fuels, for new buildings and in fuel substitution in existing buildings. The choice has been between electricity, petroleum, or natural gas. Coal is seldom used today in private homes and only occasionally in commerical buildings. The percentage of coal supplied went from 1.6% in 1973 to a low of 1% and has been climbing slowly in the 1980s to a level of 1.5% in 1984. It can be seen from Fig. 8 that natural gas has retained the dominant market share, supplying about 50% of the total energy. There was a modest increase in gas use in the 1970s and a comparable decline in the 1980s. However, dramatic changes have occurred in the demand for oil and electricity. The rapid rise in the price of fuel oil and the shortages that occurred during the embargo by the OPEC nations caused a major downward shift of oil use from 28 to 15% of market in an 11-year period. The beneficiary of the shift was primarily electricity, which climbed from 22 to 34% during the same period. Renewables are not included in this analysis for lack of specific information. Some estimate that use of central-heating wood stoves has more than doubled since 1978 and may provide heating for over $4\times10^6$ homes.

### Building Conservation

Conservation of energy was computed for the building sector by determining the deviation of the total energy use each year from what it would have been for purely exponential net growth. This method is similar to that employed for passenger vehicles, as portrayed graphically in Fig. 2. End-use conservation for residential and commerical buildings is summarized by the bar graph of Fig. 9. Conservation reached 4% in the postembargo year of 1975, was then nearly zero for three years, and more recently averaged around 8% during the recession of the early 1980s. Unlike highway vehicles, which have a six- to seven-year life span, buildings have a more protracted life expectancy, so that improvements must be retrofitted in large numbers of existing buildings to have a national impact in a 10-year span. The conservation of Fig. 9 is primarily due to the kind of savings President Carter demonstrated in a television broadcast when he lowered the White House thermostat and wore a sweater to keep warm.

There are many concepts and much development and testing underway to improve energy efficiency in buildings. Duke Power and Light has constructed their Gastonia office in North Carolina to take advantage of earth berm, as well as passive solar energy. This building reduces energy requirements for space heating and cooling by greater than a factor of two. All kinds of energy-efficient appliances are under test and will soon be ready for the marketplace. These include heat pumps; pulsed heaters; heat exchangers; integrated gas appliances for heating, cooling, and hot water in multifamily dwellings; and high-efficiency commercial hot-water heaters. The extent to which these devices will be manufactured and purchased by the consumer will be discussed next.

### Efficiency of Electrical Appliances

Electrical home appliances used 55,000 MW during 1981 or one-quarter of all electricity consumed in the United States. The National Energy Conservation Policy Act passed in 1978 directed the Department of Energy to develop efficiency standards for home appliances. Stringent standards were proposed by the Department of Energy in 1980, but the standards have not been promulgated.

Large savings in electricity could be obtained by improving the efficiency of these home appliances. For example, refrigerators account for nearly one-third of the energy used by all electrical appliances and studies show that reductions well over 50% can be made in their energy requirements.[7] Philco developed a more-efficient refrigerator of conventional size (15 $ft^3$) that they attempted to market in 1975. Even though electricity reductions of about 50% were achieved with their design, the line was discontinued for lack of consumer interest. California mandated modest efficiency improvements in refrigerator design, to become effective in 1982, and the California mandate is essentially today's national standard.

The Arthur D. Little Company conducted studies in 1977 and 1980 of improvements such as double-sealed doors and more-efficient defrosting. Their studies purported to show that refrigerators could be in production in six years that would cut the annual operating cost of electricity by 50%. The initial price would be higher, but the payback to the consumer would take less than five years. Manufacturers of refrigerators are forecasting a market of $80\times10^6$ new units over the next 20 years. Why are these companies not introducing the more-efficient units?

The unexercised potential of more-efficient refrigerators is a dramatic, clear-cut example of a whole host of energy conservation steps that are not being taken in residential and commercial buildings.[8] Why doesn't rational-consumer theory work in practice? There are many reasons. Landlords who own nearly one-third of U.S. housing and building contractors have little incentive to pay the premium, since the annual savings will accrue to others.[9] Some low-income owners cannot readily afford the initial investment. For others, the information on energy cost-saving is confusing and lacking in credibility. Many exaggerated claims were made for insulating materials and home appliances in the early days of the oil crunch. Many enthusiastically bought caulking material for windows and took other modest steps, but are unwilling to give up this year's vacation for doubtful savings five years hence.

The production of new types of refrigerators requires a significant corporate investment. Appliance manufacturers are unlikely to assume this risk when the response from the marketplace is so uncertain. The political issue is clear. Should complete reliance be placed on the "free" market or should government regulations be promulgated that would ensure reductions in electricity use? Unlike passenger vehicles, the record to date for improvements in building efficiency is poor. The mandating of higher automotive fuel efficiency has led to major reductions in oil imports. It would appear that an extension of efficiency standards already required in California would be advantageous, but there are strongly held views in favor of limiting government constraints. At stake is the potential demand in the year 2000 for 82,000 MW more of utility capacity than required today. Eighty of the largest coal-fired plants will be required to satisfy this demand if these improvements in electrical appliances are not achieved.

## VII. Industry

More energy is consumed for industrial purposes than is required for either transportation or residential and commercial buildings. Because industrial endeavor is so diverse, it is difficult to pinpoint the specific functions or factors that have a dominating input on its energy demand. In addition, industry is undergoing more rapid change than the other sectors. Heavy industry is under extreme pressure from foreign competition, for a variety of reasons. A study conducted in 1977 indicated that Japanese steel manufacturers could sell higher-grade steel in Detroit at lower cost than U.S. manufacturers located nearby. Nippon Steel imported both coal and iron ore, but used such innovative labor-saving processes that the manufacturing cost savings more than offset the cost of shipments of the coal, iron ore, and finished product. Of course, other factors enter the cost equation as well, such as labor rates and government support of financing. Many plants in the U.S. have been closed, never to reopen, and some smaller steel companies have gone into bankruptcy. In order to remain competitive both domestically and internationally, many companies have established production facilities external to the United States. These trends are obviously affecting the demand for energy within U.S. borders. The energy model must account for these fundamental changes on an industry-by-industry basis.

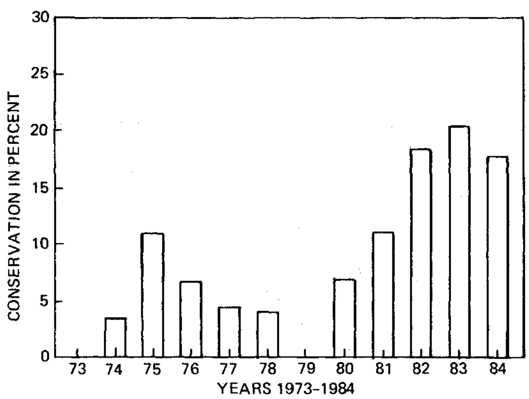


**Fig. 10 Industrial conservation.**

### Manufacturing

About two-thirds of the energy used by industry is required for manufacturing. Manufacturing is defined by standard industrial classifications. Ten of these categories account for 90% of the energy used in manufacturing. These industries are listed in Table 2 in the order of their energy use in 1984.

Chemical companies account for 14% of industrial energy demand and textile companies for slightly more than 1%. The percentage required for each category is shown for 1973, 1979, and 1984. The most dramatic change in the major industries was the drop in the energy supplied to primary metals from 18.1 to 10.8%. Chemical products increased energy demand in 1973–1979, but dropped from 3.29 quad in 1979 to 2.97 quad in 1984. The percent of energy supplied to chemical products increased to 13.9%, only because the total industrial demand fell from 25.56 quad in 1979 to 21.16 quad in 1984.

The percentage growth in energy use was determined in the same manner as for the other two sectors. The energy used by chemical products $Q_{cp}$ for example, was assumed to be in the form

$$Q_{cp} = Q_{(cp)73}(1 - C_{cp})(1 + G_{(cp)})^T \tag{5}$$

The annual energy supplied to each type of manufacturer for the years 1973–1981 was presented by Finger and Barnes of Exxon Corporation at an M.I.T. seminar[17]. All manufacturers experienced energy reductions during and after the embargo, with primary metals having the deepest cut. Each type of industry experienced a growth in energy deliveries toward the end of the 1970s, with each showing a maximum in 1979. Defined as the annual exponential change for 1973–1979, the growth $G_{cp}$ for chemical products in Eq. (5) became 0.9%, and the $G_{PM}$ for primary metals was $-2.2$%. No attempt was made in this analysis to determine the annual product levels for each type of manufacturer. Hence, the conservation determination for manufacturers in this paper includes the effect of all savings due to drops in production and some, but not all, of the conservation resulting from improvements in manufacturing efficiency. For this reason, the production growth percentages in Table 2 may be low for some types of manufacturing.

**Table 2 Variation in energy growth of major industrial users[a]**

| | | Energy supplied, % | | | |
|---|---|---|---|---|---|
| SIC[b] | Industry | 1973 | 1979 | 1984 | Growth, % |
| 28 | Chemical products | 12.2 | 12.9 | 14.0 | 0.9 |
| 29 | Petroleum products | 12.0 | 11.3 | 10.9 | −1.1 |
| 33 | Primary metals | 18.1 | 15.8 | 10.8 | −2.2 |
| 26 | Pulp and paper | 9.0 | 9.0 | 8.1 | −0.2 |
| 32 | Stone, clay, and glass | 5.9 | 6.2 | 6.1 | 0.8 |
| 20 | Food processing | 4.1 | 4.2 | 4.8 | 0.2 |
| 34 | Fabricated metals | 1.8 | 1.7 | 1.5 | −1.4 |
| 35 | Machinery[c] | 1.9 | 1.6 | 1.3 | −2.2 |
| 37 | Transportation equipment | 1.7 | 1.5 | 1.2 | −1.7 |
| 22 | Textiles | 1.6 | 1.4 | 1.0 | −1.8 |
| | Other manufacturing | 5.0 | 5.1 | 4.7 | 0.0 |
| | Total manufacturing | (73.3) | (70.7) | (64.4) | −0.8 |
| | Agriculture, construction, and mining | 26.7 | 29.3 | 35.6 | 1.7 |
| | Total industry | 100.0 | 100.0 | 100.0 | −0.1 |

[a]1973 and 1979 data from Finger and Barnes, 1984 data from computer model. [b]SIC = standard classification codes. [c]Does not include electrical equipment.

The energy delivered to all the high-energy-use manufacturers was presented and discussed in the seminar conducted by Finger and Barnes. The total for all industry is contained in the DOE/EIA monthly reports and the difference between the Finger and Barnes data and the DOE/EIA totals were attributed to the energy needs associated with agriculture, construction, and mining. The energy required for these three categories of industry dropped slightly in 1975, reached a peak level in 1979, fell moderately during the early 1980s, and is currently at its all-time maximum. As a percentage of all industry, these three categories grew nine percentage points in 1973–1984, as can be seen in Table 2.

"Conservation" in this paper is defined as the shortfall in energy use below the datum required for simple exponential growth. Unlike energy use for buildings and transportation, which reached their maximum level in 1978, industrial requirements were greatest in 1979. Hence, conservation can be seen in Fig. 10 to be zero in 1973 and 1979. During the oil embargo and shortly thereafter, energy for industrial purposes was in short supply and the enforced savings caused plant slowdowns and temporary closings. Conservation reached a maximum of 10.8% in 1975 and then, as energy allocation "normalized," forced savings were reduced. However, energy costs increased three- to fourfold, so that less-efficient plants were closed, heat recuperators were installed, domestic firms started moving production offshore, and foreign competition increased. All of these factors caused a decrease in energy growth between 1973 and 1979; in more recent years, conservation has steadily increased. The maximum conservation attained was 20.5% in 1983. Since then, the recent mild economic recovery caused a modest increase in industrial energy use, hence, the conservation downtrend to 15.8% in 1984, as shown in Fig. 10.

#### Fuel Substitution

The data provided by Finger and Barnes at the M.I.T. seminar in 1983 included the annual distribution of fuels supplied to each industry. The sources of energy were electricity, oil, gas, and coal. For some industries, the total energy supplied could be estimated, but uncertainties existed in fuel allocation and, hence, a percentage of the fuel sources was undetermined. The data presented at the seminar were programmed into the computer model, with the undetermined sources of supply accounting for about one-third of the total. Electrical use can be precisely measured, whereas the fossil fuel supplies are more difficult to aggregate. Therefore, the total undetermined fuel supplied to manufacturing was prorated to match the fossil fuel supply information contained in the DOE/EIA monthly energy reviews. In order to obtain energy use from the supply data, an energy efficiency of 95% for electrical use and 66% for fossil fuels was assumed.[10] The annual percentage change in use for each fossil fuel was assumed constant for the periods 1973–1979 and 1979–1984.

Figure 11 shows that the total percentage of oil and gas supplied to industry stayed nearly constant, from 75% in 1973 to 72.5% in 1984, despite wider annual excursions in the use of each fuel. Oil supplies to industry increased fairly linearly from 35 to 41% in 1979 and has decreased since then. Gas supplies have shown exactly the opposite trend, going from 40% in 1973 to 33% in 1979, with modest increase since 1979. At this time, oil is still the most popular industrial fuel, but by only 3 percentage points. It is important to note that natural gas is essential in many industrial processes, but none more so than in petrochemicals, which consume over one-third of all natural gas used by industry.

Electricity and coal supplies have shown more consistent trends throughout the period of investigation (see Fig. 12). Electricity supplies have grown linearly from 9% in 1973 to 13.5% in 1984 and the percentage of coal has fallen during the same period from almost 15.5 to 13.5%. The important trend toward electrical use provides a significant opportunity for further conservation by use of cogeneration.

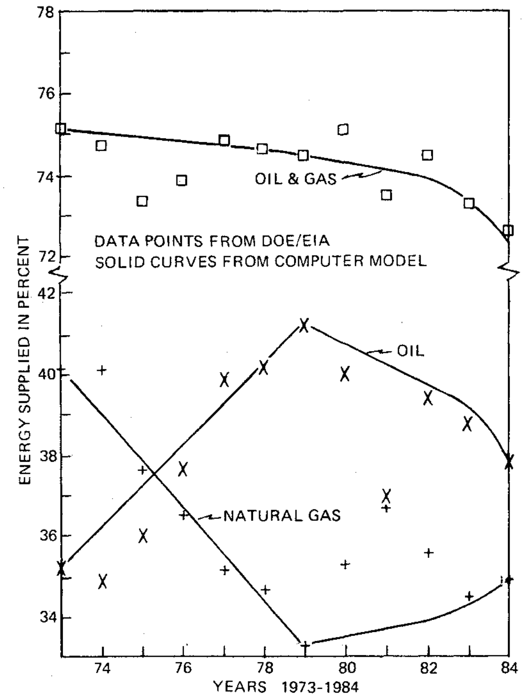


**Fig. 11 Oil and natural gas supplied to industry.**

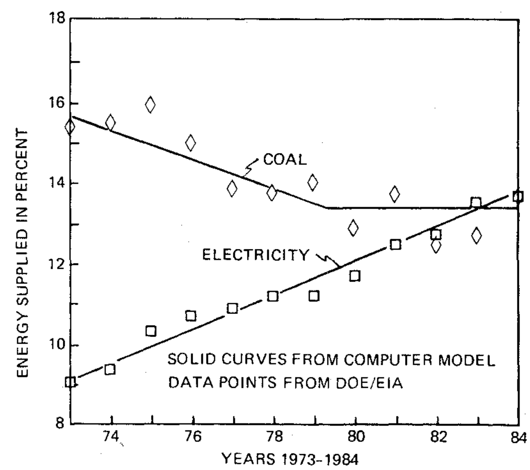


**Fig. 12 Coal and electricity supplied to industry.**

#### Improved Fuel Efficiency by Use of Cogeneration

Cogeneration is not a new concept and has been used on a modest scale for many years. The basic idea is to combine the generation of heat and electrical power into a single operation. Ordinarily, the power utilities generate electricity and dissipate the excess heat at some expense and often, with some environmental controversy. Industrial-process heat, on the other hand, is provided by burning fossil fuels or passing electricity through resistance loads. Cogeneration can be used to supply electricity and heat to buildings, either from central powerplants with district heating or on a dispersed basis with separate units in each building. As can be readily visualized, the effectiveness of cogeneration hinges on the degree to which the requirements of heat and electricity are balanced. Hospitals, for example, appear amenable since they are in operation day and night, with fairly uniform requirements for both forms of energy.

However, industrial use of cogeneration appears even more attractive, providing institutional regulations are supportive. A brief analysis of cogeneration in this section will be followed by a description of the enabling legislation and its consequences.

Well over 50% of the energy supplied for manufacturing is used for process heat and, theoretically, is available for cogeneration; namely, the generation of electricity along with the supply of heat from a common unit. It is obviously not practical to introduce cogenerators in every plant that uses process heat. The average and daily match between heat and electrical load at a particular plant is a prime consideration, but other factors are initial and maintenance outlays and environmental issues. In many cases, the benefits of cogeneration far outweigh the costs.

Figure 13 is a functional diagram of an industrial plant with cogeneration. The production processes in the plant require the delivery of heat and electricity, $Q_{dh}$ and $Q_{de}$, respectively. Normally, fossil fuel is burned to provide the heat and electricity is purchased from an electrical utility. If the fossil fuel combustor and associated elements has an efficiency $E_{(ih)}$ and the electrical utility generation and grid has an efficiency $E_{ug}$, the total energy consumed by the plant $Q_c$, is

$$Q_c = Q_{cf} + Q_{ce} = \frac{Q_{dh}}{E_{(ih)}} + \frac{Q_{de}}{E_{ug}} \tag{6}$$

However, by introducing a cogenerator into the plant with efficiency $E_{(cg)h}$ and $E_{(cg)e}$ for the generation of heat and electricity, two sources become available for both process heat and electricity. Then, the total energy supplied the plant is less than $Q_c$ in Eq. (6) and the energy avoided, $Q_{c(\text{avoid})}$, becomes

$$Q_{c(\text{avoid})} = \left[\frac{E_{(cg)f}}{E_{(ih)}} + \frac{E_{(cg)e}}{E_{(ug)}} - 1\right] \times Q_{c(cg)} \tag{7}$$

where $Q_{cg}$ is the energy provided the cogenerating unit.

There are two factors that limit the energy consumption that can be avoided. The energy for cogeneration cannot exceed the amount originally required for process heat without cogeneration. The other is institutional: The electric utility output cannot become negative unless the utilities are willing to accept the excess electricity into their grid and reimburse the company operating the plant at reasonable rates. The algebraic expression in Eq. (7) permits a determination of the maximum amount of energy that can be avoided, as well as the amount that is avoided when the plant becomes a net generator of electricity. It can be seen that the maximum energy that can be avoided is

$$Q_{c(\text{avoid})\max} = \left[\frac{E_{(cg)h}}{E_{(ih)}} + \frac{E_{(cg)e}}{E_{(ug)}} - 1\right] \times \frac{Q_{dh}}{E_{(cg)h}} \tag{8}$$

or when the efficiencies in cogeneration are equal to the industrial heater and the utility efficiencies,

$$Q_{c(\text{avoid})\max} = Q_{dh}/E_{(cg)h} \tag{9}$$

The cogenerating unit can operate without the requirement for electricity sales to the utility as long as the process heat $Q_{dh}$ remains less than the limit

$$Q_{dh} < Q_{de} \times \left[\frac{E_{(cg)h}}{E_{(cg)e}}\right] \tag{10}$$

When the process heat delivered for manufacturing $Q_{dh}$, becomes greater than the limit defined by Eq. (10), industry must be able to sell electricity to the utility.

In fact, not all of the heat can be recovered from cogeneration. In a conventional electric powerplant, the losses are about 48% in the condenser, 16% in the boiler, and 3% miscellaneous, which gives an operating efficiency of 33%. When cogeneration is used, heat losses will still occur in the boiler and, hence, the maximum efficiency that can be achieved becomes slightly in excess of 80%.

The penetration of cogeneration into industrial plants is not precisely known, but some estimate the present level as high as 8400 MW. In the future, cogeneration can be expected to increase in large industrial-scale plants before wide use is seen in light industry. Its use will also increase in large apartment buildings, hospitals, hotels, and other commercial buildings. The rate of growth hinges on whether energy prices rise and to what extent. Some estimates for the year 2000 are as high as an additional 27,000 MW of cogeneration in industry and 15,000 MW in commercial buildings.

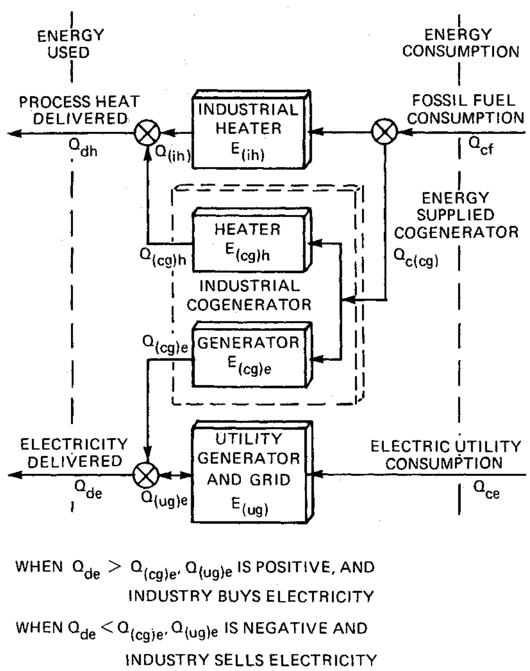


**Fig. 13 Industrial conservation from cogeneration.**

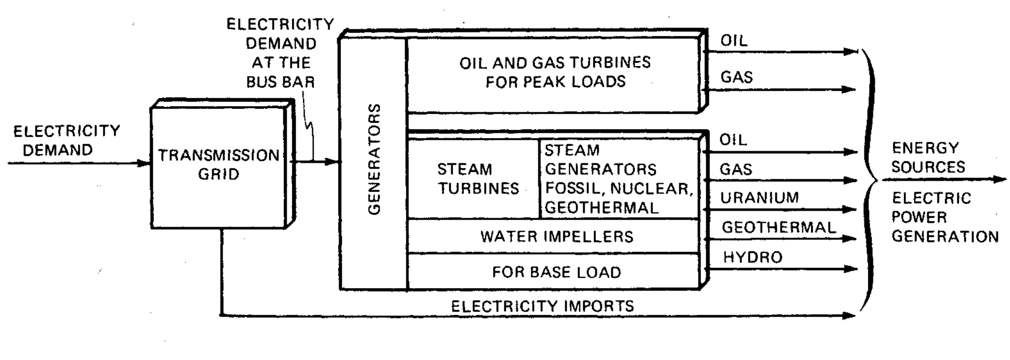


**Fig. 14 Functional diagram of electric power generation.**

**Legislation**

Cogeneration would not have reached its present status, nor would forecasts for cogeneration appear so optimistic, without federal legislation. It would not be practical for industrial firms to install cogeneration unless they could be assured of electrical deliveries when needed and unless they could dispose of excess electricity at reasonable rates. Moreover, they would not install cogeneration if by introducing excess electricity into the grid, they fell under the jurisdiction of state public utility commissions. These potential deterrents to cogeneration were recognized and formed the basis for the 1978 Public Utilities Regulatory Policies Act (PURPA). By this act, utilities were required to hook into industrial cogenerators and industry was exempted from state regulation. In 1979, the Federal Energy Regulatory Commission issued draft regulations, which became final in early 1980. The regulations defined purchase rates for electricity, but did not dictate contractual terms between utilities and industry. In general, the purchase prices paid by the utilities were lower than the costs they avoided for increased capacity. Thus, industry obtained the benefit of long-term commitments and the utilities were able to offer their other consumers lower electric rates because less financing was required for new capacity.

PURPA has been challenged in the courts on the basis of infringement of states' rights, but to date the legislation has been upheld. This fundamental issue remains and a second pertains to the ownership and operation of the capital equipment. The current act prevents utilities from owning a majority share in the enterprise. However, PURPA provides the institutional framework for expansion of industrial cogeneration. If the bill is rescinded, the utilities will have to expand capacity substantially and, in turn, the utility demand for fuel will be permanently increased. Doctrinaire decisions should not be reached in this regard; there is too much at stake.

## VIII. Electrical Power Generation

The demand for electricity comes primarily from residential and commercial buildings and from industry. Although some railroads and public transportation are electrified, the resulting demand is less than 1 part in 500 of total electricity use. The total demand for electricity grew by 33% during the 11-year period 1973–1984. This converts to an average annual growth of 2.6%, far different from the annual growth rates of 6–7% that were experienced prior to the oil embargo. However, total energy supplied to the users during this period fell by 0.8% annually and electricity took a greater share of all the energy markets.

All of the electrical conversion processes of Fig. 14 are based on electromechanical power generation. Generators can be driven by steam turbines and water impellers for reasonably steady base loads and by oil and gas turbines when rapid changes in load occur during peak hours. The steam is provided by either fossil fuel combustors, nuclear reactors, or geothermal wells. Most water impellers are driven by high-head hydropower created by damming major rivers. Minor amounts of electricity are obtained from low-head hydropower, wind-driven generators, combustion chambers heated by large arrays of solar mirrors, and direct conversion of solar radiation using photovoltaic cells.

Electricity is transmitted from the bus bar to the user over a complex of grids operated by the electrical utilities. Utilities buy and sell electricity to each other with switching gear activated automatically by computers to minimize electricity cost. Electricity is also purchased beyond our borders, principally from Canada. This service has steadily grown and is now over 5% of the total. Although imported electricity must be transmitted over some portion of the grid, for the purpose of this analysis it was assumed to be supplied directly to the customer.

**Transmission Line Efficiency**

In order to determine the energy required for conversion, the losses occurring in generation and transmission must be taken into account. The power generation efficiencies were selected from the DOE reference energy system of 1979 and the efficiency of the electrical grid was calculated each year by inserting the annual DOE-EIA data into the computer model. The DOE-EIA data provide the amount of energy delivered from each source for power generation, i.e., oil, natural gas, nuclear, hydro, geothermal, and coal. The amount of electricity generated can also be determined from the DOE-EIA data that indicate the amount of electricity supplied the users minus any imported energy. The only unknown quantity is the transmission-line efficiency, which can be calculated; the results are shown in Fig. 15. The straight line in Fig. 14 gives the least mean square deviation of the calculated annual efficiencies. It can be seen that the transmission line efficiency drops 1.75% during the 11-year period. This straight-line relationship between the transmission-line efficiency and the designated year was used in this analysis.

**Energy Sources for Conversion**

The electric utilities have been faced with difficult decisions during this highly volatile period. Prior to World War II, a major government program was undertaken to provide navigable waterways, flood control, water resources, and hydroelectric power. Grand Coulee Dam in the Northwest, Hoover Dam in the Southwest, and Tennessee Valley in the Southeast were gigantic prewar public projects for this purpose. Then, in the post-World War II period, President Eisenhower advanced "Atoms for Peace" as a domestic and international initiative. Admiral Hyman Rickover developed the first nuclear reactor for commercial power, a 65 MW unit for Duquesne Power & Light in Pittsburgh. The reactor system was similar to units in Navy submarines and ships. It

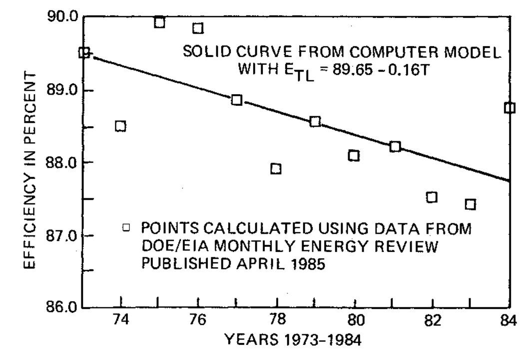


**Fig. 15 Transmission line efficiency.**

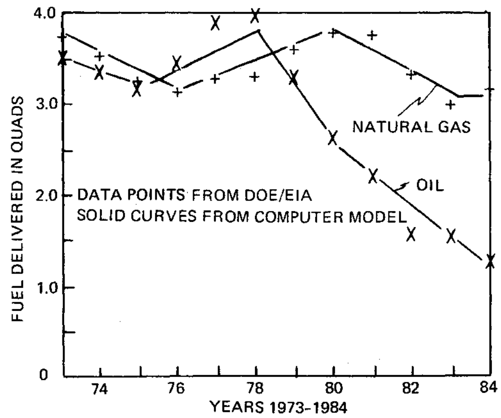


**Fig. 16 Oil and natural gas supplied to electric utilities.**

was thought that unlimited cheap power would soon be a human blessing and that fossil-fired plants and hydroelectric systems would continue to carry the load only until the millenium arrived. Just prior to the oil embargo, plans existed for 500–600 large (1000 MW) nuclear plants. At the time of the oil embargo, the utilities had begun to realize that these nuclear plans were decidedly optimistic, oil-fired plants were in jeopardy, natural gas would be in limited supply, and hydroelectric power could not be expanded without unacceptable losses of land. There were soon proponents for many alternatives ranging from solar to fusion, but coal seemed to be the path to follow, at least for several decades. Table 3 shows the fuel sources for electric power conversion today, compared with the sources in 1973.

The use of coal has increased and today provides 55% of U.S.-generated electrical power. The amount of power from nuclear stations has tripled and is now on a par with hydroelectric and natural gas in the generation of electricity. Many oil-fired plants have been shut down or converted to coal. The amount of electricity from oil-fired plants is now down to the level of electrical imports. The year-by-year variation in energy for each electrical fuel is discussed in the following paragraphs.

*Petroleum*

The National Energy Consumption Act became law in 1978, after 16 months of hearings and committee actions. Since the jurisdiction for energy legislation was not held by single Senate and House committees, but was distributed among several, a special ad hoc Committee was established in the House to oversee the action on the umbrella legislation and its constituent parts. The Fuel Use Act was a part of this total package. This act stipulated that no more oil- or gas-fired plants could be constructed and that existing plants could be kept in operation only until 1990. Inspection of Fig. 16 shows that the use of oil-fired plants to generate electricity dropped slightly during and shortly after the embargo and then increased to a maximum in 1978. Since them, the use of oil has been in a continuous decline. Some older, less-efficient oil-fired plants were decommissioned, some were mothballed, and a few were converted to coal. The drop may have resulted from the 1978 legislation, but the relatively sharp rise in oil costs is probably the primary reason.

*Natural Gas*

The use of natural gas has remained fairly constant, with maxima of 3.75 quads in 1973 and 3.80 quads in 1980 and minima of 3.15 and 3.00 quads in 1976 and 1983 (see Fig. 16). It is important to note that the relatively more favorable price for gas in the late 1970s and early 1980s appears to have kept more gas-fired plants in operation than oil-fired. However, even though gas-fired plants have remained in operation at a nearly constant level, the gas shortages in the 1970s caused nearly a 50% decline in the annual manufacture of new gas-fired boilers and, because of the Power Plant and Industrial Fuel Use Act, boiler production has dropped an additional 35%. There is currently enough natural gas available (the so-called "gas bubble") and gas-fired combined-cycle generators are now being used in Japan that are more efficient than conventional U.S. systems. For these reasons, there is strong congressional pressure to revise the Fuel Use Act as it applies to natural gas. The provision requiring alternative sources to replace the existing gas-fired powerplants was eliminated in 1981.

**Table 3 Energy sources for electric power conversion, %**

| Source | 1973 | 1984 |
|---|---|---|
| Petroleum | 17.7 | 5.0 |
| Natural gas | 19.0 | 12.5 |
| Nuclear | 4.6 | 13.9 |
| Hydro | 14.5 | 13.5 |
| Geothermal | 0.4 | 0.3 |
| Coal | 43.8 | 54.8 |
| Total supplied | 100.0 | 100.0 |

*Nuclear*

The future of nuclear electric-generating plants was dramatically altered by the events that occurred in 1979 at Three Mile Island near Harrisburg, PA. What might have happened, compared to what actually happened at Three Mile Island, is still being debated. While in operation, the plant suffered loss of coolant water, which in turn caused a fire, a partial core meltdown, and the release of highly radioactive fission products within the containment area. The automatic safety equipment attempted on two occasions to provide additional coolant, but was overridden by the plant operators. It was obvious that insufficient operator training was at least partially responsible for the accident. The media conveyed a doomsday message of such proportions that many today still perceive nuclear plants as much too hazardous for future use.

The effect of Three Mile Island on nuclear growth can be readily seen in Fig. 17. The nuclear energy supplied for power generation had grown steadily from 0.9 quad in 1973 to 3.0 quads in 1978. The Three Mile Island plant was permanently disabled in 1979. Soon after the event, the Nuclear Regulatory Commission issued many new directives calling for modifications and inspections of existing plants and design changes for all plants under construction. The utilities themselves commenced an internal review and, as a result, established the Institute of Nuclear Power Operations (INPO) to review control-room designs, operating procedures, and the qualification and training of plant operating personnel. The results of INPO's annual plant inspections are made available to all utilities with nuclear plants, as well as to the Nuclear Regulatory Commission. The way was cleared in 1980 by the combined action of industry and government for a continuation of nuclear growth, but a two-year delay in plant licensing had occurred.

Many attempts have been made to halt the use of nuclear energy on a variety of environmental, health, and safety issues. The most telling criticism was directed at the lack of plans for storage of the highly radioactive waste from spent fuel. Plans for nuclear energy dropped even further as a result of Three Mile Island. In 1978, 70 nuclear plants were licensed for operation, 122 had construction permits, and 13 had been announced or were on order, for a total of 205 plants. The total dropped to 169 in 1980, 144 in 1982, and 132 at the end of 1984. At the end of 1984, 86 plants with a combined net output of 69.5 GW were licensed for operation. Licenses for startup were issued for 6, construction per-

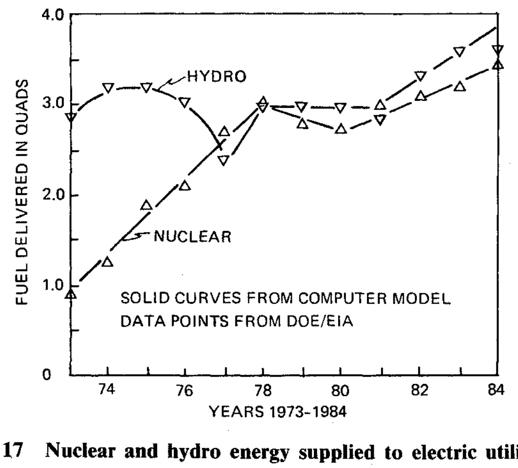


**Fig. 17 Nuclear and hydro energy supplied to electric utilities.**

mits had been granted for 38, and 2 were still on order. If all of these plants are completed, the net capacity will be 123 GW and at today's 56% capacity factors (percentage of time plants are on-line), 6.3 quads of nuclear energy will be supplied for power generation, compared to today's 3.6 quads.

The near-term prognosis for nuclear plants is now moderately favorable, but the long term is clearly in doubt. The owners of the nuclear plant under construction in Seabrook, NH, have undergone 700 days of hearings and have provided documentation literally 500 ft high. The plant is 95% complete and may be placed in operation in 1986. The average operating efficiency of all nuclear plants has improved 1.5% and an intensive and continuing operator-training program under INPO cognizance has been instituted. However, there have been no new orders for nuclear plants for eight years and the capability for design, fabrication, and construction of nuclear plants is rapidly eroding in this country. Further demand for light-water reactors is unlikely, but if it should happen, it may require expertise from France or Japan. High-temperature gas reactors have attractive features, but their development will require combined government and industry initiatives. The future for nuclear power in the United States is clearly in doubt.

*Hydroelectric*

Except for the year 1977, water power has been supplied to the 1450 hydroelectric plants in the U.S. at close to 3 quads until an upsurge brought the level to over 3.5 quads in 1983 and 1984. As stated earlier, it is difficult to expand water reservoirs for hydroelectric plants without eliminating large tracts of land, for which there is major resistance. There are opportunities to utilize existing low-head dams in New England for electric-power generators for local communities, and possibilities may exist for systems like the Northern Scotland Hydro-Electric Board's Tunnel Valley Scheme in New England and elsewhere. The Scottish project links lakes and rivers together with a complex of aqueducts and tunnels to provide hydro power to eight stations with a combined capacity of 245 MW. Not only is low-cost electricity provided, but the project enhances the beauty and the recreational value of the area. Another alternate way to expand hydroelectric capacity is to encourage further development of large resources in Canada and to make arrangements for transmission of the electricity to distribution terminals in the U.S.

Even though new hydroelectric plants in the U.S. are not at issue, arguments between public and private power interests are at the forefront today, because 189 licenses held by private- and investor-owned utilities will be coming up for review over the next 10 years. The arguments in Congress and the courts hinge on whether the framers of the Federal Power Act of 1920 intended public utilities to have preference when relicensing such facilities. If the private utilities lose their licenses, the cost to the government could run as high as $3.5 billion. Although the taxpayer and some electric ratepayers may be affected, the availability of hydroelectric power in the U.S. will probably remain about the same.

*Coal*

Coal is costly and dangerous to extract, difficult to transport, and dirty to burn. That accounts for the fact that, while in 1910 coal was the prime source of energy, by 1973 coal accounted for only 17% of the energy supply. Since then, coal is increasingly in demand, particularly for electric-power generation, and now coal has over 23% of the energy market. Figure 18 shows that increase in the coal supplied for power conversion has closely matched the net total requirement. The coal supplied for electric-power conversion increased by 5.5 quads from 1973 to 1984 in response to the total power increase of 6.0 quads (net power increase 4.3 quads. Coal now provides 55% of the energy required for electric-power generation (see reference Table 3). Consumption of coal was $790 \times 10^6$ tons in 1984, of which $665 \times 10^6$ tons was for electric power, an increase of $275 \times 10^6$ tons for this purpose compared with 1973.

Fortunately, the amount is not as large as predicted in 1977 by the World Alternative Energy Study.[11] This study, conducted by teams from 15 different nations under the direction of Carroll L. Wilson of M.I.T., concluded that coal usage would increase two to three times by the end of the century (2000). A follow-on project reviewed the implications of this growth on world trade. It is estimated that the United States has one-third of the world's coal reserves; thus the study concluded that the U.S. would become the Saudi Arabia of coal, exporting $300\text{–}400 \times 10^6$ tons annually by the year 2000, in addition to an increase in home consumption of $1300 \times 10^6$ tons. The World Coal Study (WOCOL),[12] completed in 1980, outlined prodigious requirements for new mines, railroads, harbor facilities, and ships. Even the actual growth experienced to date has been difficult to achieve and the most troublesome aspect has been environmental.

Only about 10% of the coal-fired utility boilers are subject to the New Source Performance Standards. The boilers east of the Mississippi emit $16 \times 10^6$ tons of sulfur dioxide ($SO_2$)[12] and over $4 \times 10^6$ tons of nitrous oxides ($NO_x$), or about 70% of all the $SO_2$ and 25% of all $NO_x$ emitted in the U.S. As part of the WOCOL study, the Japanese estimated the cost of importing coal and the additional cost of environmental controls necessary to satisfy their strict regulations on all types of emissions. They concluded that the total cost to burn coal in Japan would increase $35/ton for any environmental control (or 77% using present-day technology).

Although it appears that present-day high-sulfur coal can be burned while satisfying environmental standards at costs below oil and natural gas, further research and development are needed to find more reliable cost-effective technologies for burning coal.[13] The U.S. Department of Energy has submitted a report to Congress that evaluates coal technologies in terms of environmental performance, applicability, and cost effectiveness. From an environmental standpoint, the most-attractive technologies are surface and underground gasification, direct and indirect liquefaction, atmospheric and pressurized fluidized-bed combustion, and a variety of fuel cells.[14] It is important to continue research and development on gasification and liquefaction of coal, since substitutes for oil and natural gas may eventually be required. Synthetic fuel processes are initiated by the burning of coal, just as coal combustion is the first step in coal-fired electric plants. Coal-burning techniques clearly should receive the highest priority and, if fluidized-bed technology has the greatest promise, that is where the greatest emphasis should be placed. Fuel cells have attractive features for use

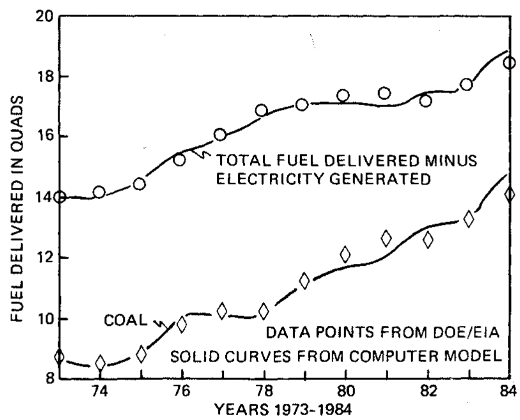


**Fig. 18 Coal and net total energy supplied to electric utilities.**

in commercial buildings and for satisfying peak loads, but not for burning large quantities of coal.

*Alternate Sources*

Geothermal energy has been used for many years as the basic source for much of San Francisco's electricity. The source is located in the Geysers area north of Napa Valley. When the steam escapes, it has a pungent, sulfurous odor, and so the counties where the steam is located are reluctant to approve further expansion. Unlike the Geysers area, most geothermal sources are in the form of hot briny water or hot rocks and are difficult to tap with economically viable techniques. Sun, wind, and tides can be harnessed for special applications, but are not expected to provide large measures of energy by the year 2000. Wood is burned in many houses, but expansion is limited by the time for reforestation and the emission of particulates. The latter have caused restrictions on the burning of wood in some areas. The burning of sugar cane in Hawaii provides 7% of the state's electricity; more can and will be done with agricultural waste in its various forms in the future. However, the disposal of municipal waste has creached crisis proportions in many municipalities and the obvious solution is to convert the combustible elements into electricity.

*Municipal Waste*

The average individual in the Unites States generates 0.5 ton of household trash each year. As a consequence, household garbage collectors must dispose of about $120 \times 10^6$ tons of trash annually and, when commercial buildings and all other sources are added, the municipal level comes to $275 \times 10^6$ tons. Many cities such as San Francisco have run out of local land for waste fill and are forced to truck refuse 50–60 miles at $0.30/ton-mile. The largest resource-recovery plants are located in Dade and Pinellas counties, FL, Peekskill, NY, and Baltimore, MD. These plants consume a total of 9500 tons daily.

The Combustion Engineering Corporation has been awarded a contract by the City of Honolulu for a 2000 ton/day plant that will generate up to 50 MW of power, to be sold to the Hawaiian Electric Company.[15] Combustion Engineering has already begun construction on the Mid-Connecticut Resources Recovery Project, which will service Hartford and 32 adjacent towns. Both the Honolulu and the Hartford plants use fuel technology to remove noncombustible materials before shredding the remaining waste into dry fuel. It is estimated that, by the year 2000, 20–25% of the available municipal waste will be burned in recovery plants having a total production capacity of 6000–7000 MW. These plants could reduce the local landfill by a factor of 8–10, provide electricity and possibly other marketable products, and at 65% capacity factor would replace $15\text{–}20 \times 10^6$ tons of coal annually.

## IX. Energy Summary

During 1973–1984, unexpected changes have taken place in energy supply and demand both nationally and internationally. During the oil embargo, the daily concern for gasoline and fuel oil shortages gave rise to "gloom-and-doom" forecasts of the future. Those predicting consumption growth less than 2% annual were felt to be unrealistic, if not unpatriotic. Discussions of massive public works and major corporate investment were conducted with great seriousness. The United States consumed 74.3 quads in 1973 and at 2% growth would have consumed 92.2 quads in 1984, but in actuality only used 73.7 quads, actually less than in 1973. Why were so many fooled and what does this experience portend for the future?

Transportation measured in passenger-miles and ton-miles increased as expected at close to 3% annually, but growth in energy demand was reduced to 0.6%, primarily by major improvements in vehicle efficiency and some decrease in miles driven, prompted by increased fuel costs.

The number of residential and commercial buildings increased 1–2%, but the energy supplied to them fell 6% from 1973 to 1984, or 0.55% annually. This study did not differentiate between savings from cost-conscious thermostat settings and conservation improvements in insulation, appliances, commercial equipment, and heating systems. However, it is important to note that energy use increased only slightly from 1973 to 1984, but with a dramatic increase of 33% in electricity use. The shift from fossil fuels to electricity accounts for the actual drop in energy supplied to residential and commercial buildings, even though energy use was increased.

Industry was the only sector in the economy that experienced a decline in energy use during the period 1973–1984. The decline was caused by a drop in most industries, but was particularly sharp in the heavy, smokestack companies. However, in spite of the nearly 30% decrease in energy supplied for manufacturing, electricity supplied for manufacturing increased 10% and for all of industry increased 21%. Electricity supplied for mining, construction, and agriculture experienced an annual growth of 1.8%.

Despite the nearly constant energy use in all types of buildings and the major decline in industry, the electricity supplied these sectors rose from $1700 \times 10^9$kW·h in 1973 to $2270 \times 10^9$kW·h in 1984. During this period, the quantity of oil and natural gas purchased by the electric power utilities dropped 40%. Hence, other sources had to make up for the decline of oil and gas. Electrical imports increased 2.5 times, nuclear 3.5 times, and hydroelectric power by 21%, but coal was the major contributor. The utilities burned $275 \times 10^6$ tons more in 1984 than in 1973. This increase in coal-fired plants has raised serious environmental issues that must be addressed in the near term, especially since coal must be even more heavily relied on during the remainder of the century.

The overall changes that have taken place since the oil embargo are summarized in Table 4. It can be seen that the total energy supplied is nearly constant, but the mix of fuels has undergone appreciable change. The consumption of oil and gas combined has dropped 8.3 quads, and nuclear, hydro, and coal consumption has increased by almost the same amount. The shift of nearly 2 quads to electricity has had a major impact. If the percentage use of electricity had remained constant in buildings and industry, total consumption would have dropped to 72.5 quads, because the drop in consumption by the utilities would have been greater than the end-use increase of oil and natural gas. Then, if nuclear and hydro were still at the 1984 levels, coal consumption would have fallen below the amount used in 1973. As future options are reviewed, the question of the growth in electrical use is one of the more important factors that must be considered.

## X. Future Options

Anyone who discusses future energy demand does so with trepidation. Clearly, the past decade has been filled with

**Table 4 Consumption of energy in 1973 and 1984, quads**

| Source | 1973 | 1984 |
|---|---|---|
| Electrical imports | 0.15 | 0.40 |
| Petroleum products | 34.84 | 31.00 |
| Natural gas | 22.51 | 18.03 |
| Nuclear | 0.91 | 3.55 |
| Hydro and other | 2.91 | 3.56 |
| Coal | 12.97 | 17.19 |
| Total | 74.28 | 73.73 |
| Electricity supplied | 5.84 | 7.79 |

some surprises. Energy use did not grow as predicted in the 1970s and, as a consequence, oil imports fell in the early 1980s. The OPEC nations, the energy cartel, which had control of oil production and price per barrel were enjoying new-found power and affluence. But as oil became a glut in the marketplace, prices fell and so did the cohesiveness of the cartel. Our memory of the past tends to fade, so it is extremely important to recognize the possibility that an oil shortage, with its geopolitical manifestations, could happen again. All reasonable steps should be taken to avoid such an occurrence and provision should be made now to have alternatives available if the world suppliers of petroleum attain a position to tighten the noose again.

The future use of energy is impossible to predict, because there are so many permutations and combinations of events that may influence the outcome. For the purpose of this study, more limited government is first considered. It is assumed that the key government legislation constraining energy use is rescinded and no new legislation nor regulations are initiated (option 1). Then, in option 2, present and new restrictions are assumed and the consequences are evaluated.

**Option 1**

The most obvious legislative restrictions arise from the Motor Vehicle Information and Cost Savings Act of 1977, the Public Utility Regulatory Policies Act of 1978, and the National Energy Conservation Act of 1978. Hence, for the first option, it is assumed that:

1) Highway traffic continues with its present fuel efficiency until the year 2000.

2) No regulations are imposed on the efficiency of home appliances.

3) No cogeneration plants are installed in commercial buildings and no new cogeneration plants are added by industry.

4) Although the electric utilities would be free to build new oil- and gas-fired boilers for steam generation, the number of these plants in operation remains constant.

It is also assumed that all nuclear plants under construction are licensed and that the new and existing nuclear plants remain in operation until the year 2000. No new hydro nor geothermal plants are projected, nor is any effort made to improve the efficiency of electrical transmission.

In this projection, it is assumed that vehicle users and homeowners would view the past much as they did prior to the oil embargo and, as a result, conservation due to saving in usage becomes one-half the 1984 level in the year 2000. This assumption also holds for all users of commercial buildings and managers of industry.

It is also assumed that, in all sectors, growth and the percentage change in fuel use continue at present levels. For example, passenger-vehicle miles driven between 1973 and 1978 are assumed to continue a 2.9% increase until the year 2000 and home and commercial electrical energy use is assumed to increase at 1.8% a year.

The effect of these assumptions on fuel consumption are summarized in Table 5. The energy consumed in the year 2000 would be 30% greater than in 1984. With governmental restrictions removed, petroleum and coal consumption would increase about 50%, while consumption of other fuels would remain nearly constant. Petroleum consumption of 45 quads would be well above the peak level of 38 quads that occurred in 1978. It is doubtful that domestic production could be substantially increased (some expect a 50% decrease); hence, oil imports would have to grow from the present 9.8 quads to over 20, well above the high levels that occurred in the period 1977–1979. Although not of international consequence, growth of coal consumption from 17.2 quads ($794 \times 10^6$ tons) annually to 29.4 quads ($1368 \times 10^6$ tons) would have far-reaching economic and environmental consequences.

**Table 5 Consumption of energy in 1984 and 2000, quads**

| Source | 1984 | 2000 Option 1 | 2000 Option 2 |
|---|---|---|---|
| Electrical imports | 0.4 | 0.4 | 0.8 |
| Petroleum products | 31.0 | 44.8 | 36.8 |
| Natural gas | 18.0 | 18.4 | 17.4 |
| Nuclear | 3.6 | 6.1 | 6.1 |
| Hydro and other | 3.6 | 3.6 | 3.6 |
| Coal | 17.2 | 29.4 | 19.6 |
| Total | 73.7 | 102.7 | 84.3 |
| Electricity supplied | 7.8 | 12.0 | 9.8 |

**Option 2**

The situation is much less acute if the current energy legislation is maintained and appropriate new regulations are promulgated:

1) Continuation of the mandated average-fuel-economy requirements for passenger vehicles and similar performance requirements for light trucks would reduce gasoline and diesel fuel consumption to about the 1978 level. Oil imports in the year 2000 would be increased, but only to the levels reached in the late 1970s.

2) Continuation of the Public Utility and Conservation Acts would lower the consumption of coal. Continuation of PURPA would permit electrical conservation of 0.44 quad in commercial buildings and 0.55 quad in industry through installation of cogenerating equipment.

3) Another 0.48 quad savings could be realized if improvements in refrigerator efficiency were mandated through the conservation act.

4) Other reductions would be possible in fuel for electrical utilities by increasing imports (0.4 quad assumed) and by improving the efficiency of the transmission grid (0.24 quad reduction for an efficiency increase from 88 to 90%). In addition, improvements in power-station efficiency might be made that would have the same positive effect.

The sum of all the changes and improvements outlined in the previous paragraphs would reduce the requirement for coal by $460 \times 10^6$ tons each year, which, coupled with reductions in energy use by highway vehicles, accounts for the lower level of fuel consumption in the year 2000 shown in Table 5 (84.3 quads compared to 102.7 quads).

**Strategic Reserve**

Even with a continuation of present legislation, oil imports would increase to the dangerous levels of the late 1970s unless there are mitigating circumstances not included in the study. It appears wise to continue purchasing oil to stock the Strategic Oil Reserves, although present budget pressures make justification of this governmental expense more difficult.

In 1977, the Department of Energy planned to reach $500 \times 10^6$ barrels in 1980 and $1 \times 10^9$ barrels in 1985. On Oct. 1, 1986, $490 \times 10^6$ barrels were in the ground and the fill rate was $1 \times 10^6$ barrels every six days. If imports reached levels of $7\text{–}8 \times 10^6$ barrels per day, as was the case in the 1970s, another embargo might again reduce imports by several million barrels per day.

This loss could be offset for 250 days by the present strategic reserve. The reserve will be increased to $770 \times 10^6$ barrels according to present plans. However, a contingency plan has not been promulgated for allocations from the strategic reserve. It appears desirable to have the government sell the fuel at the market rate and let the price determine the allocation, but it is not clear whether the Department of Energy plans to follow such a policy. The United States is in a potentially more advantageous position today, thanks to the oil held as a contingency in the Strategic Oil Reserves.

**Synthetic Fuels from Coal**

The United States is fortunate to have one-third of the known natural reserves of coal. In the longer term beyond 2000, it may be necessary to consume coal for a wide variety of purposes now satisfied by oil and natural gas. To use coal as the feed for synthetic oil or gas requires further research and experimentation. Also, coal may be mixed with water to form a slurry for pipeline transportation and as a direct substitute for oil in some applications. Investigation of such alternatives can be effectively conducted on university campuses, where future scientists and engineers can assist and gain valuable experience as part of their education.

Laying the groundwork for future synthetic-fuel plants should not be solely in the category of advanced scientific and engineering studies. As much information as possible should be gathered on scaling from breadboards to full size in such areas as environmental hazards, licensing issues, logistical difficulties with coal delivery, and the sale and distribution of the principal products and by-products from the plant. As mentioned in Sec. III, synthetic gas and other products (methanol, ammonia, sulfur, and carbon dioxide) cannot be produced at cost-competitive rates by the Great Plains Project in Beulah, ND. Much valuable data could be obtained from further operation of this plant, but the plant may be closed for fiscal reasons. The plant should be operated for one to two more years and then mothballed in such a way that it could be reopened in the future if natural gas prices rise, shortages in natural gas exist, or further operational experience becomes essential.

The roles of public and private institutions are discussed in the concluding section of this paper. It is emphasized that all institutions must have flexibility to accommodate today's dynamic world. Government, industry, business, and academe have valuable traditions, but must not accept the status quo as philosophically as the "fiddler on the roof."

## XI. Conclusion: Lessons Learned from Apollo

What did James E. Webb have in mind when he asked Lee DuBridge, President of the California Institute of Technology, to examine energy and other broad national needs for possible spin-off from NASA's space activities? He was not looking for ways to justify larger government intervention into the economic and social fabric of the nation by promotion of technology, but rather, like his deputy Hugh Dryden, he believed that space technology could provide benefits to the U.S. in practically every profession and activity. In fact, the potential relationship between space and energy projects was expressed some years later when, faced with the "oil crunch," some in high places suggested an Apollo-like effort for the U.S. to become energy independent by 1976.

I hope it is clear from this paper that the nation's complex energy demands cannot be compared directly with the Apollo Project's lunar goal. Energy must be carried in fuel tanks on $160 \times 10^6$ highway vehicles as well as trains, ships, and aircraft. Energy must also be distributed to $80 \times 10^6$ homes, commercial space (the size of 700,000 football fields), and millions of industrial firms. The planning, budgeting, and managing required to provide oil, gas, coal, and electricity in the right form, amount, and place and at reasonable prices dwarfs the Apollo Project by many orders of magnitude.

However, there are important lessons to be learned from the Apollo Project. It was noted that the ERDA and now DOE are providing resources for investigations directed toward alternate energy sources and increased efficiency in energy use. The administration of these studies and the management of follow-on experimental prototypes to prove the new concepts in real-world tests have benefited directly from NASA's experience. But was it necessary to involve the government in this process? In a quote from the book, *The Heavens and the Earth,*[2] "Free enterprise might do that on its own he [Webb] granted, but can society afford to wait for or to rely solely upon the workings of such a slow and uncertain process?"

Experience in the introduction of new technology for more-efficient automobiles and refrigerators provides the justification for Webb's concern. Significant improvements in automotive fuel economy have been achieved as a result of the Motor Vehicle Information and Cost Savings Act. However, similar improvements have not been achieved in refrigerator performance, even though the technology is available. The National Energy Conservation Act was passed in 1978 and standards were proposed by the DOE in 1980. However, the standards were never promulgated and refrigerator energy efficiency has not been improved.

Webb was intrigued with the Wright brothers' experience at Kitty Hawk. They correctly foresaw that flying was not solely a matter of lift, drag, and power. Maneuverability and control were required for their aircraft to adapt to winds and terrain and, by analogy, Webb reasoned that institutions must similarly adapt to their environment if they are to remain viable.

Webb was not saying that the government should use technology increasingly to control national endeavors. He was saying that government should have the flexibility and the capability to support national endeavors when a real need exists. Experience shows that legislation and regulation can establish a framework that permits private institutions to operate more effectively. Different groups will view government activities differently, depending on their interests, but doctrinaire views should not inhibit any of our institutions, including the government, from attempting new approaches in order to adapt to changing circumstances.

It is implied in *The Heavens and the Earth* that American leaders bought the Communist line that technology is both a symbol of social responsibility and the main engine for elimination of want, inequality, injustice, and hatred. James Beggs, the former Administrator of NASA, expressed his views on this subject in the Wilbur and Orville Wright Memorial Lecture delivered in December 1984, when he noted that our wish is long—"eliminate poverty, conquer ignorance, vanquish disease, and destroy oppression." He then went on to say that "for the first time, thanks in part to space technology and its spin off and applications, the antidotes are within our grasp."[16]

But neither Beggs nor Webb have suggested that the government should be the sole purveyor of technology, nor have they raised false hopes that technology alone can be our savior. Webb repeatedly stressed the importance of all institutions including industry, government, and universities. Each has an indispensable role, each must understand and adapt to changing circumstance, including the proper use of technology, and each must interact appropriately with the other.

Technology is a human creation and, depending upon man's goals, can be used for progress or to precipitate disaster. America had to use advanced technology to defeat Hitler in World War II and to call Khruschchev's bluff in the 1950s and 1960s. America's space program demonstrated to the world that its existing institutions could organize the development and use of technology more effectively than the Soviet Union. America's institutional resources must continue to be used to keep to a minimum our dependence on the oil fields of the Middle East. Energy-conservation technologies must be vigorously introduced in the near term and, by the year 2000, alternate sources of energy must be developed. It took 60 years for America to convert from coal to oil and natural gas, but we may not have 60 years to make the next transitions.

Technology should be developed and introduced by America's institutions to satisfy societal requirements for energy, as well as to meet other societal needs of greater consequence. The challenges of the past have often placed nation against nation. The societal needs of the future may often require more cooperation than competition. Here again, there are important lessons to be learned from experiences in space.

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