Conservation of Energy: The Potential for More Efficient Use

Amidst the current concern with ways of producing enough energy to meet projected demands, relatively little attention has been accorded research on methods of making existing supplies go further. Yet by one widely accepted estimate, five-sixths of the energy used in transportation, two-thirds of the fuel consumed to generate electricity, and nearly one-third of the remaining energy—amounting in all to more than 50 percent of the energy consumed in the United States—is discarded as waste heat (see Fig. 1). The conservation of energy is therefore a worthy and increasingly important goal. And, despite skepticism on the part of some observers as to the feasibility of wholesale changes in consumer habits and preferences, significant economies appear to be possible, many of which involve little or no change in life-styles. Both more efficient technologies, ranging from better insulation in houses to more efficient furnaces in industry, and policies that reduce rather than promote the demand for energy could well play a key role in the last two decades of this century.

Conservation of energy will be the more necessary as fuels become scarce and as the environmental problems associated with energy production and use increase. Slowing the rate of growth of energy use through conservation measures would reduce, perhaps significantly, the United States increasing dependence on imports of fuels and would allow more time for the development of improved, less-polluting energy systems.

Although it seems unlikely that even extreme conservation measures can entirely halt the need for more energy, it is undeniably a poor idea to perpetuate wasteful and often ineffective uses of energy. Available techniques for utilization of waste heat, for production of more efficient machinery, and for prevention of energy losses are seldom applied, in part because the cost of energy has been low. Energy consumption has increased rapidly and haphazardly, having doubled in the past 20 years. Consumption of electricity and natural gas has risen twice as fast. Per capita energy use is also increasing and has doubled since 1940.

A study conducted by the Stanford Research Institute of Menlo Park, California, for the U.S. Office of Science and Technology provides details of the ultimate end uses of energy in this country (*1*). The largest single application of energy is fuels for transportation (25 percent of total U.S. energy consumption), but space heating in residences and commercial buildings (19 percent) is also a major end use. Industrial applications of energy in the form of process steam (17 percent), direct heat (11 percent), and electric drive (8 percent) account for significant portions of total energy consumption. Other applications consume only a few percent each, and of these, air conditioning is the most rapidly growing, increasing two and a half times as fast as total energy consumption (*2*). But savings of even 1 percent of the more than 63×10^{15} Btu (1 Btu = 1055 joules) consumed annually in the United States would represent a significant gain in energy—equivalent to 100 million barrels of petroleum.

Where and how might more efficient uses of energy be achieved? The largest energy savings and perhaps in the long run the easiest to accomplish could come in homes and commercial buildings, which have seldom been designed to conserve energy. Inadequate insulation and the leakage of outside air into homes increases the energy consumed for heating and cooling. Similar problems in commercial buildings are often aggravated by excess ventilation and large window areas. Inefficient heating and cooling equipment wastes additional energy. Lighting and hot-water heating consume smaller but still excessive amounts of energy.

Closest to a national standard for insulation in residences are Federal Housing Administration (FHA) guidelines, which in 1965 permitted heat losses as high as 50 Btu per square foot of floor space per hour. Revised FHA guidelines issued in 1971 reduced this figure somewhat, but almost none of the buildings in use today meet the new standard (which applies only to new construction), and many older buildings have little or even no insulation.

Even the revised guidelines do not require the economically optimum amount of insulation, according to a study by John Moyers of Oak Ridge National Laboratory (ORNL) (*3*). From calculations for model houses in three different regions of the country—Atlanta, New York, and Minneapolis—Moyers finds that additional insulation in walls and ceilings, weather stripping, foil insulation in floors, and in some regions, storm windows can be economically justified. These improvements, in addition to saving the homeowner money, would save an average of 42 percent of the energy used for space heating alone, compared to that used in houses meeting the pre-1971 FHA guidelines.

Although it is difficult to add insulation to existing buildings, the use of adequate amounts in all new construction would gradually reduce energy consumption by significant amounts over a period of years. Commercial buildings are underinsulated too, according to Charles Berg of the National Bureau of Standards in Gaithersburg, Maryland, so that about 40 percent of the heating energy relative to current practice could be saved in these structures as well. The potential savings from both residential and commercial buildings amount to about 7 percent of total national energy use. Actual savings may be even greater, because as insulation is added, the air-conditioning losses are reduced, and the waste heat from lights, stoves, refrigerators, and other appliances becomes a more substantial part of the total heat required.

In addition to structural improvements in the thermal performance of buildings, more efficient heating and air-conditioning equipment is technically possible and in some cases already exists. The efficiency of room air-conditioners sold today, for example, ranges from 4.7 to 12.2 Btu of cooling per watt-hour of electricity. Efficiencies are not ordinarily stated explicitly on commercial units, although manufacturers have agreed to include this information on units sold in the New York City area. Although the amount of energy used for air-conditioning is considerably less than for space heating, it contributes importantly to the peak power demand during summer months. Moyers and Eric Hirst, also of ORNL, estimate that upgrading the average efficiency of window units from 6 (in 1970) to 10 Btu per watt-hour would have saved 15.8 billion kilowatt-hours of energy per year.

Furnaces for space heating are typically about 75 percent efficient as sold, losing a quarter of the heat in the exhaust. According to Berg, however, the frequent operation of such furnaces at low capacity and the infrequent maintenance that is common for residential units may lead to efficiencies as low as 35 to 50 percent in practice. Improved design and regular maintenance could substantially improve the performance of these units. Electric resistance heating, which is now being installed in about one-third of all new homes and perhaps half of all new office buildings, is essentially 100 percent efficient in place. However, the production of 1 kilowatt-hour of electricity requires on the average 3 kilowatt-hour equivalents of heat, and about 10 percent of the electricity is lost in transmission and distribution, so that electric heating is inherently less than 30 percent efficient.

Electrically driven heat pumps, which are not now widely used, could improve the efficiency of electric heating because a heat pump delivers, on the average, about two units of thermal energy for each unit of electrical power that it consumes; actual performance depends considerably on the climatic conditions of the region. In the past, frequent failures and high maintenance costs have been common, but improved models are now available. Heat pumps may become an increasingly attractive method of space conditioning as fossil fuels grow scarce and nuclear power plants become the prevailing source of electricity.

Solar heating and cooling, although commercially unproved, would be still more attractive as a conservation measure, because it does not consume unrenewable resources. Solar hot water heaters, which it is estimated could replace about half of the conventional water heaters or more than 1 percent of total energy use, have been in limited commercial service for some time.

Still other approaches to minimizing energy consumption in the home have emerged from an ongoing study directed by D. G. Harvey, of Hittman Associates in Columbia, Maryland, for the U.S. Department of Housing and Urban Development and the National Science Foundation. Harvey finds that outdoor gas lights and pilot lights in gas appliances use surprisingly large amounts of fuel, and he points out that electronic igniters, which could eliminate the need for pilot lights, are commercially available. Infiltration of outside air through leaky window frames and open chimney flues in unused fireplaces were also major causes of energy loss in this study. Heat recovery systems, he believes, could reduce flue losses in the heating system and improve gas furnace efficiencies by as much as 12 percent.

Frost-free refrigerators and freezers use almost twice the energy of manual defrosting units. Fluorescent lights use a quarter as much electricity as incandescent bulbs. Well-insulated ovens —including most self-cleaning ovens— consume significantly less energy. Reductions in air-conditioning would come from the use of small attic fans to ventilate this area. A deciduous tree near a house can make a noticeable difference, Harvey believes, shielding the roof from the summer sun but letting the sun warm the house in winter.

The rising sales of mobile homes, which now account for one out of every four new dwellings in the United States, may have an increasingly important influence on residential energy use. Because of their thin walls, limited insulation, and boxlike construction, mobile homes are high users of energy, often requiring inefficient space heaters in winter and several window air-conditioning units in summer. Existing standards for these relatively inexpensive, factory-built homes were not written with energy conservation in mind.

Table 1. Energy efficiency for passenger transport. [Source: E. Hirst, Oak Ridge National Laboratory]

Item	Btu per passenger mile	
	Urban	Intercity
Bicycle	200	
Walking	300	
Buses	3700	1600
Railroads		2900
Automobiles	8100	3400
Airplanes		8400

Table 2. Energy efficiency for freight transport. [Source: E. Hirst, Oak Ridge National Laboratory]

Item	Btu per ton mile
Pipeline	450
Railroad	670
Waterway	680
Truck	3,800
Airplane	42,000

Architectural practices often promote excess energy use, according to Richard Stein, of Richard G. Stein and Associates in New York City. He points out (*4*) that poor design often results in the overuse of steel, concrete, and other energy intensive building materials by as much as 50 percent. Nearly a quarter of all electricity is used for lighting. The illumination levels recommended in commercial buildings have more than tripled in the last 15 years and there is now considerable disagreement as to whether such high illumination—100 foot candles (1 ft. candle = 10.76 lumen/m^2) in many office applications—or uniform intensity of lighting is necessary or desirable. Stein believes that a 4 percent savings in total electricity use could be achieved immediately by reducing excess lighting in existing buildings and by more effective use of lighting in new buildings.

Modern high-rise office buildings consume inordinate amounts of energy. The World Trade Center, for example, in New York City uses 80,000 kilowatts, more than the entire city of Schenectady, New York (population, 100,000), and the trend to such buildings is accelerating in urban areas. Stein believes that electrical heating is particularly inefficient in such buildings, because they can readily use fossil fuels. Other energy savings are possible with reflective window glass, reduced air ventilation, and absorption central air-conditioners that operate on heat, not electricity. In all, Stein believes that careful design might reduce the energy needed to operate such buildings to half that required by conventional designs; reductions in peak power demand would be even greater.

With some exceptions, there is evidence that efficiency of energy use has not been a subject of concern in many industries, although industry consumes more than 40 percent of total U.S. energy production. The production of primary metals, basic chemicals, petroleum products, food, paper, glass, and concrete account for most of the energy used. As fuel prices rise, this apparent lack of concern can be expected to change rapidly and may result in substantial economies. The energy required to produce a ton of steel, for example, declined by 13 percent to 26 million Btu between 1960 and 1968—primarily because of more efficient blast furnaces —and is expected to decline still further.

New vacuum furnaces developed for industrial use require only a quarter of the energy consumed by earlier designs. Heat recovery devices and better thermal management of many processes may also save considerable amounts of energy. On the basis of these examples and others, Berg estimates that as much as 30 percent of the energy used by industry might be conserved. And because corporate management can respond more rapidly to changing conditions than the individual consumer or even than the fragmented construction industry, many observers expect conservation measures in industry to have the greatest potential for short-range impact on the demand for energy.

A case of particular interest is the utility industry, which has improved the efficiency of electrical generation from about 5 percent in 1900 to nearly 40 percent in the newest coal-fired plants. Oil- and gas-fired plants are slightly less efficient, and the average for all existing power plants is about 32 percent. Nuclear power plants with light water reactors also convert only 32 percent of the heat they generate into electricity; however, high temperature gas reactors that are now becoming available have efficiencies of nearly 40 percent. The development of combined cycle power plants—with high-temperature gas turbine or magnetohydrodynamic generators in addition to steam turbines—could increase generating efficiencies to 50 or 60 percent. At present, however, the generation, storage, and distribution of electric energy is inherently inefficient. As long as fossil fuels are consumed to generate substantial amounts of electricity, a state of affairs that is expected to prevail throughout this century, the use of electric power for applications where fossil fuels will do is clearly wasteful.

Transportation constitutes the largest single end use of energy, but opportunities for significant saving appear to be less, because changes to more efficient modes of travel involve changes in life-styles that are more substantial than the changes necessary for most of the conservation measures discussed previously. A study by Hirst at Oak Ridge reveals that during the 1960's passenger traffic on U.S. railroads decreased by half, automobile mileage increased by 50 percent, and airline mileage increased nearly threefold. Yet the energy efficiency is higher for railroads than for cars and airplanes (Table 1).

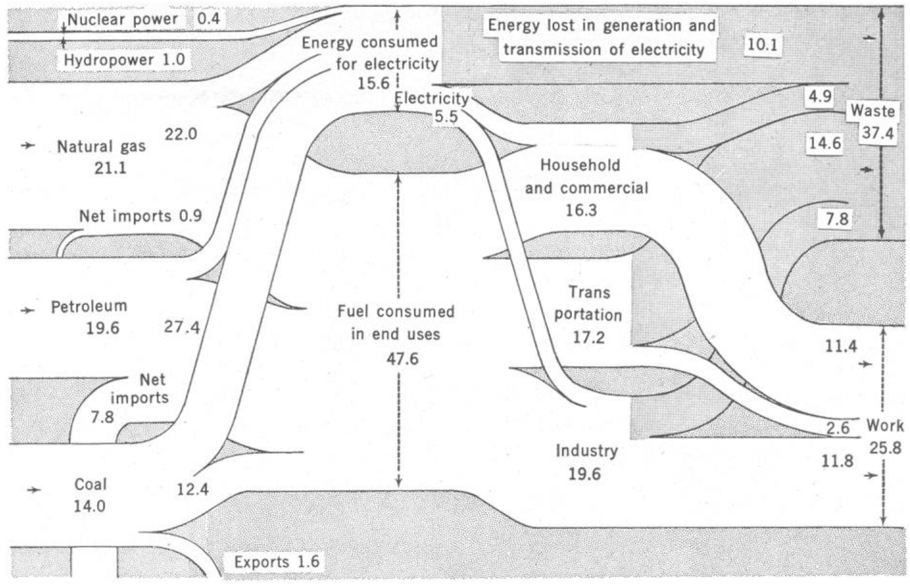

Fig. 1. Production, consumption, and waste of energy in the United States. Total consumption of energy in 1971 was 63.2×10^{15} Btu, excluding nonenergy uses of fossil fuels. [Source: Earl Cook, Texas A&M University]

Clearly most people prefer to go by car, despite the relatively high energy cost associated with this vehicle. Indeed, Hirst estimates that when both the direct and indirect energy costs are included, the automobile accounts for about 21 percent of total U.S. energy consumption. Yet the standard American car gets only 12 miles per gallon of gasoline, roughly half that of most European cars. In part, the decline of rail service and urban mass transit relative to automobiles and airplanes reflects the greater convenience, flexibility, and speed. Freight transport also shows shifts from railroads to trucks and airplanes, more energy-intensive modes of transport (Table 2). But governmental promotion of automobile, truck, and airplane traffic through the subsidy of roads and airports has also undoubtedly been influential. Reversing these shifts in passenger and freight traffic could save significant amounts of energy, predominantly in the form of petroleum—thus reducing the need to import this commodity.

Still other methods of conserving energy have been proposed. Central heating plants for groups of buildings, and in some cases whole towns, have been occasionally used both in the United States and abroad. This application can make efficient use of waste steam from a power plant. Total energy systems in which small gas turbines or fuel cells generate electricity locally, in addition to providing heat, could substantially increase the overall efficiency of energy use, although the operation and maintenance of such facilities pose difficult and costly problems.

The potential for reducing the demand for energy by means of more efficient use of energy resources appears to be enormous, amounting ultimately perhaps to 25 percent of what would otherwise be consumed. Under present practices, energy that could otherwise be saved is wasted in buildings, in industrial processes, and in transportation. To bring about some of these potential savings, however, financial incentives and other means of changing attitudes and habits in energy use will be necessary. A later article will consider some of the means that have been proposed for encouraging energy conservation as well as econometric studies of how much more energy will in fact be needed. Far from being an unrealistic notion, conservation is clearly a major energy option.

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References and Notes

1. Stanford Research Institute, "Patterns of Energy Consumption in the United States" (Office of Science and Technology, Washington, D.C., 1972).
2. Small items in the energy budget are water heating (4 percent of total U.S. consumption), air conditioning (2.5 percent), refrigeration (2 percent), lighting (1.5 percent), and cooking (1 percent) in homes and commercial establishments; industrial electrolytic processes account for 1 percent of the total, and about 3 percent is consumed in a variety of electrical appliances and other uses. Fuels amounting to 5 percent of the U.S. energy supply are converted to chemicals and hence are not consumed as energy.
3. J. C. Moyers, "The Value of Thermal Insulation in Residential Construction" (Oak Ridge National Laboratory, Oak Ridge, Tenn., 1971).
4. R. G. Stein, "Architecture and Energy," lecture delivered at the American Association for the Advancement of Science, Philadelphia meeting, 29 December 1971.