Efficient use of energy revisited

The limited supplies of cheap fuels, increasing political problems associated with them and the pollution produced by combustion—as well as other problems—make efficiency and conservation attractive strategies.

Marc Ross

In the past several years everyone has become considerably more aware of the problems of energy supply and demand. Although extensive resources of energy are available in principle, energy that is both cheap to extract and cheap to use—such as the oil and natural gas to which we have become accustomed—is very limited. The rising cost of all forms of energy is only one of the problems we associate with the provision and use of energy. The uncertainty of existing supplies—as illustrated by the Iranian revolution and by the accident at Three Mile Island—is another, though related, problem. A different kind of problem is in the development of new supplies (fluid fuels from coal, oil from shale, nuclear breeder reactors, for example); here, necessary steps in the development may be slow in coming or even unsuccessful.

Strategies

There are two principal directions for energy policy in the next few decades:

- increasing the total amount of energy available for consumption: the "supply strategy"
- improving the effectiveness with which energy is used: the "efficiency strategy"

The supply strategy involves truly massive investments to develop oil and gas fields in unconventional places; to develop coal mines and coal transportation; to develop fluid-fuel extraction plants, nuclear fuel facilities, and other kinds of centralized power plants. It also involves massive investments to moderate the environmental impacts of these developments.

In this article I will discuss the efficiency strategy, some of its technical aspects, its economics and its relationship to the supply strategy.

Although physical and economic information on existing energy use and, especially, on new technologies is seriously limited, and methods for projecting technical change are controversial, to say the least, one can draw several fairly reliable conclusions from recent events and from attempts to project the effect of technical changes on fuel consumption in the US:

- Since 1973 there have been some major improvements in the efficiency with which energy is used. Such improvements are likely to continue. The most important sectors in which the improvements have taken place are those for which energy prices have risen fastest: industry and, to a lesser extent, household heating. Many industries have technical staffs that can respond to the new energy situation, and industrial energy use has fallen an average of somewhere around 2% a year per unit of production since 1973. (The rate of industrial production can be

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Recycling aluminum uses only a small fraction of the energy required to smelt aluminum metal from ore (on the order of 10 kWh per pound). Waste aluminum—such as the empty cans shown here—thus represents a valuable energy resource. (DOE photo.)

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evaluated in several ways. I have used the Department of Commerce index, which shows a relatively slow rise in industrial production compared to the rise in GNP. In earlier decades the ratio of energy use to industrial production declined by about ½% per year, largely due to a shift toward products involving less basic material per unit.) In household heating, the owners living in existing dwellings—who were probably best able to adjust to the rising prices—have reduced fuel consumption about 15% (after correcting for climatic change). However, much of this saving was achieved by closing off rooms and turning down thermostats; most of the technical opportunities for improvement remain to be exploited. Some progress is also being made in the efficiency of automobiles, but the actual performance of the entire fleet is disappointing in comparison with expectations.

▸ There is still considerable room for improving the efficiency with which energy is used to provide heat, transportation, and so forth. We are still far from the limits that thermodynamics imposes on our systems, and research, invention and promulgation of skills can lead to great improvements over the next few years and decades.

▸ Further improvements in efficiency can come from social and economic changes even in the absence of new technology by altering the systems we use to provide our services and material needs.

▸ The extent to which efficiency improvements will be implemented is very sensitive to economic policies, such as energy price controls, tax subsidies and utility regulation. The rate at which changes are made in technology or use patterns is also sensitive to performance regulations.

▸ If we adopt strong public policies that favor improvements of energy efficiency, we can expect dramatic reductions in projected fuel use. For example, average fuel consumption per unit of building space or per unit of automotive travel could drop to ⅓ or ¼ of their present levels in a few decades. The efficiency improvements projected by various studies, in the event the US pursues an efficiency strategy, would more than double the overall energy efficiency of the US economy in the next several decades. Meanwhile some energy-intensive activities are beginning to reach limits to their growth rates as a result of such factors as the change in birthrates, saturation of the markets for specific transportation and space-conditioning products, refined design of manufactured products, and the shift of economic activity from goods to services. (For example, the use of information-related products is growing explosively while the bulk use of steel, concrete and wood products is falling behind the growth of total production.) The combined effect of these two developments (and the gradual increase of solar-related energy supply) would be to decrease the demand for fossil and nuclear fuels in absolute terms.

Let us examine some of these issues in greater detail. What, for example, is the technological potential for improving energy efficiency?

Efficiency and the second law

An efficiency should be a number between zero and one that indicates how well a particular system carries out a particular task. The conventional, or first-law, efficiency of a simple device or system is a relatively straightforward concept because the task performed by a device is usually well defined, as are the energies involved in specifying the task. As part of a summer study on the efficient use of energy in 1974, an American Physical Society group examined a much more far-reaching efficiency concept based on the second law.[1] (This effort was summarized in an article entitled "Efficient use of energy," PHYSICS TODAY, August 1975, page 23.) Rather than comparing the amount of useful energy with the total energy used for the task, the second-law efficiency compares the useful energy transferred by the given system with the maximum possible energy that an ideal engine could transfer. (In other words, we compare the first-law efficiency of the given engine with that of a reversible engine—not necessarily a heat engine—performing the same task.)

Such a second-law measure of performance can usefully be defined for very general systems. Some of the properties, advantages and disadvantages are discussed in the APS study. Even more than with the first-law efficiency, the second-law efficiency is sensitive to how the task is defined, to the boundary one selects for the system.

Let me illustrate this characteristic. For the APS study we defined the second-law efficiency of travel simply as the efficiency of the engine plus drive train of a car with specified weight, air resistance and rolling resistance. The task was further defined in terms of distances and speeds of travel, as in the well-known EPA tests of gasoline mileage.

But this is a very narrow view of the technology of travel. We could have attempted to describe the efficiency of a much larger, more comprehensive system. The task would be characterized by many more variables. I will list some of them.

One obvious variable is the equipment.

The safety, travel speed, weight, comfort and availability of a car all depend on how it is designed, and all affect its efficiency in moving people from place to place. For most American cars, for example, the weight can be sharply reduced without reducing interior size but decreasing the amount of gasoline required for transportation.

Another variable is the management of the vehicle; how one drives and maintains a car clearly affects its mileage.

We can consider a larger system than just the car or car plus driver. Some transportation needs can be satisfied effectively by means other than the automobile, depending on the trip and the simultaneous travel needs of nearby people. One can thus calculate efficiencies based on the optimum "modal mix" of different transportation modes.

Finally, we can realize that the fundamental travel-related service is changing one's location for work, shopping, recreation and social interactions. We must then consider not only the technology of transportation, but we must also ask, how much travel is required to satisfy those needs? The answer depends on how and where people live. For example, people do much less, roughly half as much, short-distance vehicular travel in affluent European countries than in the US. Urban and regional design changes can enable people in the US to satisfy demands for fundamental travel-related services with much less transportation. Telecommunication might also substitute for some travel.

To be specific, the (first- or second-law) efficiency of the engine and drive train of a given car in converting chemical energy of the fuel to rotational energy of the drive wheels is about 12% in typical US driving.[2] In an estimate I made of automobile efficiency, allowing for rolling resistance, air drag and weight (but not size) reduction, I found that autos have an efficiency of under 3%. A typical US metropolitan area with its travel equipment has a very, very low (as yet unanalyzed) second-law efficiency in providing its people with fundamental locational services. (There is, in fact, no thermodynamic distinction between states in which a body has only changed its location, so the thermodynamic efficiency of any transportation is essentially zero.) Robert Ayres and Mark Narkus-Kramer[3] pointed out the general characteristic: When efficiency is defined in terms of a fundamental task of a comprehensive system it will tend to be very low; concomitantly, there are many possibilities for technical change.

Typical second-law efficiencies are low even for some simple tasks. In the very long term, we might be able to realize much of the potential for improvement implied by the low efficiencies. But an analysis of thermodynamic efficiency provides only a narrow view of the issue. We must also ask, what changes in technology are actually taking place? This question should be examined at two levels: What new technologies are being invented? To what extent are existing technological options being adopted? I begin with invention and its companion, research.

New technology

In the decades before the early 1970's energy prices were low and falling with respect to the prices of other products. It is hardly surprising that sharply increased prices coupled with increased energy awareness should create opportunities for new technology, for products and processes not previously made available. Nor is it surprising that developments in science and technology from the 1950's and 60's tend not to have been applied at that time for improving energy efficiency.

For illustration, I discuss a few areas of technology where promising new products and processes are being developed.

Buildings. Much of the development in the buildings area arises from research conducted by physicists who participated in the 1974 APS summer study and their collaborators. I mention three examples.

Robert H. Socolow, director of the Center for Energy and Environmental Studies at Princeton University, introduced the concept of "house doctor," a professional who could diagnose the thermal problems of buildings and prescribe measures to improve the effectiveness of the fuel used. The value of this proposal has been underscored by research at the Center: Frank Sinden demonstrated experimentally that well-insulated housing can be made even more fuel efficient if one also uses other innovative energy-saving technologies.[4] Gautam Dutt and his associates have identified the "attic by-pass" as a major source of fuel waste and a source of error in straightforward analyses of ceiling insulation. An attic by-pass is a path by which warm air can flow from heated spaces (including the basement) into the attic—such as stairwells, unfinished ceilings, lighting fixtures, space around flues, and balloon walls.

Arthur Rosenfeld, who heads the building-envelopes group at Lawrence Berkeley Laboratory, analyzes the economics of efficiency improvements in residences.[5] For these analyses, the group has developed several computer programs that will be used as the basis for the nation's 1980 Building Energy Performance Standards. The figure on page 28 shows an example of the results of such an analysis. Rosenfeld's group have also been developing techniques for measuring energy flows in buildings. Recently, for example, Robert Sonderegger and his associates at LBL used a "blower door" to reduce the pressure in a house and then used a system of metered electric heaters

in the rooms to observe how air that infiltrates the building through cracks is warmed.

The windows and lighting program at Lawrence Berkeley Laboratory, headed by Samuel Berman, is working to create commercial, effective windows with selective coatings, that is with coatings that reflect infrared while being transparent to visible light. The group has also been working on efficient "day lighting" systems. One of these, a system developed for commercial buildings that combines improved ballast with automatic control of lights and window shades, saves 50% or more in lighting energy. Berman and his colleagues are also working with industry on efficient light bulbs.

Automobiles. Improving fuel economy requires design changes. One very effective step is, of course, simply to make cars smaller. In the past this had meant reducing safety and comfort as well as weight, but new developments are making it possible to design cars with large interiors, good towing ability, crash worthiness and riding comfort, while still reducing weight and increasing fuel economy.

About one-third of the weight reduction is now being achieved through substitutions of materials. In the future

Insulating new buildings and adding insulation to existing buildings is an effective way to improve the efficiency with which fuel is used for domestic and commercial space heating.

high-strength composite materials, such as carbon fibers embedded in a plastic matrix, may replace many structural steel parts, enabling further weight reduction. These materials are, however, still costly to manufacture.

New engines are an important part of the strategy to improve fuel economy. It may be, however, that refined Otto-cycle engines with electronic controls will be very competitive with other kinds of engines. In the future, many fuels other than gasoline will have to be considered, so engines—both Otto cycle and other designs—are being redesigned for different kinds of fuel such as ethanol or a variety of liquids derived from coal.

Manufacturing. The redesign of both products and processes is leading to considerable reductions in energy use. For example,

- New models of automobiles need less basic materials
- continuous casting and rolling of steel, in which certain products are rolled directly from molten steel, requires much less energy than allowing the steel billets to cool once or twice during the rolling process

Other techniques that were primarily introduced to reduce pollution also improve the energy efficiency of the manufacturing process. Examples are

- sharply reduced water discharge in pulp and paper making
- fluidized-bed combustors for coal

Finally, new control and management systems are rapidly improving the productivity of energy.

I will briefly discuss three types of technology that will have a major effect on manufacturing. All of these are in use in some form while new forms are just coming onto the market, or are being developed.

Cogeneration of electricity with steam for heat is an old type of technology that is being rediscovered.[6] The best-established form of cogeneration is steam topping, in which steam from a boiler sequentially generates electricity and provides heat for industrial processes or space conditioning. Boilers and other heaters that burn fuel directly to provide low- to moderate-temperature heat are relatively inefficient (in the sense of the second law). In effect, in-plant cogeneration improves the second-law efficiency of such heating. Conversely, by making use of the reject heat from an electric generating plant, congeneration by an electric power plant improves the second-law efficiency of electricity generation. In addition to steam turbines, systems for cogeneration include:

- diesel engines whose exhaust or jacket heat generates steam
- gas turbines (perhaps fed with gas from a fluidized-bed coal burner) whose exhaust generates steam
- fuel cells whose cooling water or air serve as heat sources.

The heat provided by cogeneration cannot be transported far, so the best opportunities for cogeneration are largely at industrial sites rather than at central power stations. Although technical development is important, the main impediment to a resurgence of cogeneration is regulation. Because coal is less suited to industrial cogeneration than are oil or gas, federal mandates that industries use coal reduce the incentive for cogeneration. In certain localities air pollution concerns could inhibit distributed generation of electricity. The major problem, however, has been electric-utility regulation, which through artificial economic barriers, inhibits the flow of electricity between cogenerators and the grid. Utility regulation inhibits utility ownership of cogeneration facilities, as well as making it difficult for a non-utility cogenerator to buy and sell electricity at reasonable rates. The force of the fuel saving and economic advantages of cogeneration is only beginning to break down these regulatory barriers.

Another, partly-developed, technology worthy of special discussion is motor controls. Although small appliance motors are often remarkably inefficient, industrial motors are usually highly efficient in themselves. Usually, however, the task of such a motor is to move material, not simply to turn a shaft; and in most industrial applications the efficiency of material motion achieved by the motor is low because of control problems. The motors for moving gases or liquids, for example, are generally over-powered; the motion of the gases or liquids is controlled by baffles or pressure-reduction valves rather than by controlling the motors. The net efficiency of such systems is roughly 30%.[7] Solid-state devices are being introduced to control the motor speed, thus obviating much of this waste. Exxon, for example, recently announced the development of an inexpensive variable-frequency digital synthesiser of alternating current for this purpose.

The third example of technological developments that will affect the energy efficiency of manufacturing is the use of sensors and automatic control. The great strides in information processing now make it possible to gather and digest much highly-detailed information about all stages of a manufacturing process.

Automatic control of the process further requires sensors to determine the state of the system and outputs that can modify the state. In highly sophisticated systems, microprocessors can provide local control and stability while a central unit can provide overall control. Quality control of hot steel and control of paper drying[8] are two examples among thousands. Developing the sensors for such automatic control systems is an especially promising area for research and development.

Variable-speed motor controls and automatic control systems are among many technologies that can reduce energy use while improving other aspects of production. An important reason why the productivity of many US industries has grown so slowly in the past decade is the low level of industrial investment. The energy crisis adds to the incentives for adopting new production technology. Another reason for low productivity growth has been the low level of applied research. This issue merits special attention.

The neglect of applied research

The total research and development effort in the US is substantially larger than that of any other nation (whether measured *in toto, per capita*, or per dollar of production). The US government, however, supports very little research that is specifically related to industrial productivity—0.4% of all research and development expenditures, according to one NSF analysis.

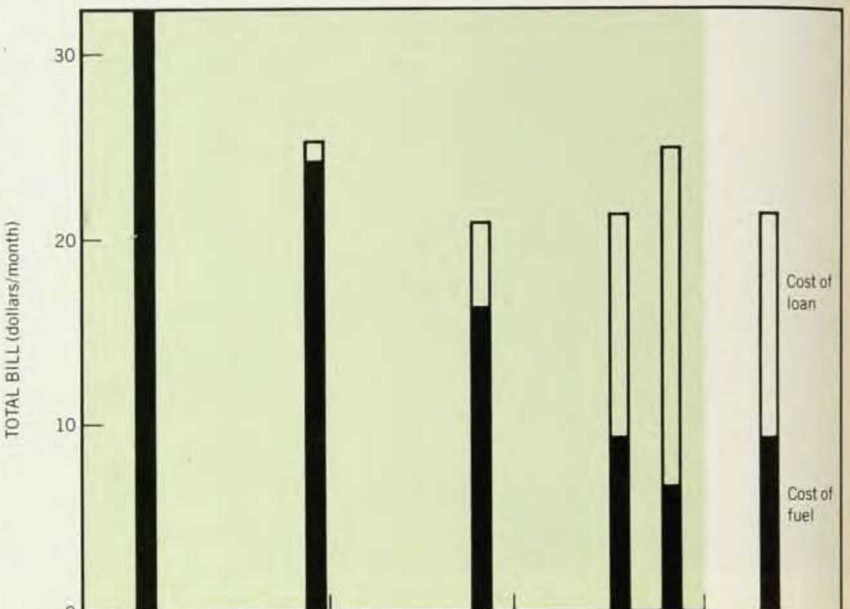
By applied research I mean scientific investigation of relatively fundamental topics selected for their technological importance; I do not include specific product development. (People in industry often call it basic research.) Although applied research is conducted by business, private support is very uneven. Especially low levels of research characterize industries that are short of cash or are subject to conditions that make it difficult for a firm to enjoy the fruits of its research efforts. Government support of applied research is, then, critical.

Support for energy-related research illustrates this pattern in more detail. The Department of Energy strongly supports basic research in areas related to energy supplies, such as nuclear and particle physics. It also strongly supports the development and demonstration of many energy-related products: nuclear-power plants, coal-conversion plants, and other energy supplies. In addition, DOE supports development and, especially, demonstration of a variety of energy-conservation devices. It can be argued that this DOE conservation program will improve upon what would have been done by private business. But even when one considers both private and governmental expenditures, applied research related to energy use, as distinguished from development and demonstration, is being neglected.

In the APS study a number of applied research topics related to energy efficiency were suggested. The industrial topics are shown in the table. Others have extended this list with such topics as air drag on surface vehicles, friction and lubrication,[9] and fundamental reexamination of basic materials processes (such as steelmaking and paper making). I am informed that none of these areas of research is being strongly supported.

This lack of support translates at universities into missing courses in physics departments and moribund departments in engineering schools. In the APS study we wrote of academic physics:

> One realization we shared during our study is the importance of classical physics, notably areas such as fluid mechanics and classical physical and chemical thermodynamics. Despite the power and scope of these subjects (and despite their practical importance), they have been neglected in



Cost of fuel savings. The bar graph shows the cost of energy service (loan payment plus fuel bill based on the average future price of gas) for an initially uninsulated gas-heated house in Oakland, California, considering four fuel-saving investments. While the first two measures would reduce the consumer's total bill, adding wall insulation would reduce it no further; the bill would rise if storm windows were also installed. The lower graph shows the "cost of saved energy," the cost of loan divided by the cost of fuel saved, for each of the four investments. Note that while installing wall insulation would be more expensive than the average price of gas, it would be cheaper than finding new gas. Thus it would be in the nation's interest to induce the householder to insulate his walls in addition to taking the first two measures. Other climates would lead to different graphs.

our educational enterprise. Academic physicists, while witnessing with satisfaction the adoption and adaptation of these subjects within other disciplines, have counseled their students, openly or subtly, to put their efforts elsewhere. This lack of breadth and diversity in physics education is a disservice to our science. Teachers who seek to remedy this situation will, we believe, find challenge and satisfaction in the classical subjects.

Whatever is achieved through better training and through research and invention, energy use will depend on the degree to which new equipment and new processes are adopted. While some changes are inexpensive, many involve a great deal of capital. What are the economics of improving energy efficiency?

Conserving energy

There is some confusion about the economics of energy efficiency because different investigators minimize costs according to different criteria and thus arrive at very different projected levels of fuel consumption. One method is to minimize the total cost of an energy-using activity to the individual consumer or firm. The total cost consists of two parts: one is simply the price of the energy or fuel (taking account of price increases during the time period under consideration); the other is the operating plus capital costs (including interest on the capital) of the activity. The recent fuel-price increases have shifted the types of activity that minimize costs in this sense to much more capital-intensive forms: it is cheaper to invest in energy-saving devices than to spend money on fuel.

A different economic criterion, based on the "replacement cost" of energy, is minimization of all incremental costs to the nation involved in an energy-using activity. The incremental, or replacement, cost of energy to the nation is much higher than the price of energy for two reasons: The replacement cost of energy is based on new sources of supply; these are, in general, more expensive than the most expensive currently used sources, and therefore much more expensive than the average price. At present, the replacement cost of energy (or fuels) delivered to final consumers is about twice its actual price. Minimizing total costs based on replacement costs thus leads to even lower fuel usage.

As well as the obvious costs involved in extracting, transporting and using energy, these activities also impose "external" or "social" costs such as pollution, damage to worker health and threats to national security, economic stability, and climate. Evaluating these costs is problematical. I believe, however, that energy supply and energy-intensive processes impose higher external costs than most.

In the graph on page 30 we plot schematically the relationship of total cost of saving energy versus the amount of fuel saved. The cost includes the annual cost of energy (which, of course, decreases when fuel is saved) and the annual cost of capital (effectively the mortgage payment, including interest) that must be invested to effect the fuel savings. As the graph shows, small investments can initially more than pay for themselves, but as the amount of fuel saved becomes larger, the additional investment to save more fuel becomes proportionally larger. The resulting curve in general has a very broad minimum.

Let us explore the meaning of this curve in detail using as an example the problem of improving an existing house with respect to winter heating. (See the figure on the left.) The various improvements are ordered from left to right according to the associated cost of saved energy. This is the annual (or monthly) finance charge to pay off the capital cost in a given period of time, plus interest charges (including tax corrections) divided by the annual (or monthly) fuel savings. A night-setback thermostat, reduction of air flows through the building shell, ceiling insulation in an uninsulated house, window improvements (such as special shutters or drapes) and furnace improvements (such as electric ignition and fuel and flue restriction) all have very low costs of saved energy. Extensive insulation jobs and storm windows and doors typically have a higher cost of saved energy.

The optimal program involves carrying out improvements to the point where the cost of saved energy of the last improvement equals the cost of energy saved (according to the economic criterion that one has selected). In other words, one carries out those improvements that bring one to the flat part of the curve in the graph on the next page. Of course, this program requires knowing the consequences as well as the cost of each improvement; unfortunately this is a more difficult problem than might be thought.

It is currently very profitable to make extensive improvements on almost all existing housing—assuming that good work is done. I have estimated,[10] very roughly, that under the energy-price criterion, an average investment of \$500 per dwelling unit would be justified, and would lead to about 30% fuel savings. Under the replacement-cost criterion, the optimal investment would average about \$1500 per dwelling unit, with fuel savings of about 60%. Of course there is an enormous variation from house to house and region to region.

Let us look more deeply into the distinction between the two economic criteria. If a householder, for example, improves the energy efficiency of a house, his benefits derive from the reduced price he pays for energy. Substantial benefits also accrue to the nation, however, because the search for new energy supplies can be deferred. Assuming a free market, all customers would experience a slower pace of energy-price increases. Effectively, the benefits to the nation of fuel savings are measured by its replacement cost while the benefits to the individual are measured by the price. Because the price is considerably less than the replacement cost, the individual householder is motivated to make a smaller investment to save energy than would be best for the national interest (\$500 rather than \$1500 according to my estimates).

It would clearly be in the national interest to motivate individuals to raise their investment in energy-conserving measures up to the levels suggested by the replacement-cost criterion, in other words to bring the benefits to the individual more nearly into line with the benefits to the nation. There are several ways in which this could be done; three of the possibilities are:

- offering incentives, such as tax credits, to householders for specific improvements
- allowing energy utilities to finance energy-saving improvements and to incorporate the capital cost into their rate base, so that the energy industry's replacement-cost economics could be applied to housing improvements
- raising the price of energy to the replacement cost (or even to a level that covers some social costs) by, for example, taxing fuels and returning the tax receipts to the people

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Applied research to increase industrial energy efficiency

Electrochemical processes

Basic research on the physics of charge transfer at electrolyte–electrode interfaces

Basic physical studies of the principles of solid electrolytes

Continued search for rechargeable batteries of greater energy density

Basic research on all aspects of surface phenomena, especially as applied to fuel-cell performance

Photochemical processes

Exploration of catalyzed solar photolysis of water

Continued studies of the semiconductor physics of photovoltaic cells

Physical processes

Studies of absorption techniques for molecular separation

Basic research on transport in membranes

Careful studies of the energy inefficiencies in ore beneficiation and water desalination to seek ways to approach more closely the minimum separative work

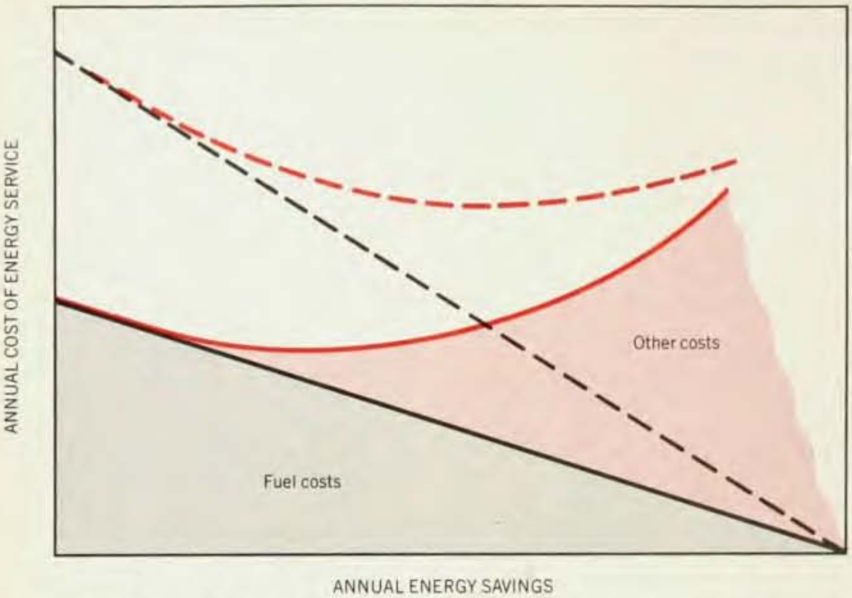
Heat transfer

Basic studies of heat transfer at interfaces—the role of convection, the role of surface irregularities

Basic studies of boiling

Fundamental investigation of two-phase flow

From reference 1



Cost of energy service as a function of fuel savings. We start with some reference system and consider investments to increase its efficiency. The annual cost of energy service is the sum of the fuel costs (gray) and the annual payment on the investment together with any additional operating costs (color). The dashed curves show the effect of increased fuel prices.

Each of these schemes would focus benefits on the householder and thus bring investment decisions on conservation technology more in line with competing investment decisions on new energy supply. Each scheme would require extensive legislation and has a number of interesting features, and an adequate discussion of all of them is beyond the scope of this article. I will, however, point out some key factors.

The first, or incentive, scheme is fairly popular with the Congress. It has a critical flaw in that incentives have limited ability to adapt to technological changes; I will discuss this point below.

The second, or utility financing, scheme has been introduced, for example, for electric heating in Oregon. It has the advantage of tapping the services of organizations that are in close contact with every building. In addition, and quite surprisingly, a utility could offer "free" energy-saving improvements to customers. A program of such improvements would lead to energy-price increases to cover the "interest" costs of the improvements. These price increases would be about the same as the price increases resulting from adding the corresponding amount of new energy supply capacity.[11]

The third scheme is represented, but only very crudely, by the proposal to let oil prices rise and tax the windfall profits. Ideally, such a scheme would increase energy prices to a desired level through a tax mechanism, and substitute the receipts for existing taxes (or rebate them) so that people and firms will have the resources to make the appropriate investments or adjustments to conserve fuel.[12] The concept is of course that consumers of energy should buy energy at prices covering its "full" costs. In general, the excess receipts should be fully returned to people on a basis unrelated to their energy purchases to use for whatever purposes they choose.

While I believe that utility (or energy-industry) financing and a shift in energy taxes would benefit almost everyone, these schemes are not as popular as incentives. Another popular public-policy approach is regulation of performance, an alternative that can be justified especially if price mechanisms are ineffective or unfair. But although incentives and regulations are politically popular, they share a serious drawback: difficulty of administration. This difficulty merits attention.

Regulation and incentives

In the present political climate, regulations to require improved energy performance and, even more so, subsidies to motivate investments in improved performance seem very attractive. The most important regulation affecting energy use is the fuel-economy standard for automobiles. The fuel economy of a manufacturer's 1985 models averaged over production, and as measured by the Environmental Protection Agency, is required to reach at least 27.5 mpg, or twice the fuel economy of the early 1970's. Auto manufacturers are meeting the requirement with little reduction in the performance and interior dimensions of cars—a remarkable improvement.

The efficacy of regulation in this case is of course due to the very small number of manufacturers and models and the uniformity of the mass-produced product. Even here there are problems: The test standard is likely to deviate substantially from actual average performance. The variance in actual performance in the individual car due to variations in use may well be very large. There may be loopholes that enable some people and firms to evade the intent of the standard. In the case of autos the most important of these problems is probably the use of light trucks for passenger travel. Trucks over 3 tons have not been regulated until recently. Even now the fuel-economy regulations for 3 to 4.5 ton trucks are very mild for the sound reason that there is a legitimate need for such vehicles, and at their weight really high fuel economy cannot be achieved. The use of these light trucks as passenger vehicles has been booming recently[10] (but not for the past year).

In my view it is important not to rely solely on regulation of performance, even in the case of standardized mass-produced products like cars. Rising fuel prices (as well as the possibility of fuel shortages) are a very important complement to regulations.

Cars and certain standardized appliances are relatively well suited to performance regulation. Housing is much less so. A critical problem is that actual performance is very difficult to regulate: It is much easier to calculate performance on the basis of design and even easier to specify items of construction. Thus, building codes often specify minimum insulation R-values and, in some cases, maximum window areas. The trouble is that buildings and sites vary enough so that such specifications are unlikely to be optimal for any one building, and may even be counter-productive. Improved measurement and analysis will, however, make it possible to move toward regulations based more closely on performance. While such a program might be relatively effective for new houses, I believe it would be quite unsatisfactory for existing housing.

As with regulations, incentives related to house heating improvements are often seriously flawed. For example, there may be incentives to add ceiling insulation where plugging air flows is what is needed. Incentives generally exclude multipurpose measures such as skylights, south-facing windows, and massive walls for passive solar heating that also bear a load. There are excellent administrative reasons why incentives must be specified in this way.

Regulations and incentives are still less valid in the industrial area. The best known example is the fuel switching policies whose flip-flops have been damaging to industrial planning. Another example is the suggestion to provide tax incentives or similar mandates for more efficient electric motors; this might inhibit putting extra money into control

Efficiency improvements in the use of energy can come from other changes than just improving the efficiency of individual machines. The transportation system shown here uses a great deal of fuel to transport people between home and work, and a traffic jam wastes gas no matter how efficient the cars involved in it are. (EPA photo.)

equipment, which would probably be a much more effective measure.

Finally, investment credits for in-plant cogeneration of electricity and steam may, in fact, be counter-productive. The problem is that while the less capital-intensive cogeneration technologies may be more efficient and less costly overall, the investment credit might lead to a different choice.[6] Even worse, tax incentives as now applied to the very capital-intensive central power stations works against any form of in-plant cogeneration.

These examples do not, however, fully illustrate the difficulty. Even a very well thought out regulation or incentive must fail to capture the advantages offered by the diversity of available technology and by the constant changes, improvements, and inventions. Manufacturers can and do alter the design of products, processes, particular items of equipment, and day-to-day operations depending on the particular qualities of their plants and products. In addition, any final product results from bringing together many intermediate products, with choices to be made about the role of each. In the complex interplay of these choices any particular incentive or regulation, aside perhaps from one that encourages information and control equipment, might well be counter-productive.

Since 1975, the professional's and the public's awareness of energy efficiency as an issue has greatly increased. We are beginning to realize that we can achieve cost-effective improvements in efficiency by factors of 2, 3 or 4 rapidly—over a few decades; these improvements dwarf the foreseeable prospects for new energy supplies. The best approach may even involve postponing into the distant future any heavy reliance on new forms of energy. On the other hand, present economic regulations (such as those for pricing energy) and institutional arrangements create formidable barriers to rapid realization of efficiency improvements. If we act effectively as professionals and citizens to promote efficient use of energy, we could remove energy from the nation's list of problems.

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