Title
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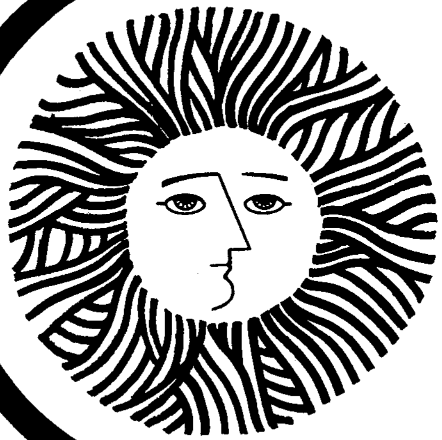
Publication Date
1975-11-01

LBL-3295 c.1
ERG 75-12
Preprint



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Prepared for Submission
to Energy Communications

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ERG 75-12
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ENERGY CONSERVATION: ITS NATURE, HIDDEN BENEFITS AND HIDDEN BARRIERS

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November, 1975

Prepared for the U. S. Energy Research and Development Administration
under Contract W-7405-ENG-48

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FOREWORD

This study began as testimony before the Federal Energy Agency Hearings on Project Independence, held in San Francisco in October 1974, the results of which are published by the FEA. When I agreed to contribute to the American Chemical Society Study, "Energy and the Environment: the Chemical Viewpoint" I envisioned a slightly expanded version of that presentation. During March, 1975, however, I spent some time in Washington, D.C., and I was appalled by the lack of agreement and understanding on the part of policy makers, economists, and scientists as to the meaning of the term energy conservation. So many engineering studies deal with specific systems, as is the case with many of the other contributions to the ACS study, and so many economic studies lean heavily on the magic of the market to make supply and demand balance without referring to any specific technical options for more efficient energy use, that I found it important to take a broad look at some aspects of conservation usually left to "someone else," in order to clarify the misunderstandings about conservation. I worried over the doom-laden forecasts from some government spokesmen and energy industry leaders, as well as prominent politicians, economists, consumer advocates, and other scientists who indicated that they believed that conservation meant curtailment of energy supplies, not increased efficiency of energy use. I felt it overwhelmingly necessary to pull together the pieces of evidence that indicate that conservation could take place on a large scale, i.e., that reductions of 20-40% of the energy requirements of processes are economically and technically possible without major changes in lifestyle beyond those which would take place in response to higher energy prices. I see, however, many important barriers to energy conservation, barriers which may impede society from using energy more efficiently, barriers which, to my mind, could not be overcome by the mechanism of higher energy prices alone.

Certainly the individual data and studies referred to in the present study need to be expanded, updated, and applied to many more kinds of energy-using systems. Certainly more careful evaluation of possible "disbenefits" from more efficient energy utilization have to be evaluated. This study hopes to suggest methodologies by which all energy systems can be evaluated. It should not be taken as "proof" that any particular policy is the best or cheapest or more promising policy, but rather an indicator of how policies aimed at efficient energy utilization might be studied.

In future work I will examine more carefully some of the economics of energy conservation, and I hope to look in detail at at least one of the countries (Sweden) where energy use generates more welfare, as measured by the Gross National Product, than in the United States.

The reader will doubtless note immediately that this paper advocates "energy conservation" as defined in the text, where conservation would save dollars, as well as energy, to the individual or firm in the long run. This narrow motivation ignores some ethical justifications for energy conservation that evade economic analysis. These include (1) the non-renewable nature of fossil fuels — even though "substitute" sources of available energy can be marshalled by society, the original stocks of low entropy oil, gas, and coal are unique, and future generations have no vote today on how much of these resources should be saved, and (2) the earth has a finite capacity to absorb pollutants, especially heat. When a group or a country of consumer/polluters pushes a region toward a collision with those limits, other consumer/polluters might find themselves forbidden to raise their levels of consumption unless they force the high consumers to cut their levels, and (3) the present distribution of energy use falls heavily on a few developed nations: continued high rates of use in these nations freezes the underdeveloped countries out of the economic market today, and these rates of use ensure that the low cost fuels will not be available tomorrow to these underdeveloped countries. This does not mean that the bulk of humanity will be denied energy fuels, but rather that the less costly supplies upon which the developed world built itself up will never be available to the rest of the world, thus slowing or halting its development. Conservation by developed countries effectively increases the amounts of fuels available at lower prices to the underdeveloped countries in the future, while exerting downward pressure on prices today.

Many individuals contributed directly and indirectly to this study, and I wish to thank Drs. E. Cook, B. Hannon, R. Herendeen, J. Holdren, A. Lichtenberg, R. Norgaard, and Gene Rochlin. In addition Mr. Pat Yarnold, and Ms. Linda Elliott, Carol Putman, Mari Wilson, and Debbie Tyber helped with graphics and assembly of the manuscript. Support of the Energy and Resources Group and the Lawrence Berkeley Laboratory (Energy and Environment Division and Atomic Beams Group) at the University of California is acknowledged. Needless to say, the opinions expressed herein are my own.

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ABSTRACT

This report discusses various definitions of energy conservation and efficiency of energy utilization. The roles of physical analysis as well as economic analysis are related, and it is suggested that energy conservation is the economic and technical procedure of optimizing energy-using systems based on present and future costs to provide greater output for lower energy inputs. Energy conservation is thus a form of higher resource productivity. Many conservation studies of individual systems are referred to, and economic examples are given as well. Methodologies are suggested for evaluating the effectiveness of energy conservation measures.

Some of the indirect effects, or "hidden benefits" of efficient energy utilization are discussed. These benefits include higher total employment, less pollution, lower demands for capital to build energy facilities, and hence lower interest rates, and less reliance on marginal or risky energy resources, meaning a slower rise in the real cost of energy.

Many "hidden barriers" exist that inhibit the functioning of the price system to produce efficient, economic energy utilization. These barriers include ignorance of the unique role of energy in economic processes, the lack of detailed information about individual energy systems or options for increased efficiency, the capital-intensive nature of energy using systems (capital can be economically substituted for energy) and the inability of many classes of energy users to respond to higher prices for energy. Other barriers to more efficient utilization include defects in the prices of energy itself, as well as social or philosophical difficulties in reaching an agreement that energy can be or should be used more efficiently.

INTRODUCTION

As the shock of the 1973 Oil Embargo dissipated, many Americans were left with the feeling that energy use in the United States in the 1970's was far from optimal. Claims were made that "conservation" would play a big role in the future of energy use. Unfortunately, however, a definition for "conservation" was rarely discussed. This paper, then, deals with the nature of energy conservation, its hidden benefits and hidden barriers.

Until recently, energy conservation was virtually ignored in work dealing with energy. Most government forecasts (See Fig. 1) (1-3) explicitly stated that conservation or increased technical efficiency of utilization was not counted in any projections. The Atomic Energy Commission's often cited Civilian Nuclear Power Series (4) projected growth rates for electricity without applying any forecasts of changes in technical efficiency of electricity utilization, and did not include the responses of users to higher prices for electricity. A more distressing view was found in the famous Energy to the Year 1985 prognosis of the Chase Manhattan Bank (5), which echoed the theme that energy conservation opportunities were unimportant. In fact this CMB study stated that:

> "It has been recommended in some quarters that the United States should curb its use of energy as a means of alleviating the shortage of supply. However, an analysis of the uses of energy reveals little scope for major reductions without harm to the nation's economy and its standard of living. The great bulk of the energy is utilized for essential purposes — as much as two-thirds is for business related reasons. And most of the remaining third serves essential private needs. Conceivably, the use of energy for such recreational purposes as vacation travel and the viewing of television might be reduced — but not without widespread economic and political repercussions. There are some minor uses of energy that could be regarded as strictly nonessential — but their elimination would not permit any significant savings" (Ref. 5, p. 52)

While it may be possible to define "conservation" in the CMB's terms, many physical scientists and economists would be appalled by the CMB analysis — or lack of analysis. In view of the confusion and disruption generated from a sudden curtailment of our fuel supply, as we saw during the Arab Oil Embargo, one can understand why some observers actually fear energy conservation (See Fig. 2). Careful analysis of the end-use efficiency of energy, however, reveals enormous possibilities for conservation.

Thus it is not surprising that the "energy establishment" began to acknowledge the importance of energy conservation. Certain groups began to include conservation in forecasts as early as 1972 (6). While much of this work was ignored by policymakers, the recent Ford Foundation Energy Policy Project findings (7) created a stir that helped establish respectability for energy conservation.

I. UNDERSTANDING ENERGY CONSERVATION

INSIGHTS FROM THE PHYSICAL SCIENCES

Certain physical laws apply to all physical systems. That these laws are of universal validity can perhaps best be demonstrated by noting that astronomical observations record physical events that took place billions of years ago, billions of light-years away, and yet the laws of physics today apply to these observations as well as to events taking place close by, today.

Laws of Energy (8):

1. Conservation of mass-energy, or the First Law of Thermodynamics:

   "You can't get something for nothing -- you can only break even." Energy (mass-energy) cannot be created or destroyed, but can change form.

2. The increase of entropy of a closed system; the impossibility of a perfect heat engine; The Second Law of Thermodynamics:

   "You can't even break even; you can only lose." Energy is constantly degraded into low quality (higher entropy) heat energy.

ECONOMICS

Economics mimics the first law by declaring "There is no such thing as a free lunch," and this writer often adds, "A cheap lunch leads to energy indigestion -- pollution, depletion, waste." Economists have always warned that underpricing of a resource leads to inefficient use, and that the use of a resource is underpriced if external costs, such as pollution, are ignored (9). The importance of this humorous digression is clear; understanding energy conservation demands an interdisciplinary understanding both physical and economic principles. Perhaps much of the misunderstanding about conservation stems from the lack of economists well versed in physical science and vice versa.

One goal of economic processes is to produce output efficiently —that is, to produce for the lowest total cost. Economic inputs include capital, labor, energy, land, and the environment that absorbs pollution. These factors are compared and evaluated by attaching dollar values to them, as well as valuing the output. Because energy is rarely used alone in an economic process, minimizing energy use does not always equate with minimizing total dollar cost. What has awakened the scientific community, however, is the fact that careful energy conservation does reduce total costs. One can here arrive at a careful definition of energy conservation:

> Energy conservation is the procedure of optimizing or adjusting energy-using systems so as to reduce energy requirements per unit of output while holding constant or lowering total economic costs per unit of output.

EFFICIENCY AND WASTE

Because energy is used in economic systems it is important to distinguish among various definitions of energy efficiency.

1. Physical Efficiency (10-13)

(a) Efficiency is measured by accounting for energy used in a process using the First Law of Thermodynamics as a guide;

$$\text{First Law Efficiency} = \frac{\text{Energy in desired form and place}}{\text{Total energy actually used}}$$

(b) Efficiency is measured by comparing energy used in a process with the minimum required by the Second Law of Thermodynamics (an ideal Carnot engine).

$$\text{Second Law Efficiency} = \frac{\text{Energy required by physical law per unit of output}}{\text{Energy actually used}}$$

Physical science predicts how much energy is required to provide work, transform substances, or change the temperature of environments. Physical energy requirements are lower limits, and efficiencies of 1 are not obtainable in practice,* especially when one counts the energy requirements of the energy system itself. The differences between First Law and Second Law efficiencies are important and are discussed in the APS study (12).

Basically, First Law analysis asks questions related to the functioning of a given system, such as "How much of the heat of combustion reaches the boiler?" or "How much of the torque from the engine reaches the wheels?" By contrast, the Second Law asks "What is the minimum amount of work or free energy required to change the temperature of an environment or substance by a given

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*Except for heat pumps, air conditioners, or refrigerators, which pump more heat than the electricity they consume.

amount under certain conditions?" Eliminating duct losses in home heating systems raises First Law efficiency because less fuel is needed to deliver a given amount of sensible heat to a room. The two kinds of efficiency, of course, are not independent. Better heat transfer in applying fuel to heat engines raises the Carnot temperature difference and thus allows higher Second Law efficiency through higher First Law efficiency, and so forth.

2. Operational/Design Efficiency

In practice, physical systems are designed to use energy according to the physical laws, but design and maintenance influence how much useful output—such as passenger miles, tons of steel, or comfort—can be obtained from energy use. Design efficiency is measured by a) comparing energy use in practice with that intended by the design of the device, or b) comparing the device or system with other possible systems. The first definition suggests that proper maintenance improves the operating efficiency or nearly anything, while the second definition recalls that a wide variety of technologies are usually available that produce similar output from energy use. Better maintenance and insulation of a furnace improves its efficiency, but different heating sytems (such as heat pumps) may offer considerably different approaches to space heating, and often consume far less energy. These efficiencies, without explicitly mentioning the laws of physics, are really the operational equivalents of physical efficiency.

3. Economic Efficiency

Economic efficiency is measured by comparing the dollar cost of alternative energy utilization schemes. These costs are measured on a life cycle basis, with consideration given to initial investment, reliability of the energy source, and varying forecasts of the price of energy. Ideally (though not in practice; see Hidden Barriers Section) the external costs are incorporated into the cost of a system. The system that is most efficient is the cheapest, or alternatively the most productive.

It should be evident that economic efficiency is the most important definition presented here, since most of the decisions of energy consumers will be mostly on the basis of economics. Economics determines how much investment, maintenance, or even care in considering what system to choose is justified in the first place. Economics determines how many extra dollars can be spent on improving the heat transfer properties of an air conditioner, how much extra investment might be justified in choosing a diesel over a gasoline engine for an auto, or how much insulation should be added to a structure. Important to the evaluation of economic efficiency is the cost of energy and the cost of money, as well as the discount rate or opportunity cost of making a certain expenditure. The discussion of Hidden Barriers explores some of the problems society faces in judging economic efficiency.

4. *Social Efficiency*

An additional kind of efficiency must be considered in any study of energy conservation. Social efficiency would be an attempted measure of social or psychological implications of energy use which cannot be assigned dollar costs in any easy economic evaluation. Some important variables are exertion, time, convenience, risk, pleasure, or nuisance. The personal automobile, as a mode of transportation may not be economically efficient and is actually very expensive. But to many, it is more socially efficient than mass transportation, and is therefore worth the extra cost. Indeed I discovered this while on a trip to Washington, D.C., when I swallowed my conservation pride and made 15 taxi trips in three days, more than during the last five years of my life. The taxi ride in Washington, D.C., is extremely efficient socially, and actually inexpensive compared to other cities or to the value time in Washington, D.C. Other variables that can be considered in social efficiency are urban design, employment, or the environment, all of which can influence or be influenced by energy utilization schemes. *Socially efficient* energy use means that people are satisfied with the way in which energy is used, irrespective of dollar or physical costs.

Any consideration of the efficiency of energy utilization should specify how this efficiency is to be measured, who is doing the measuring, and whether current costs or life cycle costs, total costs or internal costs, or total energy required (including the energy cost of building the system) are being considered.

Unless otherwise indicated, this study use the *economic* definition of efficiency.

These definitions bring out the *relative* nature of efficiency. *Waste* can be defined as the energy consumed in a process that was *not* required, according to one or several of the above definitions of efficiency. Of course, not all waste energy can be recovered.

Efficiency can also be identified with *productivity*, where this refers to total resource productivity, not just the output of a unit of labor. For many years national economists concentrated mainly on labor productivity, because resource costs were stable. Now, however, resource costs have risen faster than labor costs and in some cases, resources, rather than labor unions, have gone on strike, as in the case of the Oil Embargo.

KINDS OF ENERGY USE

Energy use in the USA is commonly classified by economic sector, and further disaggregated by actual output or form of use. Figure 3 presents relative consumption in the United States for 1972 and shows industrial and residential energy use by application but gives transportation energy use by output, such as "intercity passenger." Other studies—such as the Chase Manhattan Bank study (5)—designate "Electric Utilities" as a consuming sector, obscuring the fact that utilities *convert* fuel and hydropower to electricity that is then used in the other sectors. This designation distorts the total energy consumption of a sector or process by failing to allocate electrical conversion and transmission losses to the end user. (See also 15)

Another classification, which is particularly revealing to the physical scientist, arises from a thermodynamic consideration of the quality and quantity of energy used. Kenan, et al., (10) and more recently The American Physical Society (12) have discussed energy use in light of the thermodynamic quality of energy actually used; the APS evaluations are shown in Table 1.

The APS study estimated the Second Law efficiency of energy use (in the case of heat) by comparing fuel use with the minimum requirements of an ideal Carnot engine. The results, while only approximate, are radically different from the estimates of the famous energy flow diagram, or "spaghetti bowl" (Fig. 4) first drawn by Cook, which shows an overall First Law energy use efficiency of 36% for the US economy as a whole. The difference in these figures (Cook's original figure showed a 50% efficiency) suggest that the notion of efficiency had not been carefully evaluated until more recently. Lacking such a measure of energy use efficiency, economic planners could not be blamed for assuming as did the Chase Manhattan Bank study that energy use was efficient.

KINDS OF CONSERVATION

Given the various kinds of energy utilization, one can also classify the important conservation strategies:

Leak Plugging

Preventing heating and cooling losses in life-support systems as well as in industrial systems, correcting energy systems that are not running at designed efficiency, and eliminating unused or underused energy by retrofitting improvements. Examples include

TABLE 1

APS ESTIMATES OF EFFICIENCY OF ENERGY USE

Use	Relative Thermodynamic Quality	Percent of U.S. fuel consumption (1968)[a]	Estimated overall second-law efficiency
Space heating	Lowest	18	0.06
Water heating	Low	4	0.03
Cooking	Low	1.3	-
Air Conditioning	Lowest	2.5	0.05
Refrigeration	Lowest	2	0.04
Industrial Uses			
Process steam	Low	17	0.25
Direct heat	High	11	0.3
Electric drive	(work)High	8	0.3
Electrolytic processes	High	1.2	-
Transportation	(work) Highest		
Automobile		13	0.1
Truck		5	0.1
Bus		0.2	-
Train		1	-
Airplane		2	-
Military & Other		4	-
Feedstock	———	5	-
Other		5	-
TOTAL		100	

[a] Sources: Reference 12: "Work" is defined as "Infinite-temperature" energy by the APS study. The higher the quality of energy the larger the fraction that can be converted in to work.

insulation in buildings, heat recovery in industry, and improved maintenance of all energy systems. Leak plugging techniques are generally implemented once, then remain passively effective.

Mode Mixing

Changing the mix of transportation to utilize modes requiring less energy per passenger- or ton-mile.

Thrifty Technology

Introduction of new technology in any energy system to increase the useful output of the system per unit of energy consumed. Examples include gas heat pumps for space and industrial heat, electric ignition of gas water heaters, and improved propulsion systems in transportation.

Input Juggling

Changing the mix of economic or physical inputs to a given kind of output. Substitutions can be among energy forms, materials, or among economic variables such as labor, capital, design (a form of capital), and machines. For example, recycling is a form of input juggling. Use of returnable beverage containers substitutes capital and labor for the extra energy and material lost through throwaways.) And the use of "free" solar energy requires a capital investment. Thus all these thrifty, technology inputs require substitution of investment and design for direct energy expenditures.

Outputs Juggling

Changes in lifestyle, consumer preferences, investment practices, or shifts from manufacturing to services in the economy that lead directly to lowered energy requirements. Smaller cars, changing housing patterns, increased lifetime of consumer durable goods, changes in recreation or tourism patterns.

Belt Tightening

Belt Tightening involves turning off lights, heating or cooling, changing thermostat settings, driving more slowly, car pooling, increasing load factors in public transportation. Belt tightening involves small but important changes in energy use that cause minor inconveniences or changes in lifestyle and habits. Belt tightening, unlike leak plugging, must be actively pursued by individuals and organizations.

Curtailment

Cessation of a particular process or activity, such as driving bans or factory shutdowns, or often by rationing or allocation of fuels. Not a form of higher efficiency.

The literature of energy conservation, summarized for some important energy uses in Table 2, provides excellent examples of energy savings through these kinds of conservation, primarily under the first five strategies discussed above. *The Potential for Energy Conservation*, (18) published by the (then) Office of Emergency Preparedness explored conservation possibilities as early as 1972, and many studies since then have dealt with individual energy systems as well as economic and social problems. (See also 19-26). In Fig. 5 the "energy pie" indicates approximately 33% savings of energy in the four end-use sectors. These savings, suggested by the references mentioned in Table 2, refer

TABLE 2

SUMMARY OF STUDIES INVOLVING RAISING ENERGY PRODUCTIVITY

Strategy	Type	Potential Savings[a]	Other Effects[b]	First Cost of System	Life Cost[c]	Relative Employment[d]	References
RESIDENTIAL:[e]							
Insulation (homes)	Plug Leak	5%	Lower fuel prices Lower summer air condit. needs	up	down	up (manufacture, installation)	12,13,18, 111,115
Air Conditioning (homes, offices)	Thrifty Technology	1%+	Lower summer peaks Fewer brownouts Slower elec. growth	up	down	up (manufacture)	11,13,27, 115
Lighting, appliance efficiency	Juggle Inputs[a]	2%		same or up	down	up (construction, design, materials fabrication)	112-115
Building Design	Juggle Inputs	5%		down, same or up	down		84, 115-120
Solar Heating/ Cooling	Thrifty Technology, Juggle Inputs	3 to 5%	Could replace anticipate strains from growth in electric heating and cooling	up	same or down	up (manufacture, construction)	84,85, 105,115, 122-125
INDUSTRY:							
Industrial Heat Treatment, Process and Materials Improvement	Juggle Inputs Plug Leaks	5 to 10%	Less vulnerability of industry to fuel costs or interruption	same or up	down	up (equipment, mfg., increased labor)	19-22, 38, 126-128
Returnable Bottles vs. Throwaways	Juggle Inputs	.2%	Typical of the kind of choice we could make	down	down[f]	up	130
Recycle Paper, Primary Metals and Plastics	Plug Leaks, Juggle Inputs	3%	Stabilize resource prices, eliminate solid wastes	about same	down[f]	up	88,89,131, 132
TOTAL ENERGY (also applicable to RESIDENTIAL)	Plug Leaks, Juggle Inputs	5 to 10%	Lower energy consumption, same use!	about same	down[g]	Unknown (probably up due to on-site maintenance & monitoring	12,13,128, 129
TRANSPORTATION:[h]							
Mass Transit for 50% of Urban Passenger Miles	Mix Modes	2%	Less congestion & inconvenience	up	down	up	18,132-136
Smaller Autos, Higher Specific Efficiency	Input Juggling	3 to 5%		down	down	Slightly down & more employment elsewhere as saved $ are spent	12,13,18, 36,132-136
Shift Freight and Passengers to Rail	Mix Modes	1%	Less congestion	down	same	Unknown	132-136
LIFE STYLE:[j]							
Urban Design	All					Unknown	7
Consumers Demand Changes	Juggle Output					Unknown	7,24,39, 43

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[a] Percent of total 1972 U.S. energy consumption. To get percentage of sector or fuel use, consult (36). Figures overlap so they cannot be added together. Estimate based on "how much we would save today if we had done it this way" approach.

[b] See references for further discussion.

[c] Life costs include interest, upkeep, taxes. Estimates vary with interest rates, payout time. See (15).

[d] Compare with (24) and (7). Since employment per dollar of demand in energy sectors is low, nearly every switch of energydollars elsewhere raises total employment. Employment shifts, however, are knotty problems and the intangible expenses incurred here are not included.

[e] I ignore thermostat setbacks, though they are effective as are other belt-tightening measures.

[f] Help several birds with no stone. Organization necessary. Get more jobs and use less raw materials.

[g] Design important.

[h] Speed limits, good driving habits, technological improvements save more than clean air devices raise consumption.

[i] See Ref. 82 for indirect energy needs of automobiles, energy required to make cars, etc.

[j] I did not explicitly discuss lifestyle in this paper. Some changes here which effect energy use include living near work, vacationing near home; banning snowmobiles and off-the-road vehicles, recycling organic wastes at home, etc. See Ref. 24, 39 and 43.

to a decrease in the energy used per unit of output production, life support, transportation, or convenience. Most studies agree that months to years are needed to realize these savings, which may be masked by the overall growth in energy inputs. This slowed growth of energy use is often referred to as a "technical fix" (7).

DOLLARS AND ENERGY CONSERVATION

An important part of any energy conservation plan is the question of cost effectiveness. Does higher energy efficiency or productivity come about at increased total economic cost? The cost effectiveness of energy conservation strategies should be analyzed on a life cycle basis. That is, to make improvement in energy utilization (even under the requirement of significant first-cost increases to consumers or higher investment costs to industry) pay for themselves over the life of the energy-using system, with typical payback times ranging from zero to a few years for home insulation, to five years for appliances, industrial processes and autos, and to as much as 20 or 30 years for solar space conditioning or total energy systems. Most of the works on energy conservation cited in Table 2 do treat the economics of the various energy costs, system costs, interest and discount rates, and so forth. These studies, however, do not predict that energy consumers will opt for conservation measures, only that if they did they would save money for a given set of prices, as well as energy, in the long run.

Figure 6a, from Moyers (27), indicates how a consumer can evaluate the size of investment in efficiency that is justified. Here he can find the present worth of an investment for higher efficiency air conditioning assuming various climates, hours of operation, and electricity cost. With a chart like this one can evaluate the economic optimum of single technology.

Similarly, the cost of alternate technologies (design efficiencies) rather than alternate efficiencies of the same technology may be evaluated. Figure 6b shows the total annual costs of heating homes with gas heat versus electric heat pumps. The cost of electric resistance heating is even higher. The graph shows that higher energy productivity is efficient economically. Table 3 shows some of the results of E.I Dupont Company energy conservation program. The cost and fuel savings are impressive. Not included however are the cost of the Dupont energy conservation work itself or the cost of actual equipment adjustments, but these costs are far less than the realized savings in fuel expenditures.

ENERGY USE AND STANDARD OF LIVING

For many years, one argument of those advocating rapid growth in energy use has been the so-called relation between energy use and the Gross National Product, sometimes referred to naively as the "standard of living" or "affluence." As Fig. 7 shows, the correlation seems to be impressive. Burnham, writing in the comments section of the summary of the Energy Policy Project (7) findings, observed that growth in the Gross National Product has in the past always been accompanied by similar growth in energy use. This

TABLE 3

IDENTIFIED SAVINGS POTENTIAL OF EIGHT INDUSTRIAL PLANTS[a]

Plant Type	Total Annual[b] Energy Bill	Identified[b] Savings	Percent
Basic Chemicals	$ 5.5	$ 2.39	43.4
Textiles	.9	.29	32.0
Agric. Chem.	1.7	.28	16.7
Oil Refinery	10.3	1.12	10.8
Chem. Intermediates	13.2	1.87	14.2
Food Processing	1.1	.33	30.1
Pulp and Paper	5.3	1.70	31.5
Rubber and Tires	2.9	.47	16.4
AVERAGE	$ 5.1[b]	$ 1.05[b]	20.6

a. Source: E. I. Dupont 1973 Energy Management Client List (29)

b. In millions of dollars

analysis, however, ignores so many basic factors that it is deceptive: In the words of Rene Dubos, "Trend is not destiny." Some of the important factors that influence the real world of energy use and the well-being derived from energy, include:

- Geographic, demographic, climatological differences among countries or regions, and changes in these over time.
- Cultural differences among people, including advertising, "keeping up with the Jones," personal habits and values.
- Differences in economic conditions, including energy prices, the breakdown of the inputs and outputs in the GNP, the pace of economic growth.
- Physical differences in both the kind of things in the GNP, as well as in the technical efficiency of energy use, and the trade-offs occuring between design, planning, pollution, raw materials use, land use, capital investment, and labor in the economy. These variables refer not just to production but to other economic processes using energy.

One technical example illustrates the dangers inherent in correlating the energy inputs to an economy with its economic output. Both the United States and Sweden use relatively large quantities of electricity per capita, with Sweden supplying over half its needs with hydropower. Nevertheless, steam generation in Sweden is becoming increasingly important. The energy inputs and outputs of steam electricity generation in Sweden are depicted in Fig. 8a and the comparable balance for steam electricity generation in the U.S. may be seen in Fig. 8b. The difference in energy utilization is striking; in Sweden, 53% of the output of thermal plants is used for industrial or residential heat or electricity, while in the U.S., very little of the "waste" heat from power plants is used. This large scale difference in energy utilization is not reflected in the GNP statistics of the countries but shows up in gross energy statistics, in that Sweden does not have to burn fuel to get some of its low-temperature heat.

Historically, energy use per dollar of GNP has varied in the U.S. (Fig. 9) reflecting many contributory changes. The analysis of Mr. Burnahm reflects only the post-war period in the U.S., a period of economic boom, cheap energy (even falling prices [32,33]) and, until passage of the National Environmental Policy Act in 1969, relative neglect for the environment and the real environmental and social costs of energy use. Furthermore, Cook's analysis of end use energy efficiency (Fig. 10) shows a plateau in application efficiency for many uses of energy occurring after 1950, though important gains in air and rail transport efficiency occurred as a result of post-war technological changes. Elsewhere, automobile efficiency declined (35,36) while electric power produced per unit of fuel peaked and even declined slightly around 1970 (32).

Finally, energy prices began to rise dramatically, starting in the early 1970's (32), reflecting increased environmental costs, increased real costs of energy due to physical scarcity, increased artificial costs (e.g., oil prices) and increased prices due to shortages.

Summary: The Case for Conservation

The economic case for conservation can be stated in the following way. Today, a dollar's worth of conservation investment has a higher payoff in both dollars and in BTU's that a dollar's worth of investment in energy recovery. Or, a dollar spent on conservation goes farther than a dollar actually spent for fuel. Figure 11 illustrates this in another way. The curve symbolizes the toal cost of a product or service as a function of energy use per unit of product. "Today" marks a spot that in the past was at or near the minimum of the curve to the right, toward higher efficiency, or less energy per unit of output. New utilization techniques have also lowered the energy requirement per unit of output in many manufacturing and building technologies. As long as the "X" moves lower, it may be moved to the right. Once the minimum has been reached, at 40%, (an approximate figure) the cost of additional energy use becomes cheaper than additional conservation. This general description seems to hold for most energy using systems (25). Adding environmental and social costs (see below) may very well justify pushing the "X" slightly beyond the direct cost minimum as well. Whether energy utilization will move toward the optimum point solely in response to the price of energy is another question entirely, and is considered in Section 3. However, Just (37) and Meyers (38) have pointed out that in industry energy use has become slightly more efficient physically and economically, even in the face of falling energy prices, as new utilization technologies became available and at an economically attractive cost.

The effect of conservation on the growth in energy use can be illustrated by comparing Figs. 12a and 12b. The "gap" shown in Fig. 12a arises because domestic energy supplies are thought to lag behind demand (1-3) when effects of price and technology are not considered. It is suggested that this gap be filled by a variety of solutions: oil imports, accelerated use of nuclear power, coal, domestic oil and gas (hastening depletion), synthetic fuels, solar energy, geothermal energy, or some other form of available work. Certainly, all of these supply options are important, but the high cost of additional supplies suggests that increased energy productivity can supply the goods and services ("standard of living") otherwise made available from energy in the "gap" at a lower total cost. In this sense economic conservation (higher energy productivity), or more quality of energy use, rather than quantity alone means doing better, not doing without. The next section of this study will examine some of the hidden benefits of better energy utilization.

2. HIDDEN BENEFITS OF CONSERVATION

It is important to consider the indirect benefits of higher energy use efficiency because policy makers will always be faced with cost-benefit analysis of conservation strategies, and often the indirect benefits added to the direct savings of energy and dollars provide even more support for a particular policy of conservation.

EMPLOYMENT

Though the relationship between energy and employment is a confusing one, certain statistics indicate that careful conservation leads to increased employment per unit of energy output, or even to increased output from the non-energy parts of the economy.

The Energy Policy Project (7) and other sources (32,33) have collected statistics on employment in the energy industry (summarized in Table 4a). What is striking about these numbers is the relatively few energy industry employees per dollar of energy sales to end users. Historically, the largest gains in energy industry employment during the 1950's and 1960's were in the retail gasoline sector, while coal recovery employment dropped and other extraction industries decreased their employment per unit of energy or dollar of sales. Investment in energy industries, especially in oil and in electric utilities, is by far the highest per employee of the major industries (Table 4b) (33). Employment in the utilities in particular has failed to keep pace with growth of the utility system, as shown in a variety of ways in Table 4c.

Figure 13 illustrates the interaction of labor and energy in the economy. A dollar of capital investment, spent on production materials, or spent on final demand, requires a certain amount of labor or energy (and capital). In addition, the producer demands labor, energy, and capital to make the inputs that he purchased in order to supply the dollar of final demand. Using input-output models (24,39-41) one can estimate the average total labor and energy intensity of any economic transaction. Figure 13 actually shows the energy and labor

TABLE 4a

ENERGY, 1974

National Income	4% of National Income
Value Sold	9% of GNP[a]
Personal Consumption	7% of PCE[a]
Indirect Costs in Personal Consumption (in goods and services)	4% of PCE[a]
Investment of Energy Industries	22% of Non-Residential Gross Domestic Investment[a]
Employment:	3% of Total Employment[b]
Extraction, refining, pipelines, utilities	1.75% of Total Employment[b]
Retail, wholesale dealers	1.25% of Total Employment[b]

Sources: a. J. Holdren, private communication; (Assembled from U.S. Statistical Abstracts).

b. Reference 7: Data are for 1971.

TABLE 4b

CAPITAL INVESTMENT PER EMPLOYEE IN SELECTED U.S. INDUSTRIES (1971)[a]

Electric Utilities	$ 173,000
Petroleum	150,000
Motor Vehicles	42,000
Chemicals	36,000
Paper	22,000
Food	22,000
All Manufacturing	22,000

[a] Source: Edison Electric Institute, 1973 (Ref. 33)

TABLE 4c

SELECTED ELECTRIC UTILITY STATISTICS[a]

	Capacity kw	Output 10^{12}kwh	Revenues $\$10^6$	Construction Outlays $\$10^6$	Employment[b] 000's
1961	190	.80	$12,220	$ 3,300	343
1971	370	1.62	$24,700	$12,000	394
1973	440	1.85	$31,700	$14,900	415

[a] Source: Edison Electric Institute, 1973 and 1974. (33)

[b] Of the total number of employees, roughly 25% were engaged in construction.

requirement per dollar of final demand of many important goods and services, with the national average buried in the lower left corner. As can be seen from the figure or from Table 5, energy and raw materials have low labor-intensities, and high energy-intensities. Manufacturing is toward the middle, while services are labor-intensive and not energy-intensive.

Most kinds of energy conservation represent substitution of capital, materials, know-how, or belt-tightening and lifestyle changes for energy; compare, for example, two air conditioners operating in similar homes, under similar loads in the same climatic region. Moyers (27) showed that users could economically justify buying more efficient air conditioners under most circumstances, with the energy thus saved (translated into dollars) repaying the higher first cost (including interest) and still realize a savings after first cost recovery, usually within 3 to 5 years.

It can be seen that some of the money spent on energy for a less efficient air conditioner is now used for materials and labor, resulting in more carefully constructed, efficient air conditioner. Since manufacturing is generally more labor-intensive than electric utilities, the switch to the more efficient unit raises the total demand for <u>labor</u> (see Table 5). The money left over after the extra cost is recovered is used for other personal consumption, which generally has a higher average labor intensity than electricity (Table 5). Thus conservation leads to higher demand for labor in pursuing conservation technology, and induces more economic enterprise (hence jobs) by releasing previously committed energy money.

TABLE 5

The energy and labor intensities of the largests (dollarwise) personal consumption activities, ranked by energy intensity, for 1971. From Hannon and Puleo, 1974 (42). Note the differences in the average labor intensities of electricity and kitchen appliances.

Personal Consumption Expenditure Sector Description	Energy Intensity, Btu/$	Labor Intensity, Jobs/$1000
Electricity	502,473	0.04363
Gasoline and oil	480,672	0.07296
Cleaning preparations	78,120	0.07332
Kitchen and household appliances	58,724	0.09551
New and used cars	55,603	0.07754
Other durable house furniture	45,593	0.08948
Food purchases	41,100	0.08528
Furniture	36,664	0.09176
Women and children's clothing	33,065	0.10008
Meals and Beverages	32,398	0.08756
Men and boys clothing	31,442	0.09845
Religious and welfare activity	27,791	0.086365
Privately controlled hospitals	26,121	0.17189
Automobile repair and maintenance	23,544	0.04839
Financial interests except insurance co.	21,520	0.07845
Tobacco products	19,818	0.05854
Telephone and Telegraph	19,043	0.05493
Tenant occupancy non-farm dwelling	18,324	0.03502
Physicians	10,271	0.03258
Owner occupancy non-farm dwelling	8,250	0.01676
Average, including energy purchases	70,000	0.08000
Average, non-energy purchases only	52,000[d]	-------

[a] 1967 figure. The corresponding 1967 figure for average including energy was 80,000 Btu/$. Source (1967 figures): R. Herendeen, private communications.

The result is more goods or services and more employment, with less energy — in direct contradiction to the notion that prosperity (if the GNP defines prosperity) can only grow in step with energy.

Of course, the exchange of labor and capital for energy could lead to the mistaken idea that the economy is less productive because essentially more man-hours are required to produce the same GNP. What this idea overlooks is that the structure (or quality) of the GNP is now different because the mix of goods and services has changed. In Fig. 13, the average energy and labor intensities of the economy move slightly towards the lower right sector as energy is conserved.

In industries that conserve energy, employment will also increase because nearly every energy conservation program (28) (Leak Plugging) calls for a number of energy specialists to monitor and adjust energy usage in the industry's facilities. Similarly, implementation of conservation plans creates a new demand for equipment, consultants, architects, designers, and other specialists. The costs of switching to a more efficient use of energy are borne out of savings from energy bills, and the net dollar saving is either passed on to consumers, reinvested, or taken out in profits. In each case, energy expenditure is replaced by non-energy expenditure, generally increasing employment.

Finally it should be mentioned that one of the arguments for "juggling outputs" (24,39,43) has been the observation that the less energy-intensive goods and services tend to be labor-intensive. If consumers preferred less energy-intensive items, either in response to higher energy prices or a desire to save energy (as suggested in Ref. 43 concerning gifts) the energy/GNP ratio could sink, even without changes in energy utilization or in the ratio of services to goods. Some changes in consumer preference, such as switching to buses, could even improve efficiency by increasing load factors (35,42), changes in travel and tourism would effect transportation energy use, and changes in aesthetic and architectural preferences could alter energy demands in housing and buildings.

CONSERVATION AND POLLUTION

When energy conserving practices are adopted, the net result is an increase of useful output per unit of energy input. But energy processing activities are among the most polluting (see Ref. 44). If, for example, a homeowner in the Tennessee Valley Authority service area insulates his house and buys a heat pump, thereby saving approximately 50% of the electricity commonly used there to heat homes (28), then less coal need be strip mined (about 4 tons per home less), fewer power plants need be built, less cooling water is used, and less air, land, and water pollution is created per night of comfort in the winter or per day of cooling in the summer. Since the demand for materials required by energy-saving technologies is usually only slightly higher than for correspondingly less efficient options, the pollution caused by the extra investment will be small compared to that saved by energy conservation.

Similarly, reduced automobile size, increased use of mass transit, and increased automobile life result in less pollution per passenger-mile of travel. A finding from the Environmental Protection Agency (36) showed that lighter cars tended to be affected relatively less than heavier cars by the inherent energy penalty of pollution control devices. Reducing the size and weight of the larger cars, while improving gasoline mileage, also will improve air quality, even without additional changes in anti-pollution equipment.

The effect of conservation on pollution is important, for as the number of sources of pollution of all kinds grows, and as the amount and kinds of pollutants grow, more abatement technology will be required to maintain a constant level of pollution. As Cook (16) and others showed (Fig. 14), costs of pollution controls tend to increase out of proportion to the increments of control. Singer (45) observed that the total bill for pollution abatement could rise in the future faster than the GNP itself, an effect expected on the basis of the assumption of higher population and per capita consumption of everything (See also 46). As Holdren's diagram indicates (Fig. 15), the use of energy has two effects on well-being: a positive effect through its application to numan needs in the economy, and a negative effect through its adverse effects on the environment. Increasing then the economic and human well-being obtained per unit of energy expended, would reduce the adverse pollution cost of required energy uses, the ensuing lowered pollution itself contributing to human well-being. (The fact that "well-being" is difficult to quantify doesn't mean that it can't be enhanced!)

It is often claimed that "large amounts of energy will be needed to clean up the environment." Electric utilities (33,47) and other industry spokesmen (5, p. 26) often make this claim (49). However, Hirst (48) and the National Petroleum Council (Table 6 from 48) estimate that the energy cost of meeting clean environment standards for 1980 would be about 4% of the total energy use anticipated for 1980. Ross et al. put this amount at about 2% (44). Hirst points out, rightly, that recycling, smaller cars, mass transit and other anti-pollution measures also tend to save energy. Thus the energy requirements of pollution control, while not insignificant, are not "large" as often claimed by the energy industry.

Since the problem of pollution is especially sensitive to the rate of use of pollution-creating processes (45,46), higher rates of energy use will require more pollution abatement per source in order to maintain the same level of overall environmental quality. This will mean higher expenditures per net Btu used, and higher costs for goods and services. Since higher energy productivity economically reduces gross energy inputs to everything, the gross amount of pollution is reduced, so that abatement costs go down; or alternatively, the value of a dollar's worth of abatement is higher. Since one of the costs of abatement, albeit small, is energy itself, lowered energy demand through conservation would mean an additional environmental payoff. The comments under Marginal Energy Sources (below) apply here, since marginal sources generally produce more pollution per Btu. Lower rates of use mean less pollution from these marginal sources.

TABLE 6

NATIONAL PETROLEUM COUNCIL ESTIMATES OF 1980 ENERGY CONSUMPTION TO MEET ENVIRONMENTAL STANDARDS[a]

	Increase (trillion Btu)	Percent of total energy use[a]
Automobile emission controls	914	0.89
Electric utility industry		
Control of waste heat		
Control of air pollutants	183	0.18
Sewage, water, and solid waste treatment	1,000	1.95
Environmental control by industry	976	0.95
TOTAL	4,073	3.97

[a] Source: Ref. 48

[b] Total projected energy consumption for this case in 1980 is 102,581 trillion Btu.

CONSERVATION AND CAPITAL REQUIREMENTS

In 1974 electric utilities began feeling a capital crunch, and many found themselves canceling or deferring some or most of their planned capital construction (50). Some of these cancellations and deferments arose because utilities revised their demand forecasts downward, but some deferments were solely because of a shortage of capital.

Energy industry spokesmen had warned of the need for capital for many years. The energy industry generally consumes the greatest share of all investment capital in the U.S. (32), especially when measured against industry sales or industry employment (See Table 4a). If electric demand were to continue to grow at nearly 7% per year, doubling every 10 years, the electric utilities would outconsume by far any other group of industries. As recently as 1973 or 1974 many were still expecting utilities to maintain this growth rate until the end of the century (51-37). The so-called Nuclear Electric Energy Economy (55) would accelerate this growth even more, while fossil fuel substitutes like shale oil or coal gasification also promise to soak up increasing amounts of capital per unit of energy output or per unit of capacity. Any inefficient or high energy-use future could be expected to generate less employment than a more efficient or less energy-intensive future as a function of capital investment.

But as the energy industry share of all capital investment grows faster than in the other sectors of the economy, these other sectors will have to forego investment and growth, or all consumers will have to give up a larger share of their incomes, through higher prices, higher taxes, or higher interest rates, in order to finance the expansion of the energy industry into expensive nuclear, shale, and coal-gas energy. Certainly the energy industry will continue to grow in nearly any scenario covering the next 25 years. Conservation, however, slows the growth of the energy industry, saving capital, easing pressure on interest rates, and allowing more personal consumption.

One question concerning capital investment that can immediately be attacked by energy planners is that of marginal benefits from energy related investment. Granted that investment in expansion of energy production must take place, what investment in energy conservation would, nevertheless, be cheaper than investing in extra energy production to make up for needs in the case of non-conservation? Nuclear power, shale oil, coal gasification, and advanced oil recovery techniques are important to the energy future, but investment in these facilities at the margin produce less energy per dollar than investment in insulation and other conservation measures saves (13,25).

In agreement with our previous argument, Canfield and Freeman testified before the Senate Commerce Committee that the marginal cost of higher energy efficiency in industry was greater than the cost of producing extra energy instead (58). The air conditioning data of Moyers suggest that the extra capital required to save energy (in this case energy conversion capacity) is less than the cost of building equivalent capacity to generate energy (in this case, expensive peak power). While the heat pump can replace electric resistance heating used primarily at off-peak hours, the prospects of financing and building large numbers of base-load coal and nuclear power plants to provide the extra electricity, if resistance heaters (rather than heat pumps) are adopted nation-wide, is awesome.

An economic evaluation of the aggregate savings from efficiency comes from the American Institute of Architects (59). The AIA study shows that investment in energy efficient buildings, both in new structures and in retrofitting, will pay off in savings of over 12 million barrels of oil per day equivalents, an amount equal to the typical capacity of any of the accelerated supply options considered in Project Independence (Fig. 16). The AIA carefully acknowledges that here the capital investment in building technology is slightly higher than that required to provide the extra energy (if the conservation option is ignored). However, the study claims that the total payoff is larger, so that on a life cycle basis conservation is more economical. The AIA study notes that environmental costs would be lower in the conservation case, and input-output data suggest that the manpower requirement to build and run efficient buildings would be higher than the equivalent requirement to provide the extra energy. Though these conservation strategies may require more capital than supply options, the long term payoffs are higher for conservation because buildings far outlast energy production facilities.

These comparisons are important, if government works directly with consumers and businesses, or indirectly through banks, in granting loans to finance energy conservation. The energy industry is experienced in accumulating capital, and can aid itself in this by charging more for its product. Indeed, one proposal made by President Ford in his State of the Union energy message (60) was to allow utilities to include in-progress construction in the rate base, so that they could raise capital more directly from consumers. But similar action on the part of consumers (see the Hidden Barriers section to follow) means a kind of enforced saving above and beyond today's rate of consumer saving — that is, higher first costs repaid through lower operating costs. Consumers may find themselves unable to raise their own "energy capital," even if they could obtain accurate information on real costs of energy systems and future prices of energy. Evaluation of the capital cost of energy conservation alongside that of energy production will allow public and private planners to allocate funds on the basis of the greatest public and private payoff.

CONSERVATION AND MARGINAL ENERGY SOURCES

Conservation has another effect on the future of energy production; it slows the rise in physical costs (and dollar costs) associated with marginal, less accessible, more energy-costly sources of energy (34). A nuclear power program can consume a large fraction of its own output during expansion if expansion is too rapid (61). Tertiary oil recovery, as well as shale oil and coal gasification, produce far less *net* energy than the actual Btu content of the fuel in situ (62-65). For "scarcity" of energy really means "high entropy" or dispersal of energy fuels; increasing amounts of low entropy (fuels) are needed to recover these marginal fuels (66). Conservation eases the transition from accessible to scarcer energy resources. That the real marginal cost of energy

production from conventional sources is rising today is evident from Fig. 17. The rise in real cost of drilling due to scarcity is awesome, and nearly exponential with depth. More important, the requirements for increased earth moving, drilling, water, and waste disposal forewarn of rising environmental spoilage per unit of net energy actually gained from energy harvesting. Rieber's analysis of western coal (67) indicates that lignite, with only half the Btu content of bituminous coal, requires substantially larger environmental disruption per Btu recovered, and more ash and sulfur per BTU of heat obtained in a boiler. Similar comments apply to release of gas by nuclear stimulation, or to oil shale production. Birdsall (68) estimated that the recovery of 18×10^6 bbl/day of *gross*, not net, energy from shale (25 gallons per ton of rock) would produce enough rock to build a two-lane road from Los Angeles to New York daily. What is clear from these examples is that expensive or marginal energy resources, no matter how large they may be in Btu *in situ* content, pose tremendous environmental problems if they are to be exploited on a large scale as compared to 1975 energy demands in the U.S. Conservation, with its lower growth in energy harvesting allows society to buy time for the testing and environmental engineering required to ensure safe and clear recovery of net energy with net social benefit. This is especially important for technologies such as nuclear power in which the risks from mis-management are great (69-70, 47). In addition, "income sources," such as solar energy or geothermal heat, which are large in supply but limited in rate (71) contribute more to an energy budget which is reduced by conservation. Solar energy in particular offers environmental advantages because of its use of already existing solar heat. Society's choice of which energy sources it will exploit depends greatly on what total rate of energy utilization it will require. But in any case, conservation makes that rate more manageable.

3. HIDDEN BARRIERS TO EFFICIENT ENERGY UTILIZATION

While the economic and physical analyses leading to the conclusions presented so far are relatively straightforward, the reasons why energy is not today used with maximum efficiency (measured in any way) are complicated. The Chase Manhattan Bank Study cited in Section 1 (5) indicates that few energy analysts before 1973 ever believed that there was any inefficiency to be dealt with in the energy budget. When Cook (16) first drew the "spaghetti bowl" (Fig. 4) he estimated the overall efficiency of the U.S. energy budget, measured as the ratio of utilized heat and work to total energy inputs, to be around 50%. One is surprised to see that these figures had been quoted and repeated almost universally (17) until Cook himself revised the spaghetti bowl, assigning an overall efficiency of 36% to the system. Before Cook's first estimate, few observers had questioned or investigated U.S. energy-use efficiency as measured against any standard. Thus, it is not surprising that "efficiency" as a measure of energy utilization never entered seriously into any discussion or projection of energy use. Ignorance of efficiency as a factor has hampered those who try to apply a useful tool, economics, to the analysis of a physical process, energy use.

Economists invoke a different tool, the market place, as the measure of efficient use of resources (9). Price determines the optimum use of resources, balancing the rate of supply of energy with the rate of demand. When the price of a commodity rises, the user may elect to use less, substitute, or do without it. If use is sensitive to price, the relationship between use and price is termed elastic (72). If, on the other hand, changes in prices do not induce changes in use, or induce relatively small changes in use compared to the change in price, the relationship is termed inelastic.

The curves in Fig. 18, from Ref. 54 suggest that econometric studies can predict changes in levels of demand in response to changing prices. These estimates serve as a useful example for the problems being considered here. Curve 3 shows that, all other things being equal, consumers would demand far less electricity in the year 2000 than the conventional wisdom (constant prices, Curve 1) would predict. (See Ref. 1 for an example of such a prediction.) The issue, however, becomes one of making up for the difference between the output or utility available between Curves 1 and at 3. The present study essentially claims that technical and economic changes can make up for whatever benefits are lost if Curve 3 rather than 1 represents the final level of consumption. But the hidden barriers discussed here may effectively prevent energy users from making the required economic adjustments, so that instead of "doing better" users find themselves doing without (73).

Unfortunately (as noted above) economic studies of elasticity rarely evaluate the technical options available to the consumer of energy, instead predicting the aggregate response of many customers to a change in prices and measuring the response as a change in demand. Physical analysis of changing economic conditions as well as the technologies involved can often reveal surprising options for energy conservation that are not recognized by econometric studies (74,75). That is, for a given level of energy costs, certain energy systems will be more economical than others. In a free market, each consumer will in theory adjust this energy use to the economic optimum by responding to price changes.

But there are many important reasons why today's economic systems, enterprises and entrepreneurs, or individual consumers cannot respond to changes in price. Most importantly, use of energy is not in itself a consumption goal, but is instead in conjunction with some other personal or economic end. Even today, the cost of energy is usually only a small fraction of the cost of consumer goods (cf. Table 7a) or of the cost of production (cf. Table 7b). This illustrates an important barrier to energy conservation: that the relatively low cost of energy compared to other expenses may mean that even where conservation is economic, the savings may be ignored. In addition, consumers are usually unaware of the cost of energy embodied in various products (See Table 7a). For some energy-intensive things (airline travel, plastics, aluminum, cement, to name a few well-known examples) producers tend to pay more attention to energy costs, as might be expected. But changing production methods

TABLE 7a

BTU CONTENT AND ENERGY VALUE CONTENT OF SELECTED GOODS AND SERVICES[a]

Product	Energy Content (btu/$)	Gallons of Gasoline Equivalent	Energy Value Content[b] (¢/$)
Plastics	218,097	1.74	13.2
Man-made Fibers	202,641	1.62	7.4
Paper Mills	177,567	1.42	7.9
Air Transport	152,363	1.22	12.0
Metal Cans	136,961	1.10	7.3
Water, Sanitary Services	116,644	.93	11.6
Fabricated Metal Products	91,977	.74	5.8
Knit Fabric Mills	88,991	.72	6.5
Floor Coverings	79,323	.63	5.8
House Furnishings	75,853	.61	5.3
Electric Housewares	74,042	.59	5.6
Motor Vehicles & Parts	70,003	.56	5.9
New Residential Construction	60,218	.48	4.5
Hotels	40,326	.32	5.4
Hospitals	38,364	.30	5.4
Retail Trade	32,710	.26	4.4
Banking	19,202	.15	2.5
Doctors, Dentists	15,477	.12	1.9

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[a] Source: Bullard, 1974 (76)

[b] These values are for producer's prices, and do not take into account mark up to retail price, about 66%.

TABLE 7b

ELECTRICITY IN SELECTED U.S. MANUFACTURING INDUSTRIES, 1939-1967[a]

Industry	Cost of purchased power (% of product value) 1939	1967
Primary metal industries	1.8	1.8
Fabricated metal products		0.6
Chemicals and allied products	2.0	1.7
Paper and allied products	3.9	1.9
Food and kindred products	1.1	0.4
Transportation equipment	0.7	0.4
Petroleum and coal products	1.2	0.8
Stone, clay and glass products	3.2	1.5
Textile mill products	2.3	0.9
Electrical machinery	1.1	0.5
Rubber products	1.6	1.0
Lumber and wood products	1.8	0.9
Furniture and fixtures	1.0	0.5
Leather and leather products	0.6	0.4
Miscellaneous manufacturers[b]	0.9	0.4
ALL MANUFACTURING	1.41	0.79

[a] Source: Ref. 33

[b] Includes ordinance and accessories.

is another matter, especially when energy prices rise quickly. The problem of rising energy costs is particularly acute for aluminum smelters, which are commonly located near unusually cheap government power as in the Pacific Northwest or TVA area (77).

Another barrier to changes in demand is the capital-intensive nature of energy using devices and structures. If, for example, the relative prices of certain foods change, consumers can change their demand on a day-to-day basis without regard to past expenditures or present possessions. Energy use, on the other hand, is largely determined by the existing stock of devices and structures available to each use. For a homeowner, the physical condition of his house, its design, the design of the heating system, and the weather determine how much heating fuel he needs to maintain a given indoor temperature. He can influence his heating requirement by improved maintenance, retrofitting of insulation, increased maintenance, warm clothes, or lowered temperature. (Ref. 78-80 discuss "belt-tightening" quantitatively.) The savings from such measures are usually smaller than those realized when his house and furnace are optimized in the original design (See Ref. 81).

Industrial energy users will gladly invest in more efficient equipment, but the time to do so depends on the age of their present equipment (see Ref. 18). Automobile owners who rush out to sell their "gas guzzlers" find a falling market for these cars, and in no case can the energy originally used to make them be recovered. (This original energy usually amounts to a year's worth of gasoline consumption equivalent! [82]) So, while consumers could drive less, heat less, maintain more often, or retrofit, their responses, whether through shifting technologies, juggling inputs, or changing lifestyles may come only after many painful years of expensive, uneconomical energy utilization (83).

In order for an energy user to make any kind of choice about economic energy use, he must have complete and accurate information about the energy and life-cycle costs of alternatives. This information is difficult to find for homes, businesses, and many appliances, though labeling appliances and automobiles has begun to raise both energy consciousness and the level of available information (84). Industries that use large amounts of energy employ consultants (85) to measure and plan energy use, but small businessmen, homeowners and renters do not individually spend enough for energy to justify paying for energy consulting services.

Even with complete information, it may not be possible for energy users to respond to higher prices through improved efficiency. Howeowners may not be able to choose homes on the basis of energy fitness alone. If enough buyers reject a leaky, inefficient home, its price will fall, but eventually some buyer will occupy it. Some families move often and do not think about energy, but the house will remain for decades. Renters cannot always justify adding insulation to property they do not own, nor can they force their landlords to insulate buildings if the renters pay the utility bills. Often several residential units are metered collectively, especially to take advantage of reduced block utility rates, but consumers then lose the direct incentive to conserve as prices rise (86). The same

disadvantage hits small businessmen in large structures, where the utility bills are included in the rent. Industries hit by rising energy costs could pass those costs on, especially if competition is limited or if the energy costs are small compared to the total value added, as is often the case. Finally, when only a minority of consumers are willing to conserve energy, they may fall victim to the desires of the majority who want less efficient products (See 9); witness the complaints of consumers about the lack of small or efficient domestic cars to which the auto industry only now seems to be responding.

Similar incentive barriers exist for the production of energy-efficient equipment. Manufacturers have no incentive to produce only energy efficient autos or appliances if advertising, social pressure, consumer habits or marketing procedures (such as rebates) give apparent advantages to less efficient equipment (Fig. 19, Ref. 83). The consumer sees only the first cost, not the operation cost or life-cycle cost. Banks do not have to lend more money to make structures energy-tight, although utilities could refuse to provide service to new inefficient structures. Developers will not risk the extra cost of insulation and other energy-conservation measures if competitors can omit them, charge less, and obscure or cover up the differences with misleading advertising. Rauenhorst (84) pointed out that, as a developer, he would make energy-efficient structures at higher first cost than his competition, but he feared that the competition could outsell him on the basis of the attraction lower first cost to the buyer.

Even if energy users could respond directly to rising prices, there are distortions and imperfections in the prices themselves. While electric utility fuel and capital costs are rising, electric power is still sold on a declining block basis in most parts of the country (85,86). Heavy users pay a demand change and a total energy charge significantly lower than the energy unit charge to residential consumers. Extra charges for peak-period usage, when production is most expensive, do not yet exist in the U.S., even though the maintenance of a peak reserve capacity is expensive in terms of capital, and the peak-load equipment is usually less efficient than the base-load equipment. Ironically, even in 1974 many utility executives defended the status quo of electric utility prices while others argued that rate increases were necessary to pay for rises in capital and fuel costs (87). Although utility pricing practices seem certain for revisions, the whole procedure will take time. Meanwhile, users of electrical equipment will find it difficult to optimize, while today's rates still encourage greater use and tomorrow's rates are so uncertain.

An anomaly in natural gas distribution, the so-called "interruptable customer," also reduced incentives for conservation. In the 1950's and 1960's, gas pipeline capacity, rather than gas itself, was in short supply, so users who would agree to switch to alternate fuels or shut down were given a lower price. Now natural gas itself is in short supply (89), while alternatives are either environmentally unacceptable (coal, high sulfur oil) or expensive and themselves hard to get (low sulfur oil). Industries must now

scramble to adjust to higher prices or curtailment. No one has calculated how much more gas would still be available today if there had been conservation in the past, although fear of curtailment certainly stimulates conservation today.

Furthermore, the price of energy rarely reflects its full cost. Price controls keep energy prices below market prices, and sometimes below actual marginal costs. The depletion allowance on fuels passes some of the risk cost on to taxpayers and lower prices by allowing producers a substantial tax benefit, as do other pricing practices for petroleum (See 90). The high price of OPEC crude oil, propped up by the OPEC cartel, creates an artificially high price-of-substitute against which natural gas or domestically produced oil might rise (91). Government policy subsidizes housing, highway transit, and air travel, regulates natural gas in interstate commerce (but not intrastate natural gas, used in producing-state) and so on. The result, of course, is a price system wildly distorted from real costs (92).

Environmental costs are still excluded from market prices for energy, causing a further distortion of the market system (see 9 for a discussion of the economic aspects of pollution). Political battles take place in the U.S. Congress over a sulfur tax on coal, a reclamation tax on strip mining, the cost of using low sulfur-oil, lead-free gasoline, or smog devices on cars (93). The environmental risks of nuclear power, still hotly debated (94), have not been quantified to indicate whether nuclear power is presently under-priced, but the cost of safety is of increased concern to nuclear advocates (95) and regulators (96). One public utility regulator (96) in fact, recently questioned the power of the Nuclear Regulatory Council to halt operation of a plant in Vermont in order to check for possible pipe cracks. The public utility regulator complained that the cost of inspection amounted to $100,000 per day, which was the cost of fuel oil burned elsewhere to make up for the loss of the nuclear plant. He had clearly not yet decided what nuclear safety is worth. Similarly, the cost of risks of oil spills from off-shore drilling or oil shipping could be resisted by the very consumers and firms who benefit from the production and use of this oil. Internalizing the external costs of energy use will be a difficult political process, since politicians and consumers alike will be faced with charging themselves more for that which was apparently costless pollution.

One barrier to conservation faces consumers and all businesses alike, namely the need for capital to substitute better technology for inefficient energy use. Postponing present consumption to invest in future benefits is a formula for economic growth. Consumers will save and invest if the value of the discounted future benefits — saved energy, and more important, saved expenditures — is greater than the value of the foregone consumption. That the kinds of studies cited in this paper present convincing arguments that this investment is overwhelmingly justified provides no guarantee that consumers and producers will do it. As a Congressional Aide points out to the author, consumers who can least afford to waste energy can also least afford to raise capital, and businesses for whom competition dictates that cost-effective conservation is imperative usually operate on too low a profit margin to be able to assemble capital, while wealthy consumers and businesses with large profits from less competitive markets, all of whom could more easily afford conservation investments find less competitive pressure to do so. This "dismal theorem" about the response of energy users to the need to conserve deserves further study.

Adding to the frustration is the difficulty in finding rewards beyond direct cost savings for those who <u>do</u> conserve. Individual firms or consumers do not directly perceive the dollar value of the threat to national security allegedly posed by large oil imports; thus, they receive no direct compensation for acting to minimize that threat. They do not receive direct rewards for reducing externalities such as pollution. For example, suppose Mr. Green buys a smaller, less luxurious car than Mr. Brown, and Green further uses mass transit whenever possible. Green's actions mean less congestion, less pollution, and though the operation of the market, lower gasoline prices for both Green and Brown due to lowered energy demands. Green also contributes to Brown's security from oil embargos or curtailments. But, Green also foregoes the pleasure and status of cruising around in a large car, which judging from their numbers on our streets, must still be important to many owners. Green could be rewarded through governmental subsidy of the mass transit system, perhaps partially financed by taxation of the weight or horsepower of Brown's admitted gas guzzler.

In 1975 the majority of the American people did not believe that the energy crisis was real (97), while the Federal Energy

Administration found that voluntary compliance with suggested thermostat setbacks was the case in only 20% of the surveyed users (98), though in the Los Angeles area, direct threats of vastly increased utility bills, threats which were contained in a message from the Mayor, did bring shocking decreases in electricity use (99). If the public attitude remains one of "let the other guy conserve," even in the face of clear economic benefit to each consumer as well as to the nation as a whole, then the government may well be forced to opt for "mutual coercion, mutually agreed upon" (100) as a way of enforcing conservation. In France, according to NBC news (March, 1975) energy squads patrol Paris streets in search of lights and heat left on, overheated buildings, and car motors left running. Such activities recall wartime conditions when governments enforce efficiency in the interests of national security. I do not endorse such direct action, but believe that it should be studied (101).

Indeed, even if the average consumer was willing to alter his behavior in order to effect higher employment, lowered inflation, more national security, energy savings and other benefits, he will have difficulty perceiving the effects of his behavior. If consumers act in the desired fashion, the disadvantages of not conserving, both public and privately measured, will never be appreciated. For example, I have been confronted in many lectures by homeowners who cut back on heating and lights during times of rising utility rates. The homeowners insisted that they had been hoodwinked, because they were unable to compare their actual bills for a given month with the bills that would have resulted had they not conserved.

Of course, some utilities, notably Consolidated Edison of New York, found it necesary to increase rates in the short run because conservation caused under-utilization of present facilities. In this way conservation, while increasingly attractive from an economic standpoint, still faces informational and behavioral barriers, barriers which have only been considered briefly in the literature (102).

Perhaps the most difficult barrier to energy conservation is the doubt that energy needs to be conserved in the first place. The idea that man must eke the next unit of output from higher efficiency, rather than higher gross inputs, suggests a true confrontation with the finite world. As often noted, energy prices fell for many years, while the side effects of energy use, especially cheap energy use — pollution, urban sprawl, the decay of mass transportation, and the endless substitution of energy for other production factors — became a way of life (103). Now American society, and indeed the world, is faced with the prospect of intervening to use energy more efficiently, not because society has run out of energy, but because society is having difficulty even <u>running</u> at today's rate of consumption (104).

Consideration of the distribution of energy usage in the world (Ref. 32 Fig. 20) shows clearly that most of the world has not begun to realize the social benefits of energy use, while part of the world struggles with the side effects and economic dangers of too much <u>wasteful</u> energy use. The sales pitch for cheap nuclear fission, cheap fusion, or cheap solar energy, none of which in fact are cheap (105), delay individuals and institutions from making economic adjustments now for more efficient energy use. The hope for a cheap, quick "technical fix" obscures the possibility that nature has, in fact, imposed a kind of 55 MPH limit on our activity.

To some, the challenge for changes in energy utilization might be misinterpreted as some kind of planned threat to the American economic system, a challenge that some do not want to face. To me, however, the need for energy conservation must be interpreted as a fortunate signal indeed that while man's physical activities and uses of resources are rate-limited, both technical and social changes in structure and behavior or operation of systems are possible that will allow us to win more social benefit from fewer and harder to win resources.

The non-technical barriers to efficient energy utilization are many, and removing these barriers entails political action as well as a straightening out of the economic system in nearly every phase of social activity, because today all activity uses energy. Government, industry, and the people must decide how much regulation, how many kinds of efficiency or performance standards, what pricing policies, what kinds of taxation on energy use, or subsidies for more efficient energy utilization will be necessary (106, 107, 108). Government will have to arbitrate the claims of energy consumers and producers dealing with policy and price; scientists will have to demonstrate energy using systems, energy conservation ideas, and novel energy sources. Economists must analyze the dollar aspects of all energy ideas. Everywhere the role of physical science and measurement in shaping inputs to policy must be recognized.

SUMMARY

The role of energy in an economy can only be understood through consideration of both an economic description of energy inputs and outputs (using prices) as well as a physical analysis of details of the activities that actually use energy in the economy. Analysis of energy use leads to several definitions of energy efficiency, waste, and conservation, definitions that are sometimes, but not always, close to those of traditional economics.

Combined physical and economic analyses of energy used today shows a great potential for efficient energy use. Most energy conservation procedures are economic at 1975 energy prices, and affect structures and processes more than lifestyle, though lifestyle does affect energy use. While energy conservation will save energy and money, conservation practices tend to increase employment, to decrease pollution, and, by easing demands on dollar and energy capital required to make and operate energy producing facilities, it will slow the rise in the real cost of energy. Conservation faces, however, a full range of important non-technical problems, problems rooted in the history of energy utilization at low energy prices as well as barriers connected with defects in the pricing of energy, the control of the end use of energy, and the time necessary for society to adjust to rapidly rising energy costs.

A variety of social, political, economic, and technical changes are often suggested as remedies for today's energy indigestion. These include de-control of fuel prices, energy taxes, rationing or allocation, subsidies or low-interest loans for efficiency, bans on certain end uses or social activities, and educational programs designed to change people's attitudes. Energy policy that is designed to encourage efficient use of energy will probably have to incorporate many of these policy measures, using both traditional market tools and other means. Since energy costs average over 10% of the Gross National Product, any government program aimed at curbing the 1974-75 recession-inflation could well employ energy conservation in order to squeeze unproductive energy dollars back into the non-energy part of the economy. Even before considering the question of how much energy to import, one must confront energy conservation today: Inefficient energy use means inefficient (and costly) misfunctions in the American economy. Perhaps recognition of the influential role of energy waste in creating the 1974-75 economic quagmire, more than any other policy or revelation, will induce more efficient energy utilization.

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Process	Luri-Gas	Hygas	CSF-Coal Process	Coal-Methanol	Shale-Syncrude
% of Btu's recovered in desired form	56.2% Gas	59.7% Gas	33.2% Fuel Oil 21.5% Gas	39.6%	66.5%
Other byproducts by Btu content	15.3%	8.2%	12.2%	1.5%	7.4%
Total	71.5%	68%	67%	42%	73%

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FIGURE CAPTIONS

FIG. 1 Summary of some forecasts of energy use in barrels of oil per day equivalents (See Ref. 1 for sources).

FIG. 2 This ad appeared in national magazines in 1974.

FIG. 3 Pie chart showing U.S. energy use in 1972 (from Ref. 14).

FIG. 4 Energy flow chart, or "spaghetti bowl," due to E. Cook (16). Units are 10^{15} Btu/yr. and efficiency is First Law Efficiency

FIG. 5 Pie chart summarizing potential savings from conservation. (Gathered from Table 2 and Ref. 13.)

FIG. 6a Present worth of 1 kW savings in air conditioning (27).

FIG. 6b Comparison of heating costs: gas, electrical resistance, heat pump. While the costs are obsolete, they illustrate how changing prices shift the optimum toward some systems and away from others. (From Ref. 28)

FIG. 7 Energy use and the national income per capita displayed for some important industrial nations. Note how the U.S. and Canada have high use of energy per dollar (30,31).

FIG. 8 Comparison of thermal generation of electricity in Sweden and the U.S. (31).

FIG. 9 Historical variation of energy use per dollar of GNP(16).

FIG. 10 Historical changes in First Law efficiency (16).

FIG. 11 Optimal use of energy determines cost of a product or service. See Ref. 25 for further discussion.

FIG. 12a The Energy Gap. (Growth rates from Refs. 1-3 and 7.)

FIG. 12b The Energy Gap partly filled, partly dissolved by more efficient utilization. The point at which higher efficiency and increased supply meet is a function of energy price, technology, conservation options and policies. (Cf. Refs. 7, 25, or 26 and discussions therein.)

FIG. 13 Energy and labor intensities of some important goods and services in 1963. Vertical axis is 10^6 Btu/$, horizontal axis 10^5 jobs/$ (24,39).

FIG. 14 The cost of pollution control rises sharply with incremental gains in abatement (16).

FIG. 15 Energy use and "well-being." (From J. Holdren, private communication.)

FIG. 16 Comparison of some energy supply options (1) with the amount of savings possible in buildings in 1990. Conservation is a capital investment that substitutes for supply. (From Ref. 59)

FIG. 17 Rise in the cost of drilling oil and gas wells with increasing depth (16).

FIG. 18 Three predictions of electricity use growth, based in part on future prices (54).

FIG. 19 An ad for an air conditioner with low first cost, but higher operating cost due to low First Law efficiency. The Energy Efficiency Ratio is only 5.2. Is it really a bargain?

FIG. 20 Per capita energy consumption vs. cumulative fractional populations of the world's total population for various nations and regions.

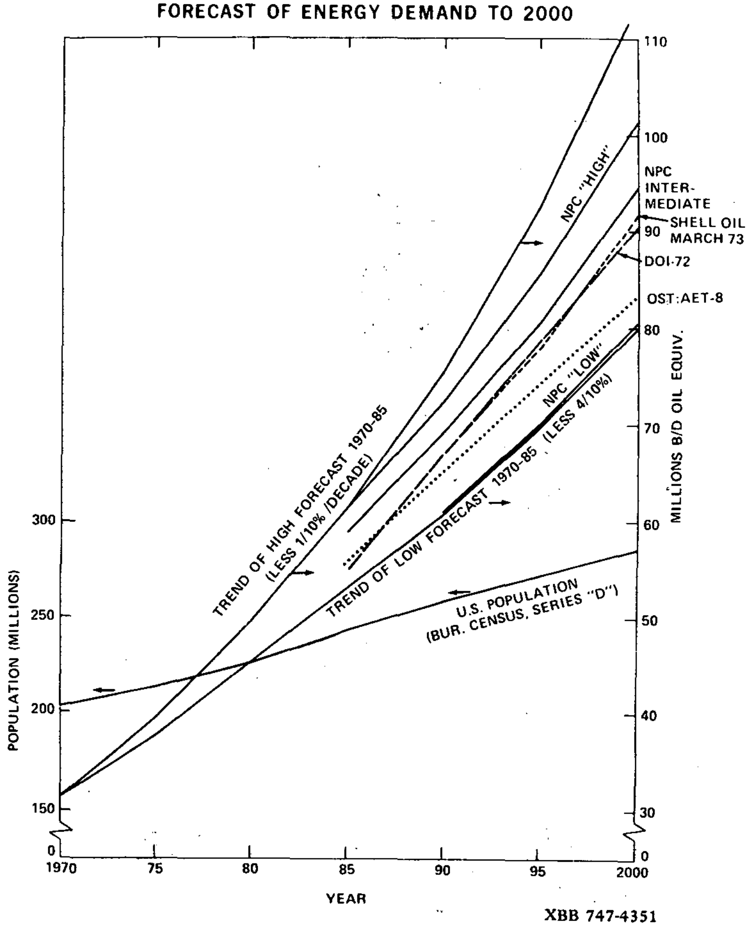
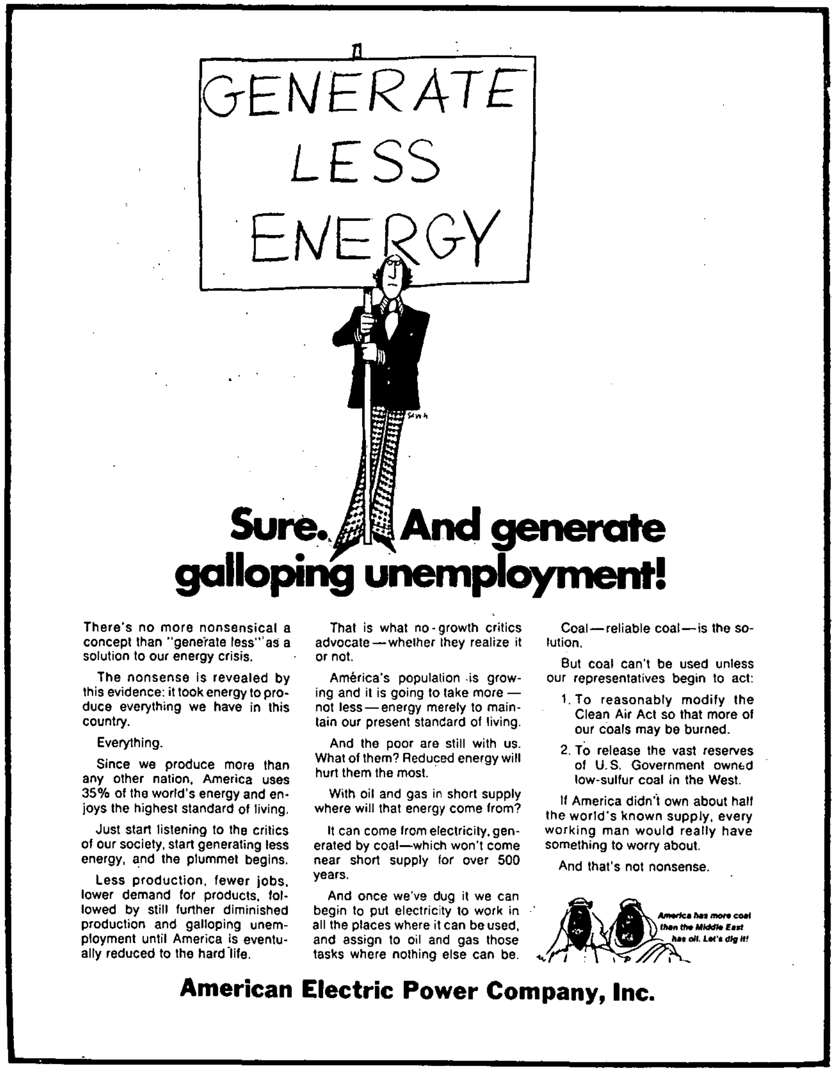


FIG. 1 Summary of some forecasts of energy use in barrels of oil per day equivalents (See Ref. 1 for sources).



Sure. And generate galloping unemployment!

There's no more nonsensical a concept than "generate less" as a solution to our energy crisis.

The nonsense is revealed by this evidence: it took energy to produce everything we have in this country.

Everything.

Since we produce more than any other nation, America uses 35% of the world's energy and enjoys the highest standard of living.

Just start listening to the critics of our society, start generating less energy, and the plummet begins.

Less production, fewer jobs, lower demand for products, followed by still further diminished production and galloping unemployment until America is eventually reduced to the hard life.

That is what no-growth critics advocate—whether they realize it or not.

América's population is growing and it is going to take more—not less—energy merely to maintain our present standard of living.

And the poor are still with us. What of them? Reduced energy will hurt them the most.

With oil and gas in short supply where will that energy come from?

It can come from electricity, generated by coal—which won't come near short supply for over 500 years.

And once we've dug it we can begin to put electricity to work in all the places where it can be used, and assign to oil and gas those tasks where nothing else can be.

Coal—reliable coal—is the solution.

But coal can't be used unless our representatives begin to act:

1. To reasonably modify the Clean Air Act so that more of our coals may be burned.
2. To release the vast reserves of U.S. Government owned low-sulfur coal in the West.

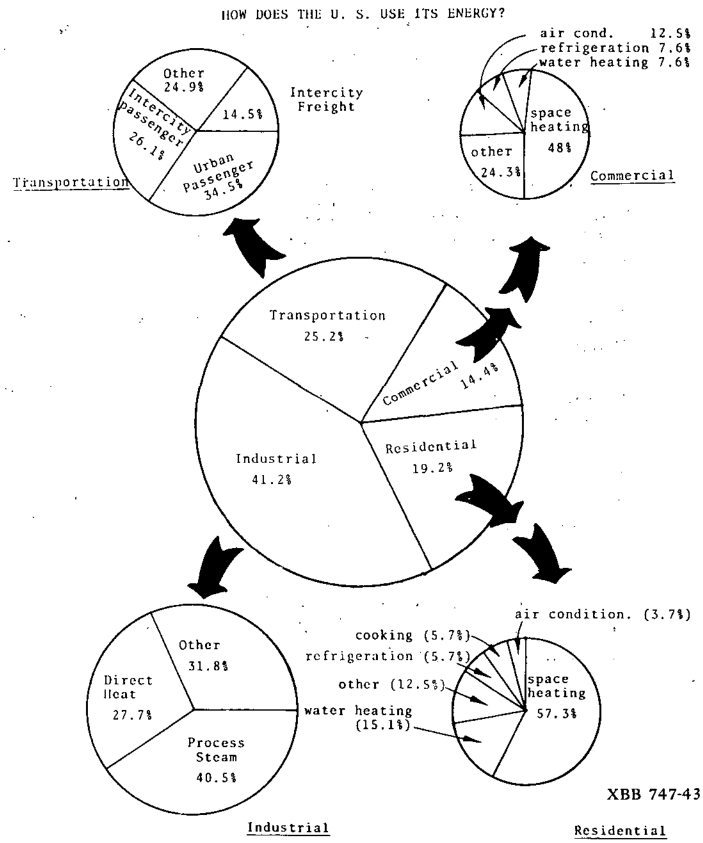
If America didn't own about half the world's known supply, every working man would really have something to worry about.

And that's not nonsense.

American Electric Power Company, Inc.

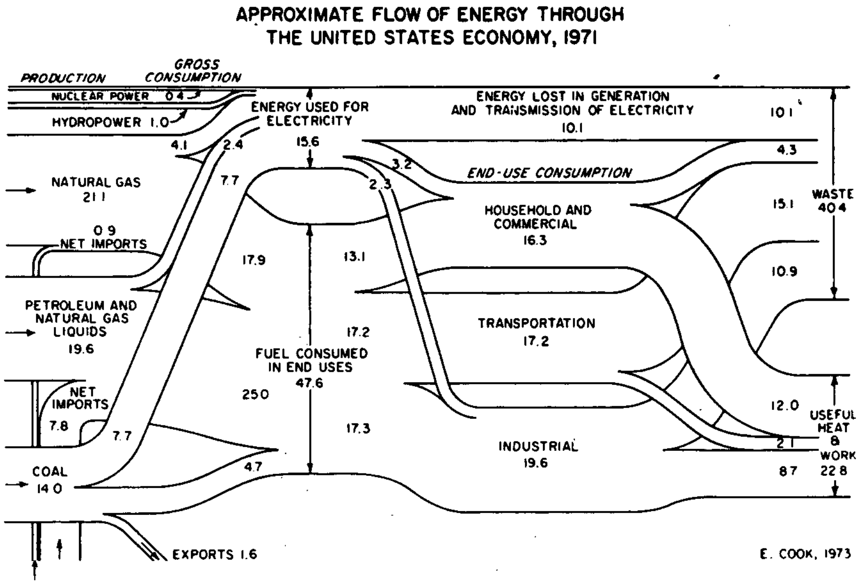
CBL 754-3205

FIG. 2 This ad appeared in national magazines in 1974.



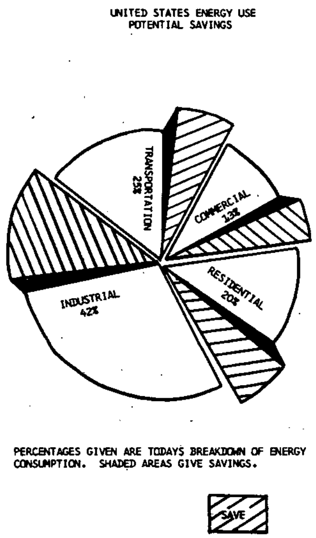
XBB 747-4355

FIG. 3 Pie chart showing U.S. energy use in 1972 (from Ref. 14).



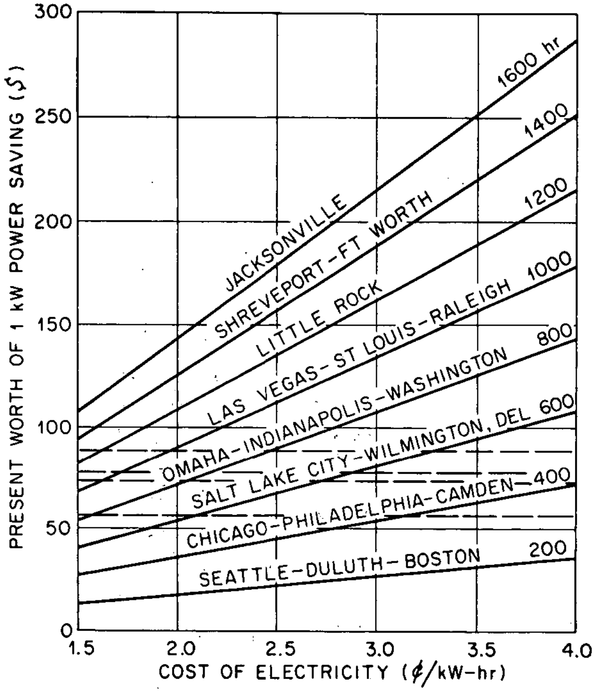
CBL 754-3152

FIG. 4 Energy flow chart, or "spaghetti bowl," due to E. Cook (16). Units are 10^{15} Btu/yr. and efficiency is First Law Efficiency



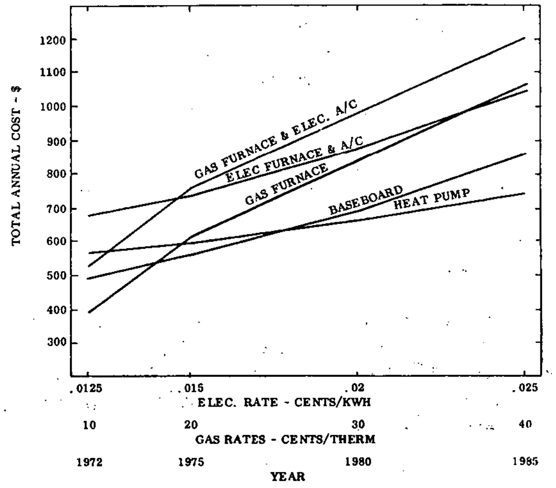
XBL 756-1653

FIG. 5 Pie chart summarizing potential savings from conservation. (Gathered from Table 2 and Ref. 13.)



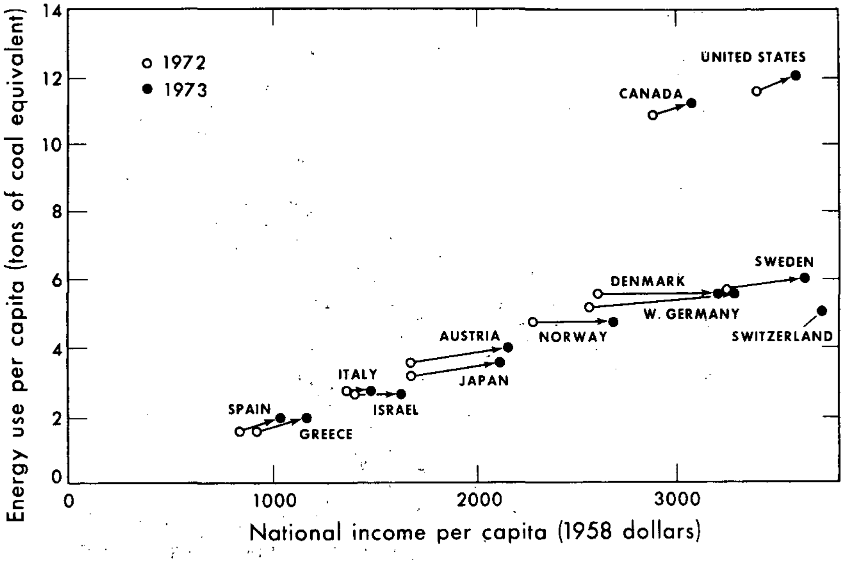
XBB 744-2407

FIG. 6a Present worth of 1 kW savings in air conditioning (27).



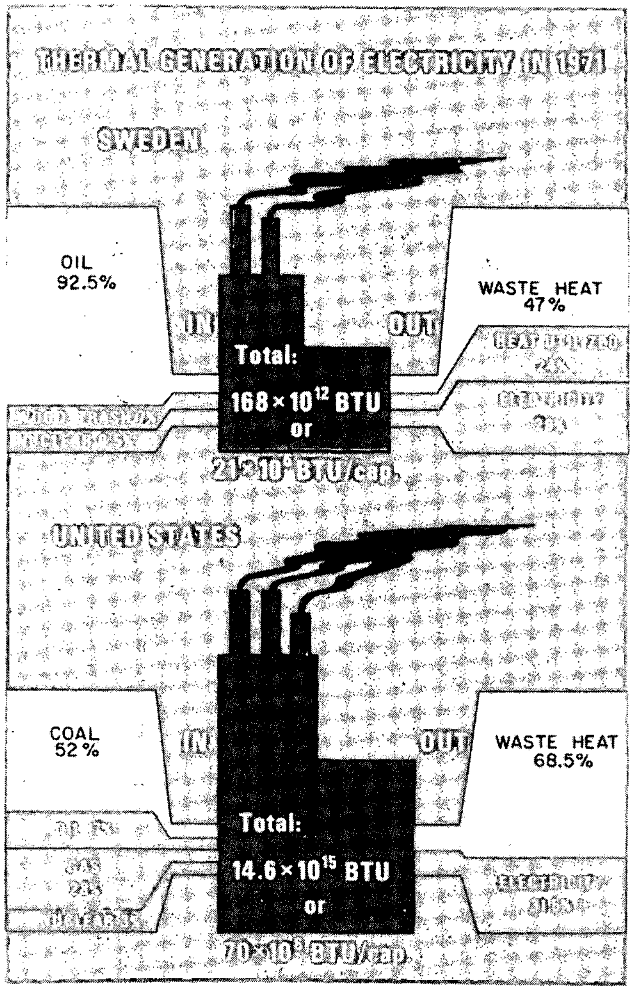
XBL 757-1757

FIG. 6b Comparison of heating costs: gas, electrical resistance, heat pump. While the costs are obsolete, they illustrate how changing prices shift the optimum toward some systems and away from others. (From Ref. 28)



XBL 759-4096

FIG. 7 Energy use and the national income per capita displayed for some important industrial nations. Note how the U.S. and Canada have high use of energy per dollar (30,31).



CBB 755-3827

FIG. 8 Comparison of thermal generation of electricity in Sweden and the U.S. (31).

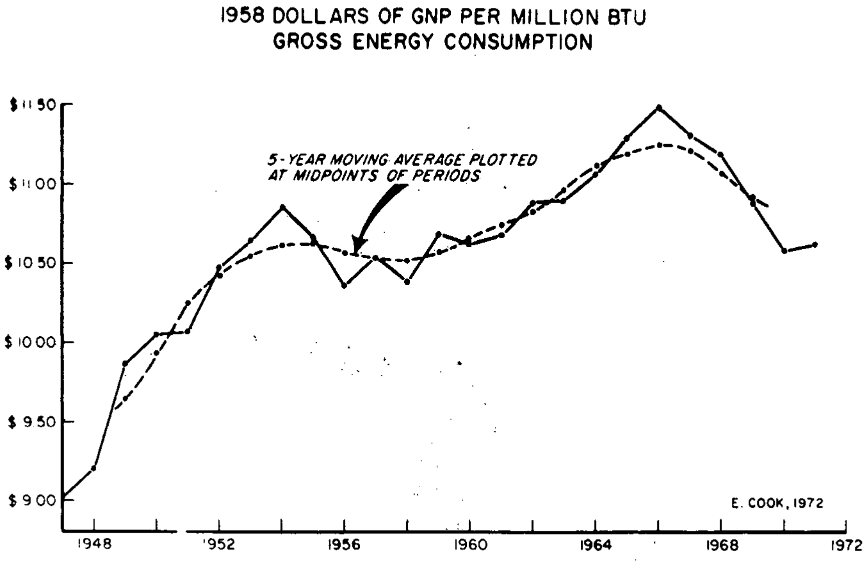


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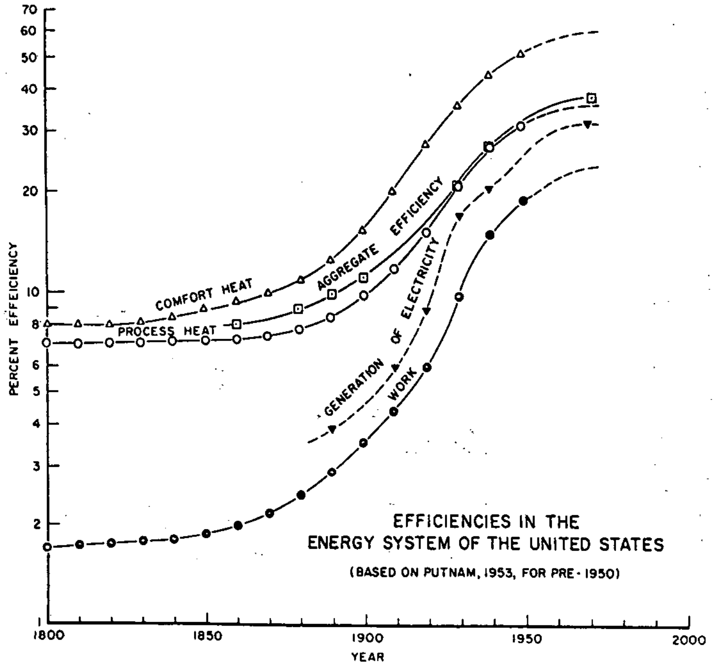
FIG. 9 Historical variation of energy use per dollar of GNP(16).



CBL 754-3163

FIG. 10 Historical changes in First Law efficiency (16).

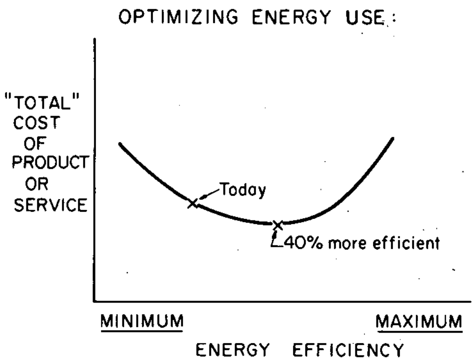


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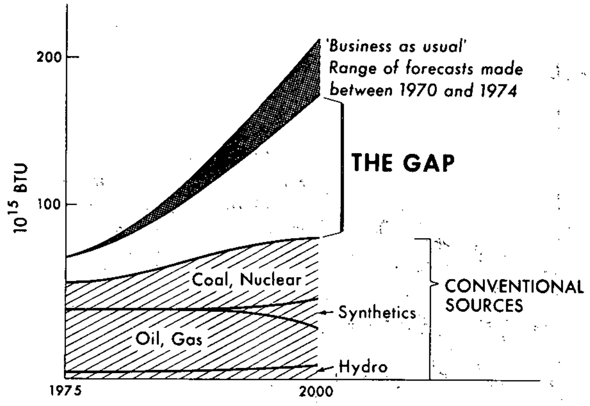
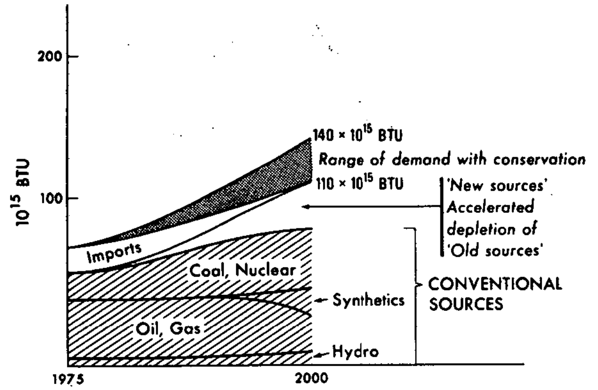
FIG. 11 Optimal use of energy determines cost of a product or service. See Ref. 25 for further discussion.



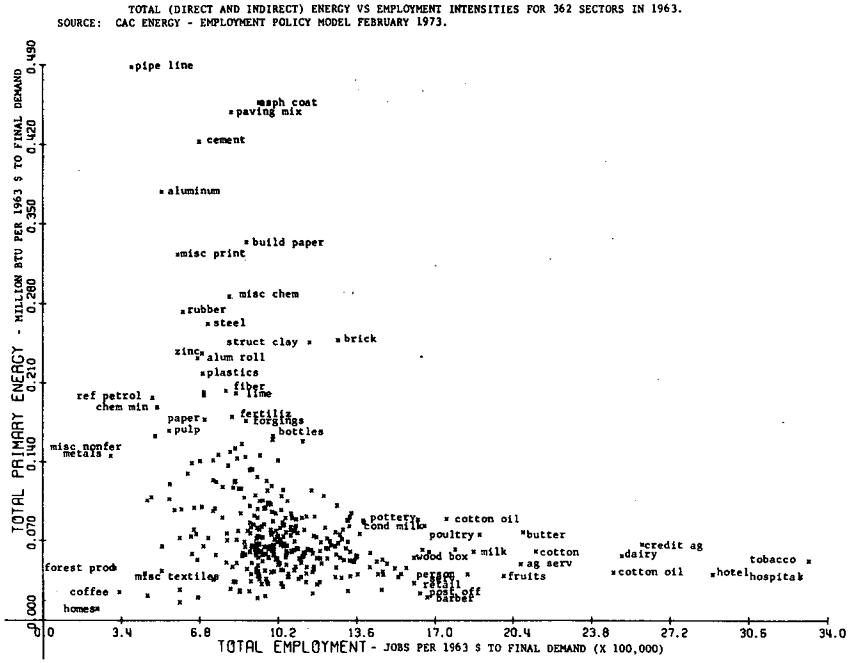
XBL 759-4093

FIG. 12a The Energy Gap. (Growth rates from Refs. 1-3 and 7.)



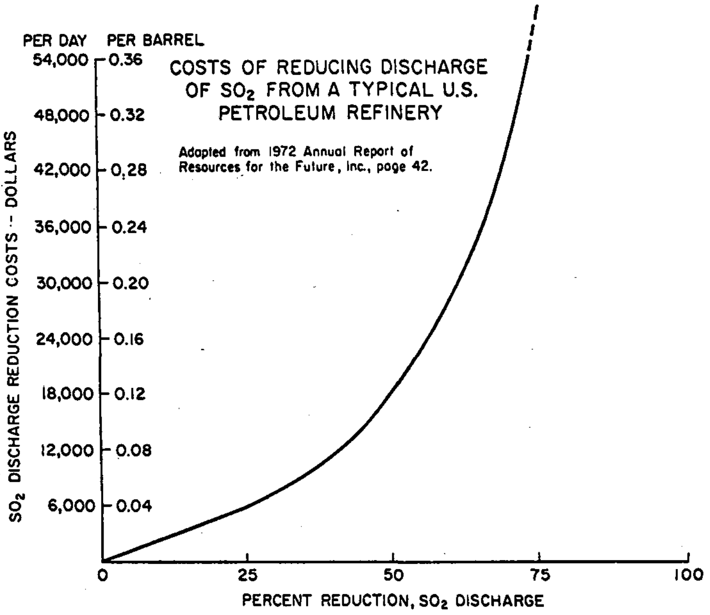
XBL 759-4092

FIG. 12b The Energy Gap partly filled, partly dissolved by more efficient utilization. The point at which higher efficiency and increased supply meet is a function of energy price, technology, conservation options and policies. (Cf. Refs. 7, 25, or 26 and discussions therein.)



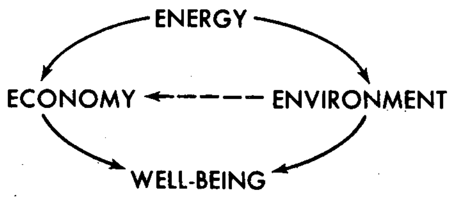
XBB 744-2413

FIG. 13 Energy and labor intensities of some important goods and services in 1963. Vertical axis is 10^6 Btu/\$, horizontal axis 10^5 jobs/\$ (24,39).



CBL 754-3164

FIG. 14 The cost of pollution control rises sharply with incremental gains in abatement (16).



XBL 759-4095

FIG. 15 Energy use and "well-being." (From J. Holdren, private communication.)

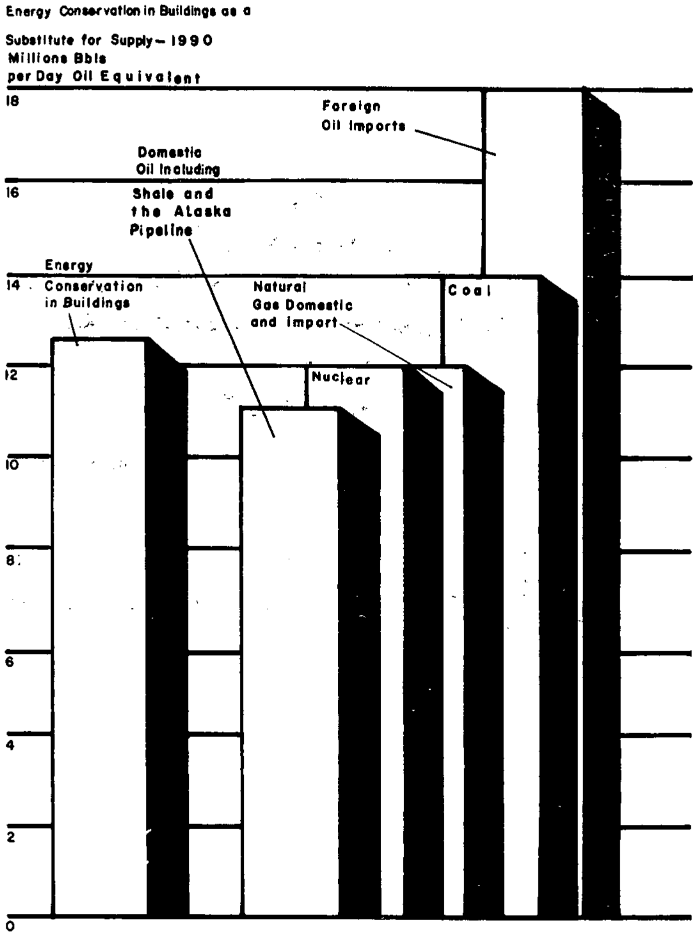


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FIG. 16 Comparison of some energy supply options (1) with the amount of savings possible in buildings in 1990. Conservation is a capital investment that substitutes for supply. (From Ref. 59)

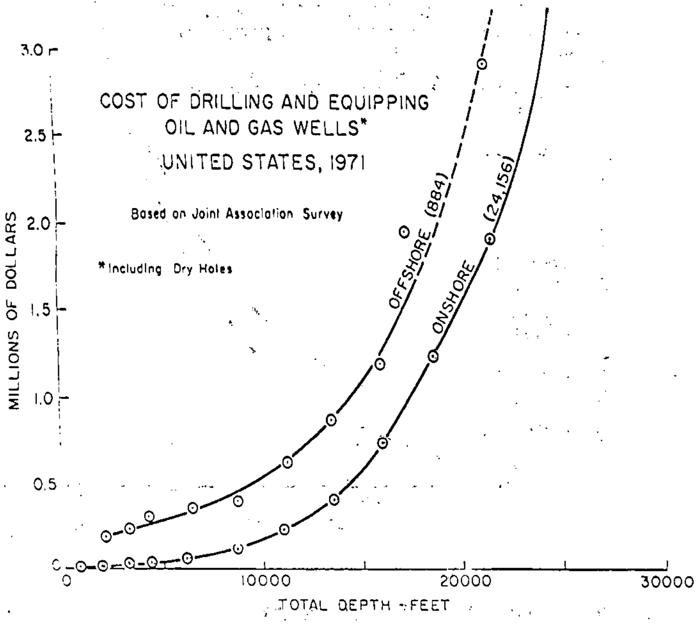

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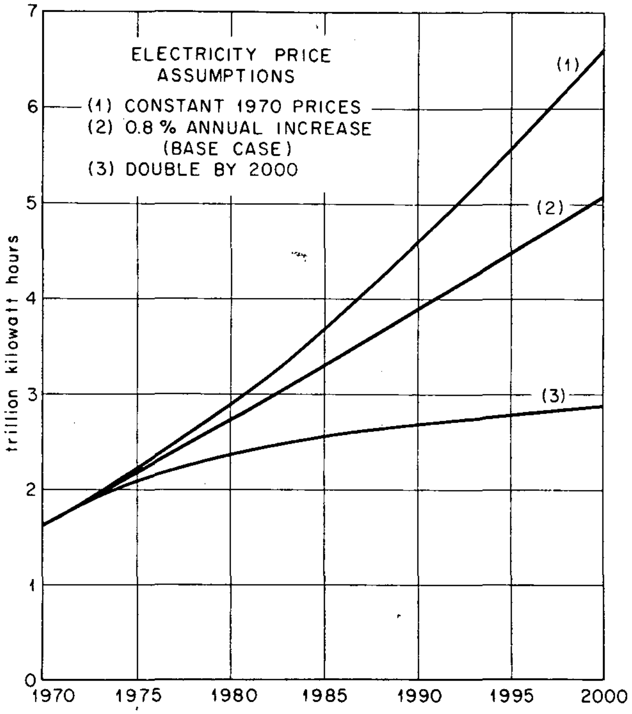
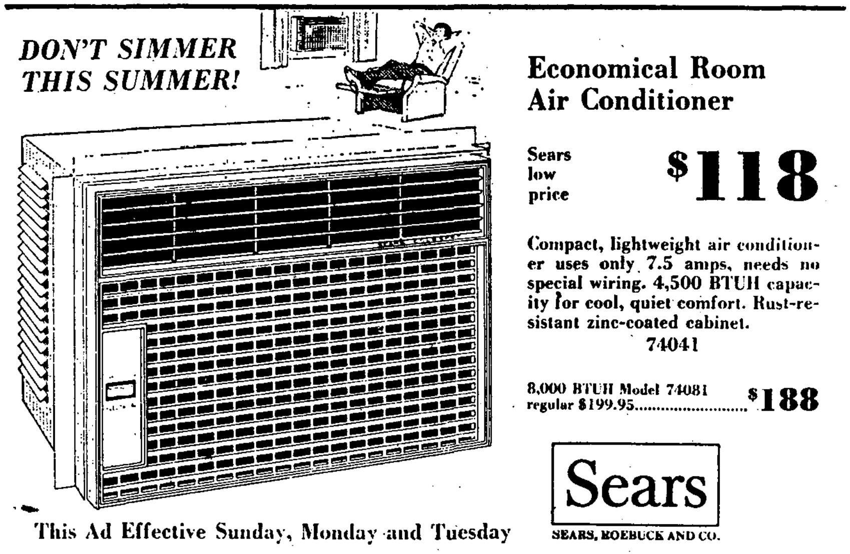
FIG. 17 Rise in the cost of drilling oil and gas wells with increasing depth (16).



XBC 742-692

FIG. 18 Three predictions of electricity use growth, based in part on future prices (54).



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Economical Room Air Conditioner

Sears low price **$118**

Compact, lightweight air conditioner uses only 7.5 amps, needs no special wiring. 4,500 BTUH capacity for cool, quiet comfort. Rust-resistant zinc-coated cabinet.
74041

8,000 BTUH Model 74081 regular $199.95........................ **$188**

Sears
SEARS, ROEBUCK AND CO.

This Ad Effective Sunday, Monday and Tuesday

XBL 757-1758

FIG. 19 An ad for an air conditioner with low first cost, but higher operating cost due to low First Law efficiency. The Energy Efficiency Ratio is only 5.2. Is it really a bargain?

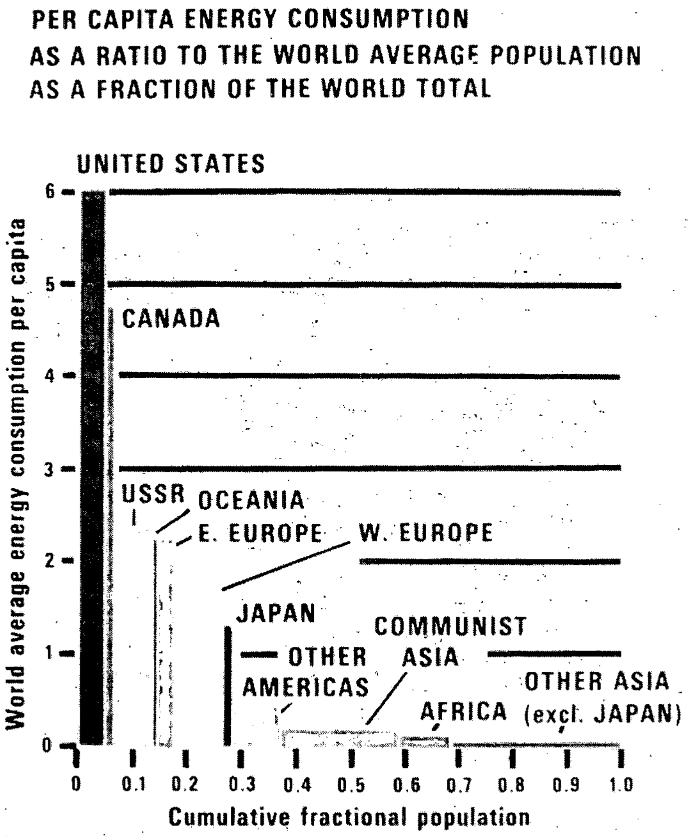

FIG. 20 Per capita energy consumption vs. cumulative fractional populations of the world's total population for various nations and regions.

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