Title

EXPLAINING ENERGY: A MANUAL OP NON-STYLE FOR THE ENERGY OUTSIDER WHO WANTS IN

Author
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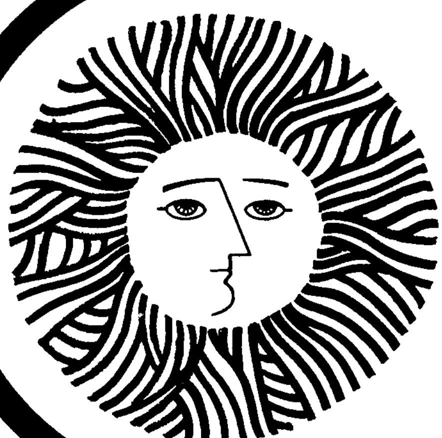
Publication Date
1976

LBL-4458 c.1
ERG 76-04



EXPLAINING ENERGY:
A Manual of Non-style for the Energy Outsider Who Wants In !

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California

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LBL-4458
UC-95a, TID-4500, R63
ERG 76-04

EXPLAINING ENERGY

A Manual of Non-style for the Energy Outsider Who Wants In!

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January 1976

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SPECIAL ACKNOWLEDGMENTS

I wish to thank the many colleagues and organizations who made available to me their drawings, illustrations, or slides which were "borrowed" for these notes. I apologize to those whom I did not contact regarding permission, especially my friends in other government "energy institutions." The owners of Figs. 31 and 123 never responded; in a few other cases I could not figure out whose figure I had come up with. Special thanks are due J. Holdren and the Sierra Club (Figs. 74 and 75), Mr. P. Ross (Westinghouse Corporation, Figs. 8, 9, and 73), Ms. Lois Walker (General Electric, Figs. 34 and 44), the Trustees of the M. C. Escher collection (Fig. 3), East-West Network (Fig. 4), Dr. Earl Cook (Hi, Earl!!) (Figs. 24, 33 and 88), Dr. W. Haefele and Science Magazine (Fig. 26), the Petroleum Industry Research Foundation (Fig. 10), Addison Wesley Company (Fig. 45), Dr. Bruce Hannon (Fig. 56), Pacific Gas and Electric (Figs. 71, 95 and 116), Dr. Maria Telkes (Fig. 90), Mr. R. Romanchek, Pennsylvania Power and Light (Figs. 91 and 92).

A special note of thanks is due the people who helped assemble this manuscript: Carol Putman of the Atomic Beam Group, Linda Elliott, Linda Marczak, Debbie Tyber and Mari Wilson of the Energy and Resources Group, Bob Barton of the LBL Technical Information Department who edited this revised version, and Marthamae Snyder who did the layout.

Lee Schipper
January 1976

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CONTENTS

Introduction 1

"Whatcha Got There?" 3
What is energy, why a "gap", efficiency

"How Much ya Got?" 13
How much is there, costs of development

"How Much D'ya Want for It?" 14
Supply and demand, environmental costs

Who Has All the Energy? 17
Resources, suppliers, conversion efficiencies

Want More? 21
Growth, projections, the energy cost of things, energy in the economy

Filling the Supply Pie Tomorrow 29
Sources and alternatives for future energy supply

Nuclear Fission 30

Nuclear Fusion 34

Fossil Fuels 35

Solar Energy 37

Geothermal Energy 39

Other "Non-scheduled" Energy Sources 40

Another Look at Energy Use: Conservation 40
Conservation as a "supply" of energy, "quality" of uses

Efficient Energy Pies 43
Comparison of conservation strategies, life styles

How Big Can the Pie Get? 48
Limits?

Footnotes 52

Bibliography 55

Addresses 72

INTRODUCTION

Recent events, dubbed the "energy crisis" have created a great demand for teaching and analysis of the world and American energy systems. Because for most of the public energy means gasoline and utility bills, which are but a small fraction of income, it came as no surprise that few had the opportunity, time, or motivation to examine or question the details of this system that is so fundamental to our existence. As controversial as the energy system has become, it also lends itself well to objective analysis, since much of the basic information is the concern of physical science. Yet in the wave of publicity following the oil embargo, little time or space in the media was devoted to explanation of the basics of the energy system; politicians daily advocated violation of fundamental physical laws, and the public remained confused. I was told by one television producer that the basic knowledge was too boring to be presented on the tube, because viewers would switch quickly to "I Love Lucy." Another news commentator cautioned me, "Pretend that you are speaking to eighth graders."

I have therefore felt a need to assemble a guide or outline of the most asked about, controversial, and basic characteristics of our energy system. In my judgment, the parameters of supply, demand, environmental impact, growth, conservation, future energy sources, research and development, and certain sociopolitical issues form the basis of all discussions of energy. I developed several programs from 30 minutes to three hours long in which I discuss these parameters, illustrating them with slides, exhibits and demonstrations. Audiences ranged from technical engineers to street people, from third graders to senior citizens. But the demand for explaining* energy has increased, and I sincerely hope that more qualified people in a variety of disciplines both in and out of the physical sciences will lend their time and effort to such programs. Hence this manual.

It is hoped that explainers and would-be explainers will use this manual not as an indisputable source of information, but rather as a guide to organizing materials and selecting topics. Some of the slides are shown here to stimulate interest in the often neglected art of graphic display. The captions attempt to suggest areas for discussions. Certainly for every slide shown,** 20 or 30 could be added, but those shown illustrate come of the energy facts least understood and most mistreated by the public.

Certainly, too, I have included my own judgment and values. These, of course, are always open to discussion, and the reader should always consider the variety of "positions" surrounding various issues, remembering at the same time that much of the input to the discussion of energy policy is nevertheless quantifiable or measurable.

But even objective numbers can be misleading. Industrial energy consumption, for example, is often quoted as being 32%, 42%, or 75% of the national total. All three numbers are correct, because the first does not include fuel for generation of electricity while the third includes commercial use of energy and industrial transportation energy as well as all fuel consumed in generation of electricity. Hence, the warning that explainers must take pains to define their numbers and illustrate their derivations. On the other hand, I can honestly say that there is a saturation point beyond which even the most technically-minded audiences will not absorb numbers. An out, however, involves either comparing numbers in the same units, or illustrating numbers with objects. Honeywell Corporation, for example, illustrates graphs of energy usage/shortages with oil barrels such that the numbers can be safely ignored, but the relative quantities are clear.

Finally, readers/explainers should familiarize themselves with a wide variety of literature. A small sampling is given here in the bibliography, and nearly every work cited contains itself a useful reading list. Included in the list are certain institutional sources for information which are particularly helpful and, in some cases, downright generous when it comes to providing materials. I have prefaced with "M" those references which are musts.

Many of the slides shown were designed by me and drawn by Bob Stevens of Lawrence Berkeley Laboratory Graphics for use in programs at LBL and in the surrounding community. A typical "energy" show might contain anywhere from 30 to 150 slides, depending on the audience and time allotted. Discussion is desirable, again subject to time limitations. People want and need to get puzzling questions off their minds. In general, audiences are amazed and confused by the large doses of information they face, but at the same time they are inspired, perhaps at last, in knowing that so much is knowable.

Readers should note the plethora of material available at little or no cost from Congressional committees, government bureaus, the Government Printing Office, industry and lobby groups, environmental organizations, and, of course, research institutions. Government Hearing pamphlets often reprint entire issues of magazines or collections of research papers, some of which are otherwise unobtainable. Committees of Congress maintain calendars from which alert readers can spot energy-related hearings. The committees, as well as local Congressmen, are usually glad to send out the printed materials.

Of course, all material should be carefully scrutinized, especially as to assumptions and sources, expressed or implied. For example, many projections of energy use in the future, including those most often cited, state expressly that they represent only a continuation of present trends, with no account of changing economic conditions, efficiencies, technologies, environmental conditions or human values. Yet, such projections often appear as hardened predictions of what must happen in the future. By the same token, the notion of energy options, i.e., that there may be several

*Explainers are teachers, lecturers, organizers, seminar givers, journalists, writers, media producers. They are not limited to physical scientists. In fact, the dissemination of information beyond "energy people" is the object of this paper.

**A catalog of 1500 slides is in preparation.

energy futures from which we can choose, is gaining acceptance as each future is closely scrutinized to see if it represents a world that is physically, as well as socially, possible. Particularly difficult to treat, however, is the notion "causes of the energy crisis" which depends a great deal on political judgment as well as fact. I prefer to develop programs which expose the energy system in a way not dependent on fixing the blame for the current situation, in a way which does not depend on the "fact or myth" dichotomy often cited during the recent problem with oil.

I have also made ample use of other aids, machines, and various kinds of electric generators which can be operated by the audience, including a bicycle generator. In addition, I obtained, rather easily, samples of crude oil, coal, shale oil, and, with permission from Lawrence Lab Health and Safety staff, I was able to use a pound of pure Uranium (natural abundance) and a small amount of Cesium-137. While the latter two items are not recommended, the former should be considered musts and many fuel suppliers can help with oil and coal (see Figs. 37 and 71).

The most exciting tool developed so far is the "Energy Environment Simulator" made available to me by the Energy Research and Development Commission and Oak Ridge Associated Universities (Figs. 1 and 2). This simulator is an analog device which graphically keeps track of energy sources, rates of use, the various end uses of energy, environmental problems, resource exhaustion, and population growth, in a simplified model in which time ticks off at the rate of a century a minute. Everything in the machine is controlled by the audience except total amounts of fuels originally available, although that can be changed with a little effort. The goal of playing the game is to compare various energy future options, both in supply and demand. A careful lecturer can pinpoint the meaning of twisting any dial, so the game is very realistic. Satelite controls allow several groups to compete or cooperate. The machine illustrates the multidimensional nature of the energy system, and a recent group of public health officials who tried it gave the simulator good reviews in surveys which they filled out. Most participants relax their older attitudes while playing, creating a dialogue with the audience hard to match elsewhere. Interested explainers or potential audiences can contact ERDA for more information.

During the anticipated national debate on energy issues there will undoubtedly be a cry for citizen participation in the decision-making processes. The people who will take part, as well as those who may only watch from the sidelines, will be asking for information so that they can act as informed participants. The material in Explaining Energy is intended to guide those who will be acting as informers and teachers giving "first courses in energy" to find quickly the literature and methods of energy. Journalists, writers, and political observers may also find it helpful to review Explaining Energy. With these thoughts in mind, the reader is invited to go further and develop his own program to "explain energy."

Fig. 1. The author with the Energy Environment Simulator developed by ERDA and the Oakridge Associated Universities. (XBB 744-2283)

Fig. 2. Panel of the Energy Environment Simulator. (CBB 746-4107)

I wish to acknowledge the help of many people in preparation of this guide: Drs. John Holdren, Gene Rochlin, Mel Simmons, Carl Shinners, and Howard Shugart for their suggestions and help in preparing the manuscript; and the many government, industry, research, and environmental contacts that have helped me obtain information and visual materials. Finally, special thanks to Drs. Larry Akers and John Yegge and the staff of Oak Ridge Associated Universities, and many people at various branches of ERDA, all of whom got me mixed up in this in the first place!

I have listed the addresses of many helpful organizations in the back of the bibliography.

"WHATCHA GOT THERE?"

This picture, first published by United Airlines "Mainliner Magazine" in an article on energy use, illustrates what many feel was the national energy posture for many years. Energy companies worried about what the glutton ate, environmental groups were equally concerned with what came out the other end! With the oil embargo and apparent shortfalls in oil supply the rest of the public took note. We would like to develop some of the basic information and issues about the energy system here, independent of the speculation of whether the recent oil crisis was "real or contrived." The subject is multidisciplinary, hence nearly every listener will come face to face with the new terms and concepts that are illustrated here.

Figure 4 shows an energy system that is indeed complicated. It is often hard for people to understand the difference between stored-up energy (as resources, reserves, or stocks of fuels) and power, or the rate of energy conversion, a function of demand, conversion capacity, and fuel availability. Since we have not yet exhausted all fuel resources, most believe the current difficulties are due to a variety of problems concerned with the rate of flow or conversion of energy, and the economic, political and environmental problems associated with these flows. Any gap between supply and demand results in some kind of energy crisis, even if the "causes" are human!

Note, too, that solar energy is directly or indirectly the source of nearly all the fuel and

Fig. 3. An energy glutton! (Reprinted by courtesy of Mainliner Magazine, as carried aboard United Airlines, copyright East/West Network, Inc.)
(XBB 744-2709)

energy used today. Nuclear energy appears stored as heavy elements (fission) and in light elements (fusion) found in the earth's crust and oceans, and nuclear energy also accounts for geothermal heat. Note well that energy is used to recover and produce energy, a point often overlooked, and that energy is used in copious amounts to prepare a form of energy called food; as much as 6 to 10 times more energy to produce, process, and prepare food than is contained in the total ultimately consumed(11). Notice that the diagram does not stress the transportation of energy, except for imports as shown. Note too, the important fact that ALL POWER ENERGY POLLUTES, and that all energy use adds to the rate of heat formation at the surface of the earth, except for hydropower and some forms of solar energy that redistribute that heat.

An energy gap (Fig. 5) arises when the flows in any part of the diagram get out of balance; when "demand" exceeds "supply", or when the rate of supply is limited by pollution or capacity to process energy. Note that these two concepts refer to rates of use or conversion. Reasons for this "power gap" are many and they are always debatable (Fig. 6).

It is important, however, to consider two dilemmas which are hard to evaluate. One, illustrated by Fig. 8, is that the United States uses fastest those fuels generally recognized to be in shortest total supply. The other is the problem of importing fuels. The cost of imports (Fig. 9, figures are pre-embargo) is higher per barrel (mid 1975) than that of domestically produced oil because of the actions of the Organization of Petroleum Exporting Countries' cartel. This price is several times the real cost of production, and the effect of oil imports on the U. S. balance of payment is worrisome. Equally important is the possibility that some or all of these imports may be cut off for political or economic reasons. For sudden curtailment of energy supply is a different matter than use-conservation. Thus even when foreign oil is freely flowing perceptions of national security lead some to desire to reduce imports by law, or by substitution of domestically produced fuels. These aspects of the "energy crisis" are visible in the higher price of energy and while many argue (28) that world oil prices will fall, it is reasonable to deem the combination of problem with the environment, the rate of supply, imports, the effect of sudden price increases, and the uncertain prospects for future supplies a "crisis".

How the "gap" is closed is the domain of the subject of energy policy, and that involves government and industry policy, tax policy, luck, international politics, the weather, and so on. Leaving many of these topics dangling for the time being, we would like to look at the physical characteristics of the energy system, ones which, to a large degree, exist regardless of the decisions made under the rubric of "energy policy".

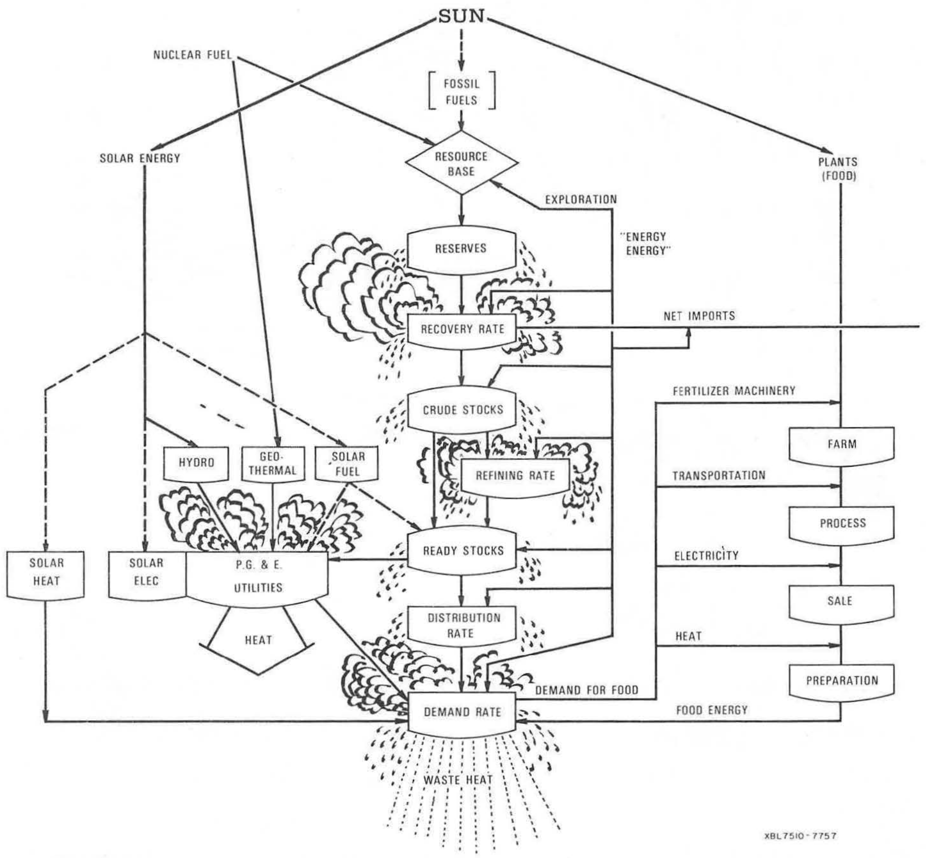
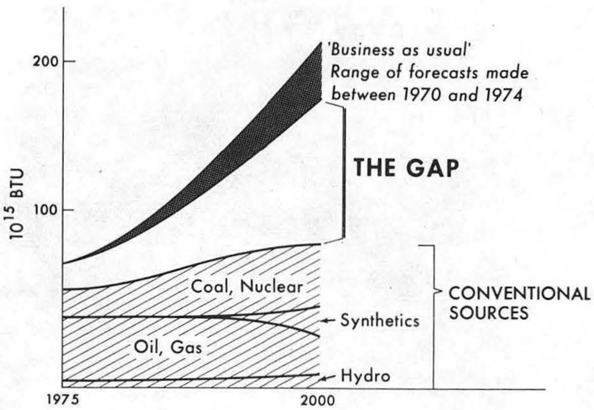


Fig. 4. The flows and stocks of the energy system.



XBL 759-4093

Fig. 5. The energy gap.

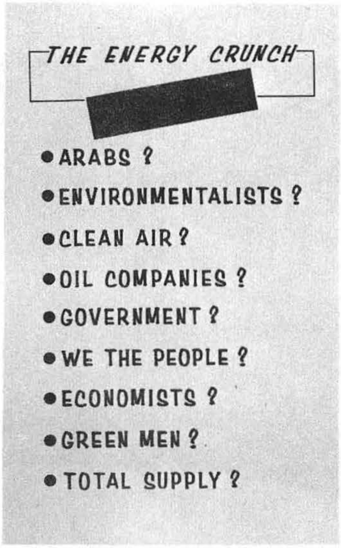


Fig. 6. Some possible causes of the energy crisis.
(XBL 742-764)

Fig. 7. Is the energy crisis more than gas station lines like this one in Berkeley in February 1974? See Note 2 for a simple explanation of gas lines. (BBC 747-4887)

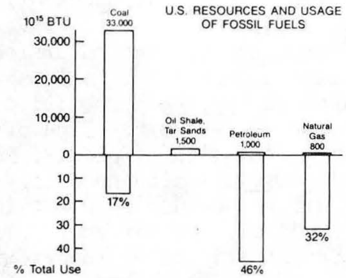


Fig. 8. U.S. resources (upper) and usage (lower) of fossil fuels. We are using what we have the least of the fastest(!) (From Ref. 567).

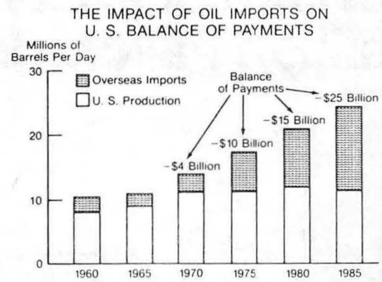


Fig. 9. The impact of oil imports on U.S. balance of payments: energy imports are causing increasing deficits in balance of payments (From Ref. 567).

One widely held misconception is that energy in the pipeline (that is, energy in the system which is between "reserves" and final demand) is an indication of overabundance in the system. Many uninformed critics of the recent oil shortage pointed to the large amount of fuel "in the pipeline" as evidence that there was no real shortage. Figure 10 suggests one partial accounting for 1973. While there were probably many irregularities we should note that when the flow into the pipeline is less than the flow out (demand) then one can draw on stocks, which are counted as being in the pipeline, or reduce demand, or increase the rate of supply, or perform some combination of all three. Typically the oil pipeline in the USA contains about 45 days' supply of various forms of oil, refined and crude. Policymakers must decide how much of this to draw on, and how much to reduce demand or increase supply, but one must very carefully account for all stocks and flows before making conclusions about the "reality" of a crisis (28,114,115).

Energy is the capacity to do work, lift things, or transform substances or environments. Power is the rate of using energy, (Fig.11). It is important to understand the kinds of energy: energy of motion, or mechanical energy (Fig.12b), also called kinetic energy, is a familiar "active" form. Heat (Figs. 12c, 13) is a form of motion, the more or less random motion of particles or molecules of a liquid or a gas or vibrations of molecules in a solid. Temperature measures the concentration of heat energy per particle. More important are stored up forms of energy, or potential energy. Since any book can fall and gain speed from gravity, we speak of gravitational energy as a form of stored energy. The fool in Fig. 12a is experiencing the conversion of gravitational to kinetic energy as he falls. Electrical energy, mechanical energy, both special cases of electromagnetic energy is another kind of energy, and light is a manifestation of electro-magnetic energy, chemical energy, including energy stored in fuels, actually arises because of electric forces between atoms. Similarly nuclear energy is stored in the forces among particles of the atomic nucleus itself. Chemical and nuclear reactions are usually used to convert these energies to heat.

Fig. 10. Some of what Exxon wants you to know is worth knowing! (CBL-747-4883)

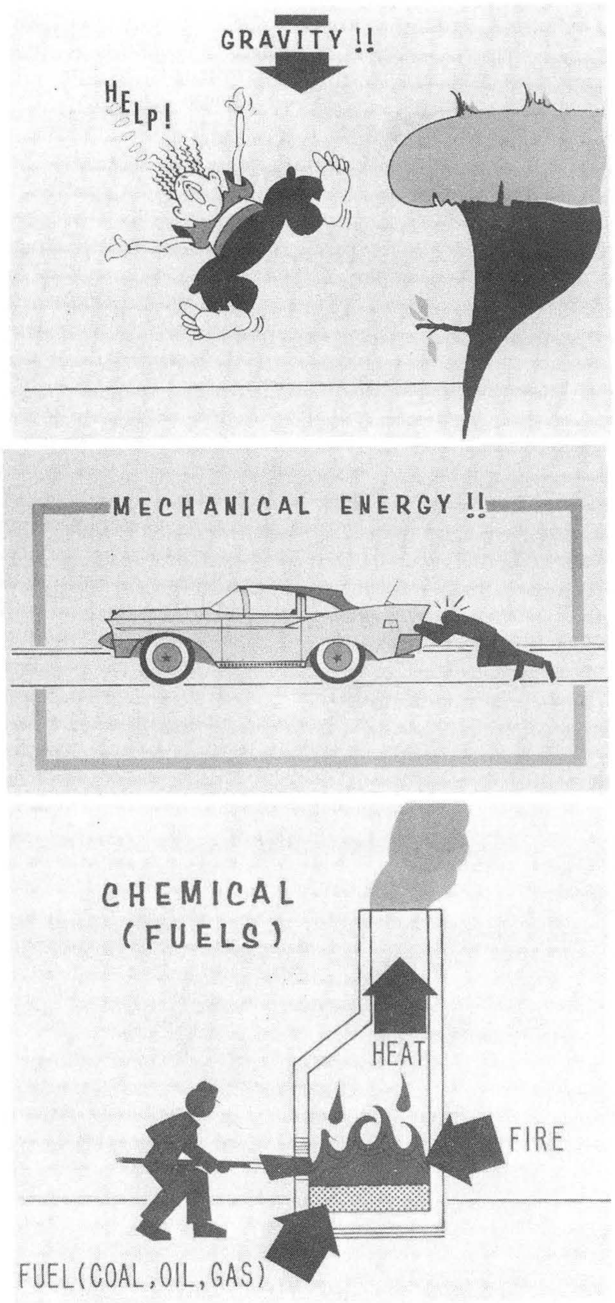


Fig. 12. Three kinds of energy illustrated. (See Refs. 9, 11, or 12 for more on these basics.) (XBL 742-726, -699, -730)

ENERGY, WORK, AND POWER

ENERGY is stored work.

WORK is the exertion of force through a distance.

POWER is the rate at which work is done.

Fig. 11. Definitions of energy, work and power. (XBB 747-4331)

HEAT

1. RANDOM MOTION, VIBRATION OF MOLECULES, ATOMS
2. MOST DILUTE FORM OF ENERGY
3. "FLOWS" FROM "HOT" TO "COLD"
4. TEMPERATURE MEASURES CONCENTRATION OR QUALITY
   "HOT" – CONCENTRATED
   "COLD"– LESS CONCENTRATED
5. THE ULTIMATE WASTE: YOU CAN'T "GET RID OF HEAT"

Fig. 13. Heat has important properties. No technology past, present or future will get rid of heat. And the earth can only radiate it into space at a finite rate. (XBB 745-3346)

The laws of energy are conveniently summarized in Fig. 14 (5,6,9,-12). It is important to know what energy can and cannot do (Fig.15). Readers will recognize the first and second laws of thermodynamics, as well as a general principal stating that "no exceptions will be made". It is important to define these laws carefully, since many people expect unscientific miracles from technology or ask that political decisions overrule fundamental principles. The "free lunch" rule (Fig. 16) is illustrated with a typical energy bill of the early '70's showing about what we paid for the amounts shown. Since most audiences are unfamiliar with energy units or prices, explainers should give some easy examples in heat terms, in terms of quantities of fuel, and in terms of tasks which can be done (like bathtubs of hot water) see Table 1. That a "cheap lunch" (Fig.17) leads to problems, especially environmental problems, is agreed upon by nearly everyone, though debate ranges as to the worst problems (Fig.18). In addition, few can agree on who should pay for what and how much. The difficulty in including environmental costs, such as pollution, in the price of energy is receiving careful study, too, and is an interesting issue (154,801,802,804,822).

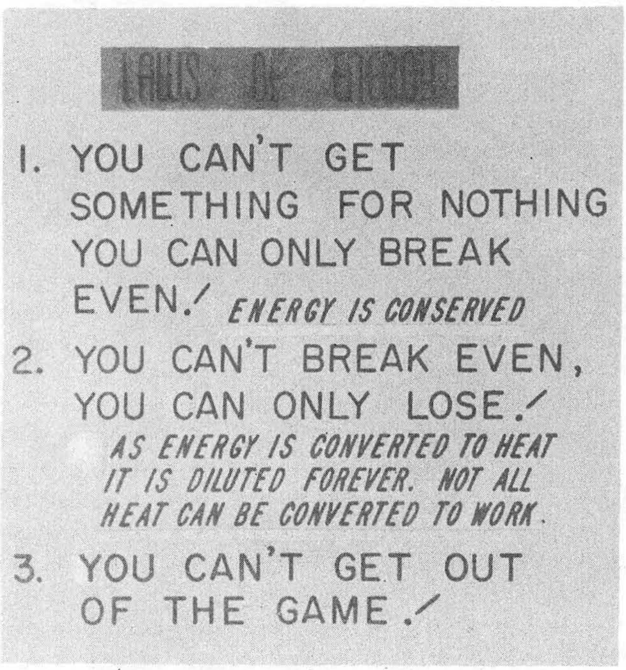


Fig. 14. The Laws of Energy (paraphrased). (XBL 742-683)

Auto manufacturers have recently been advertising (and in some cases labeling) the gas consumption of their cars, though often the claims have bordered on the absurd: "Thrifty Eight Cylinder," "Gas Stingy Six Cylinder," "We drove 100 miles on only a quarter tank in our (large car)." In the latter ad the sponsors neglected to remind the listener that this car had a 27 gallon tank; no mention was made of the cost of filling the tank. The point here is that energy consumption can be described subjectively--"stingy," "thirsty," and so forth, with no references to actual numbers or standards. But alert teachers will point out that energy comsumption can, and should, be quantified and further translated into easily understood units mentioned above (see note 4).

Confusing to some are the problems in translating the various sizes (or scale) of energy units and power rates. Energy can be measured in abstract units, like British Thermal Units (Btu), one of which heats 1 pound of water 1 degree Fahrenheit, in gallons of gasoline (which are defined to contain certain number of Btu's), or in units of output, such as "heat for ____ homes," "gasoline enough to drive a Volkswagen three times from Paducha to Iowa Falls," and so forth. Power is usually measured in watts (kilo-, mega-, giga-, or even tera-, referring to 1,000, 1,000,000 and so on) or in units of fuel used/time taken, such as barrels of oil/day. An interesting statistic usually overlooked by even those familiar with energy is the measurement that per capita power use (all forms) in the USA amounts to about 12,000 watts. Most listeners immediately shout out "watts per second, or year?" But watt, being a rate (1 joule/sec) includes the time already! (See Table 1.)

Figure 19, from Honeywell Corporation, emphasizes the difference between kilowatts, or thousands of watts, a rate of flow of energy, and kilowatt hours, the total amount of energy transferred. A kilowatt hour is any combination of (kilowatts) × (hours) which gives 1. Though kilowatt hours are used most commonly with electricity, they have equivalents in other units, reminding us that energy is convertible from one form to another. Table 1 summarizes the various energy units, as well as some useful energy equivalents that can be effectively compared.

The calls for energy conservation have increased public interest in energy bookkeeping: "How much energy does it take to . . .?" I usually use the example of the lights at the Riverfront Stadium in Cincinnati as a good illustration of some of the pitfalls. These lights consume electricity at the rate of one megawatt (1000 kW). But the local power company must burn fuel at the rate of about 3 MW to produce this electricity.[5] Keep this up for four hours, you have a lot of energy, right? This was pointed out by many energy savers during the Winter 1974 Crunch, but they may have cried "wolf" too soon. First of all, the amount of energy consumed at the ball park is no larger than that which the fans (say there were 40,000) would consume at home and probably quite a bit less.* But, suppose that the fans journeyed to the game in 10,000 autos, making average trips of 5 miles each way at the average 15 miles/gallon. We can summarize the results:

(4 hrs) × (3000 kW) = 12,000 kWh
(10,000 autos) × (2/3 gallon)* = 6666 gallons
* round trip of 10 miles = 2/3 gallon per car

Since one gallon of gasoline equals approximately 36 kWh, we see that the cars consumed nearly 20 times more total energy than the lights. Most audiences, of course, are shocked and stunned. Such is the power of Energy Bookkeeping. (See Note 1 for another example.)

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* For example, 40,000 people watching 20,000 TV's @ 100 watts consume electricity at the rate of 2 MW.

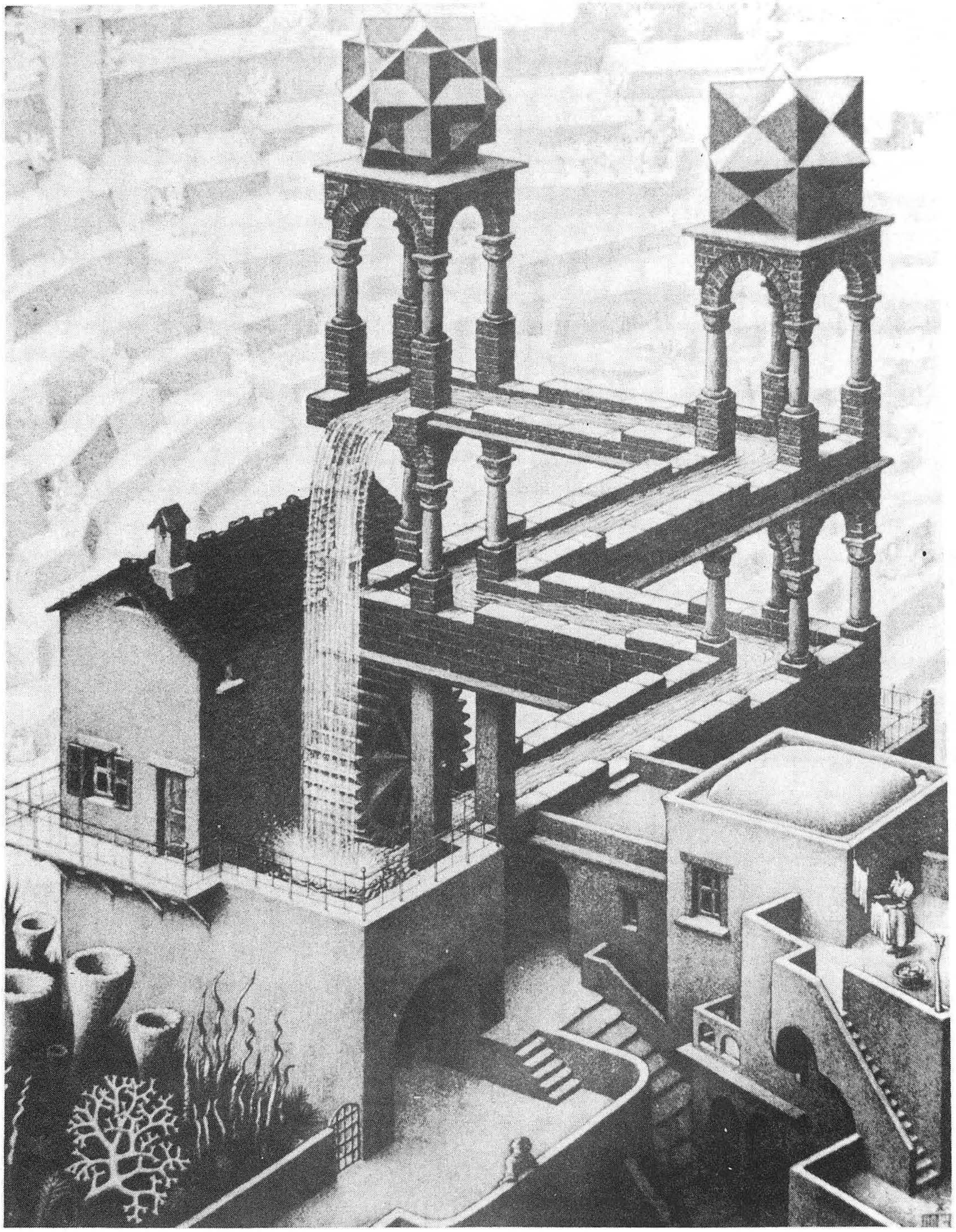


Fig. 15. What is wrong with this picture? A perpetual motion machine such as this is often implied in many uninformed statements about solutions to the energy crisis, but no solution can violate the fundamental laws of physics. (From Collected Works of M.C. Escher, ed. Tijl, Zolle, Holland, 1968. Courtesy of the Escher Foundation, Haags Gemeentemuseum, The Hague, Holland.) (XBB-747-4330)

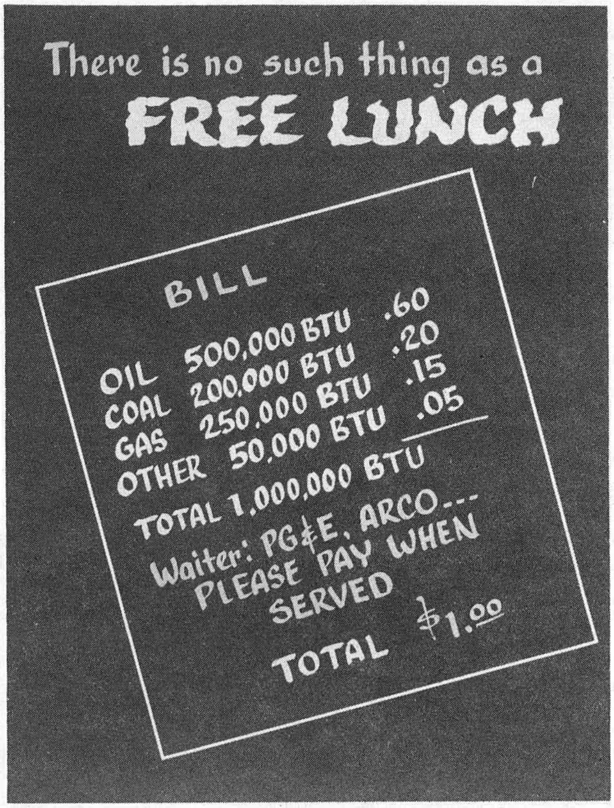


Fig. 16. Summing it all up. (XBC-744-2387)

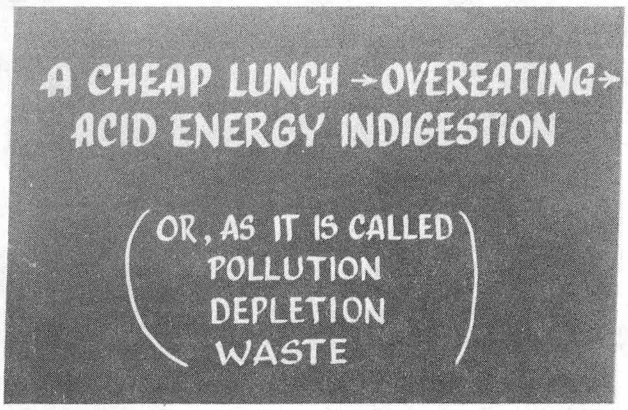


Fig. 17. Economists tell us that underpricing resources is a "no -no." They're right-right! (XBC-744-2391)

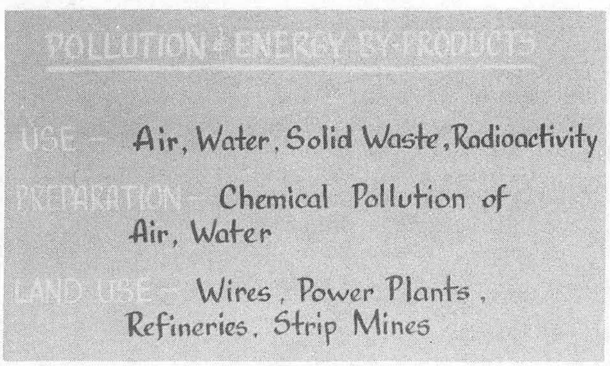


Fig. 18. Some kinds of pollution resulting from energy use. (XBC 744-2389)

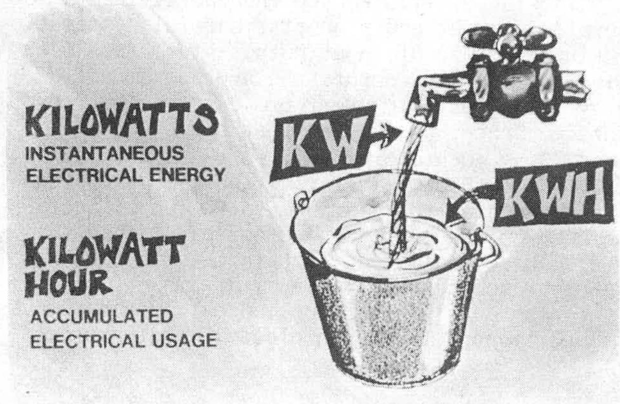


Fig. 19. Power is "how fast", while energy is "how much." (From Honeywell Corporation.) (XBB-747-4332)

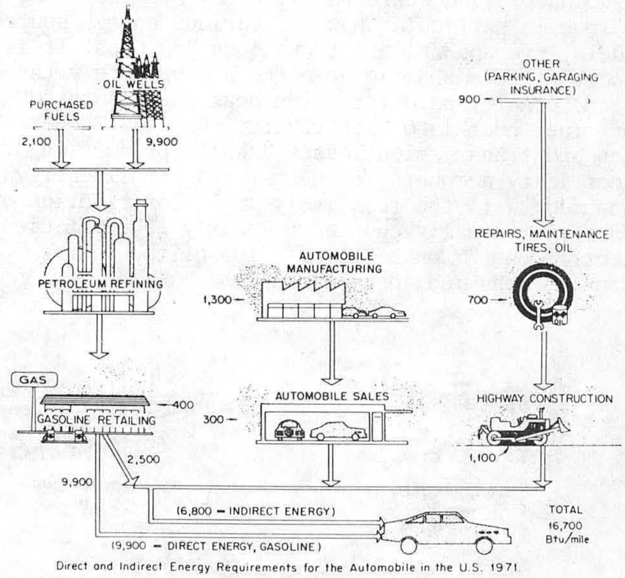


Fig. 20. The total energy cost of an automobile expressed in Btu/mile. (From Ref. 330). (XBB 747-4333)

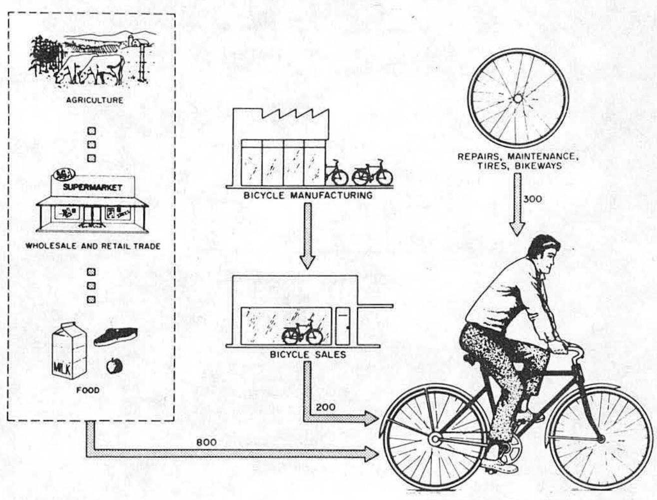


Fig. 21. Energy for bicycling (Ref. 332). (XBB 744-2425)

In Figs.20 - 23 we see the energy inputs to several different end products. Careful systematic thinking, and use of input/output statistics (267, 303) allows one to compute the average amount of energy that goes into every process in commerce or industry. Hence, we can say that autos consume about 2/3 as much energy indirectly as they do at the gas pump (330). Similarly, the energy content of a ton of steel or aluminum, of a can of beer (the beer or the can), a sheet of paper, and so forth, can be evaluated. Certain industry and government sources publish typical amounts of energy consumed by popular appliances, such as stoves, air conditioners, and even electric toothbrushes (57).

Understanding energy units is the key to interpreting physically the nature of the spaghetti bowl (Figs. 24 - 26) made popular by E. Cook and others in the early '70s (in Ref. 24). Note that we do understand where nearly every Btu goes, and we know in particular how the various energy sources (fuels) are apportioned to various end uses. It is important to emphasize here the approximately three-to-one penalty paid for using heat engines to convert fuel heat into electricity, shown as "generation and transmission losses." While production of electricity accounts for nearly 25% of all energy consumed, with the relatively small contribution of hydropower usually counted as nearly 100% efficient, electric energy makes up only 10% of the energy actually consumed in an end use.

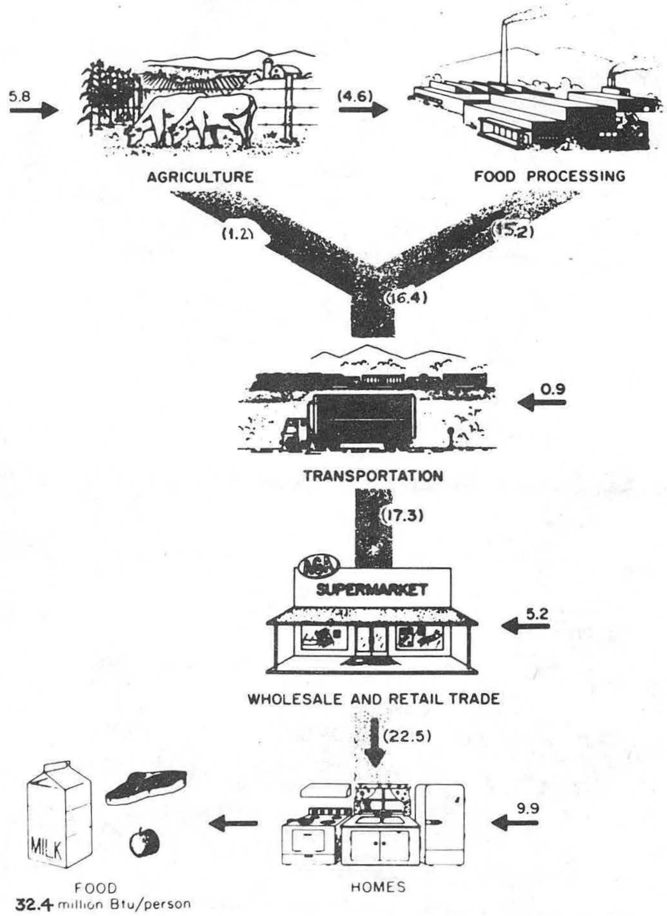


Fig. 22. Total energy for food: Six to ten calories of fuel for one calorie of food energy (Ref. 304). (XBB 747-4334)

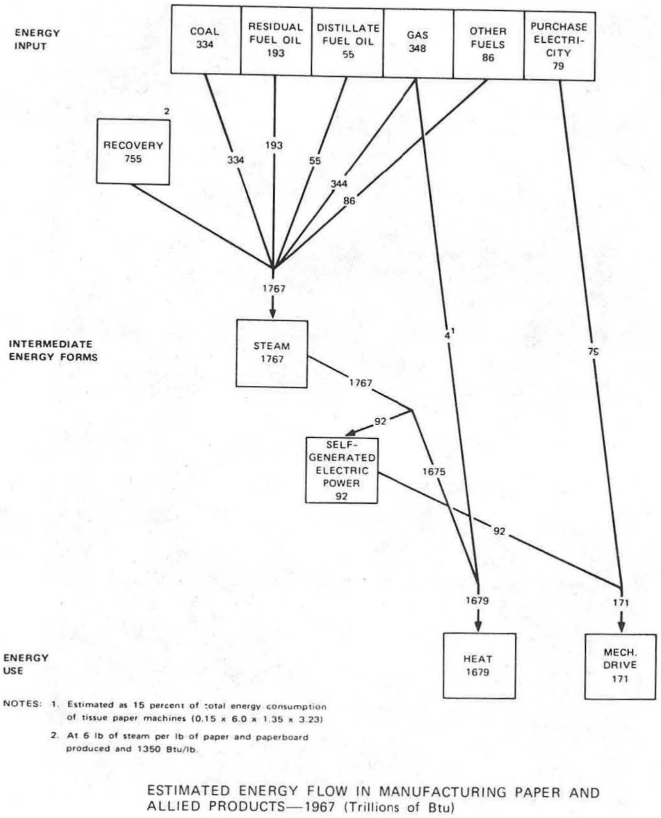


Fig. 23. Energy inputs for manufacturing paper and allied products (Ref. 52). (XBB 744-2423)

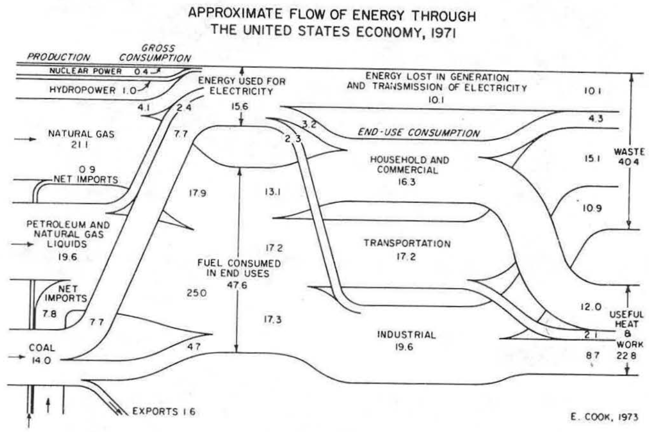


Fig. 24. A "spaghetti bowl" diagram of energy flows. Efficiency estimated from First Law by Cook. Note that the overall "efficiency" is only 36%. (Reprinted by permission, see Refs. 159, 160 or 281; see also Note 6.) (CBL 754-3152)

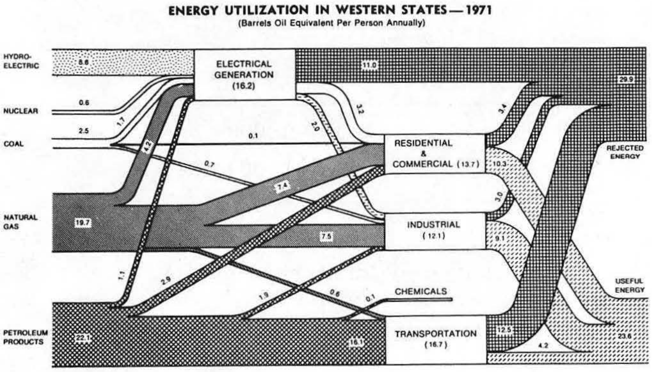


Fig. 25. A spaghetti bowl energy flow diagram for energy utilization in the Western States, 1971. (XBB 744-2683)

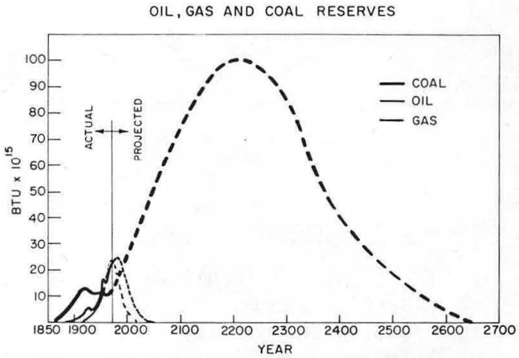


Fig. 27. Hubbert's Pimple: The use of coal, gas and oil projected. (Adapted from Ref. 2.) (XBB 747-4336)

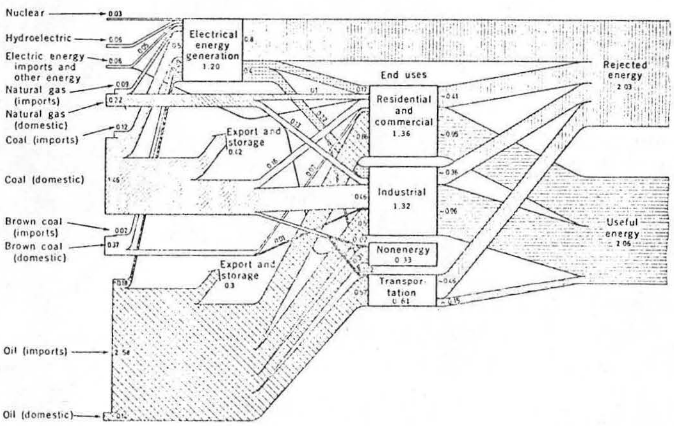


Fig. 26. A spaghetti bowl energy flow diagram for West Germany, 1971 (Ref. 22). (XBB 744-2414)

PRICE OF ENERGY

1. R & D
2. EXPLORATION/MAINTENANCE
3. INVESTMENT
4. RECOVERY
5. TRANSPORTATION OF FUEL
6. ENVIRONMENTAL CLEAN UP
7. REFINING
8. DISTRIBUTION
9. MARK UP, PROFIT, ADVERTISING, DEMAND EFFECT, COURT COSTS---

Fig. 28. Why energy costs so much.

Table 1.

ANY ONE OF THE FOLLOWING CAN YIELD
1,000,000 BTU USABLE AS PHYSIOLOGICAL OR POWERPLANT FUEL*

12,500 Large Eggs	571 Pounds of Sugar
9,174 Pounds of Cabbage	469 Fifths of 100 Proof Whiskey
2,660 Pounds of Potatoes	308 Pounds of Butter
1,560 Quarts of Milk	122 Pounds of Firewood
800 Pounds of Ground Beef or Bread	80 Pounds of Coal
625 Pounds of Dried Corn or Grain Sorghum	8 Gallons of Gasoline
606 Pounds of Wheat or Flour	0.05 Ounce of Uranium (1% burnup)

1 100-liter (≈ 30-gallon) tub of hot water, heated from 20°C to 35°C (68°F to 95°F), requires about 6000 Btu or 26 tubs to a gallon of gas.

1 aluminum beer can requires about 6800 Btu of total energy or, 3½ six-packs to a gallon of gas. Note that this is for the can alone. The beer itself requires far less.

*EARL COOK, 1974.

Table 2

UNITS OF ENERGY AND POWER:
ENERGY CONTENT OF FUELS*

M = 1,000

MM = 1,000,000

Units of Energy

1 kilocalorie (kcal) warms 1 kilogram (2.2 lbs) of water 1 degree Centigrade (1.8).
1 British Thermal Unit (Btu) warms 1 pound of water 1 degree Fahrenheit.
1 foot-pound (ft-lb) lifts 1 pound 1 foot.
1 joule (J) lifts 1 kilogram 10.2 centimeters (4 in).

Units of Power

1 watt (W) = 1 joule per second
1 kilowatt (kW) = 1000 watts
1 Megawatt (MW) = 1000 kW
1 horsepower (hp) = 33,000 ft-lb per minute

Conversion Factors

1 kilowatt-hour (kWh) = 860 kcal = 3,413 Btu = 3,600,000 J
1 kcal = 4184 J = 3.97 Btu = 3080 ft-lb (a food calorie is a kcal)
1 Q = 10^{18} Btu (one billion billion Btu); 1 Quad = 10^{15}Btu
1 hp = 746 watts; 1 kw = 1.34 hp
2500 kcal/day = 121 watts = 1 average American food diet
12,000 watts = 1 average American non-food energy diet

Energy Content of Fuels

1 lb TNT = 478 kcal
1 lb bread = 1,300 kcal = 5150 Btu
1 lb wood = 1,800 kcal = 7150 Btu
1 lb Eastern coal = 3,300 kcal = 13,100 Btu
1 lb crude oil (0.14 gal) = 4,800 kcal
1 barrel (bbl) = 42 gal
1 lb gasoline (0.18 gal) = 5,700 kcal = 22,000 Btu
1 lb natural gas (25 ft^3) = 6,600 kcal
1 therm = 100,000 Btu = 25,200 kcal
1 lb uranium 235 = 8.6 billion kcal (note: in nature you find 140 lbs U^{238} to 1 lb U^{235})
1 ton Eastern coal ≈ 26 million Btu
1 barrel crude oil (42 gallons) ≈ 5.8 million Btu
1,000 cubic feet natural gas ≈ 1,000,000 Btu

There are about seven barrels of crude oil to a ton.
Often all energy is expressed in Metric Ton Coal Equivalents (about 28 MM Btu) or barrels of oil equivalent (BOE).

*Source: John P. Holdren, private communication.
See also page 9, above.

One must define "used energy" and "waste heat" carefully; in fact, recent studies tend to raise the fraction of energy use termed "waste". Waste is hard to define objectively, but Refs. 250-253 contain interesting methodologies for objectively evaluating energy waste.

Examination of Table 3, reveals that heat (and cold) are the predominant end applications of energy use in structures and industry, while heat is the intermediate energy form for conversion of fuels to electricity or motive power. Cook's diagram really defines efficiency as:

$$\frac{\text{Energy in desired form or place}}{\text{Total energy used}} .$$

This physical definition can be extended by observing that the second law of thermodynamics (Fig. 14) says that the amount of fuel (or "available energy") required to transform the temperature of a substance or an environment can be reduced by utilizing available heat and "pumping" up (or down) the temperature of this heat using the energy in the fuel: we can thus estimate energy requirements for a desired process by either the first law or the second law of thermodynamics (250,251,252,253).

However, physical analysis alone ignores vital problems in energy system design, maintenance, or such other parameters as insulation in a home. Taking these parameters into account, we can define "efficiency":

$$\text{efficiency} = \frac{\text{minimum energy required by physics}}{\text{energy actually used in practice}} .$$

But an even more important definition of efficiency takes economics into account. Considering the cost of energy, maintenance, and the various alternative systems that use the energy, figuring the cost of all this per unit of output (e.g., comfort, a unit of production, or a passenger mile), and considering the "cost" of pollution, or psychological factors like (in-)convenience, time spent, comfort, etc.,

Table 3

Production of electricity uses heat	85%
Combustion engines use heat	100%
Homes use heat	75%
Businesses use heat	55%
Industry uses heat	75%

What the spaghetti bowl doesn't say: Heat is used at some point in nearly every energy conversion process or application.

$$\text{efficiency} = \frac{\text{cost of "cheapest" system}}{\text{cost of system being used}} .$$

(Don't forget to count interest, the cost of tying up money in an energy system, and so forth). While economic efficiency as defined here may seem complicated, it is the kind of efficiency energy users seek in typical situations.

Economics may be the most important force determining how man uses energy, but it is always the laws of physics and technology that determine what may or may not happen. This point is often overlooked by those unfamiliar with physical science. Note, too, that all energy used winds up as heat; both "useful" energy and "wasted" energy (see Fig. 13 and Table 3).

Many references contain such spaghetti bowls for a variety of years, locations, and energy futures (22,35,39 and 62).

"How much ya got?"

In every energy discussion, the question "How much fuel do we have?" is always brought up. Explainers should be very careful to define their answers, and be prepared to state real costs, including environmental ones. The most graphic display of "how much" was popularized by M. King Hubbert who used the resources curve, "Hubbert's Pimple" (Fig. 27) to illustrate the expanding use of a particular source of energy that only levels off and falls when rising prices, scarcity, or environmental restraints make continued growth in the rate of fuel use undesirable, uneconomic, or impossible. Or, new technologies or discoveries might make use of a fuel unnecessary, or enable the rate of use to be lowered through increased efficiency even before environmental, economic, or supply constraints act. This happened to coal in the 1950's. In the Hubbert diagram, the *total* area under the curve is limited to the total amount of fuel which will be ultimately discovered. The shape of the curve describes the growing or falling rate of use. The position of the peak, that is, the time of the maximum rate of use and what, if any, efforts can be made to prolong the duration of peak use, are important subjects. Reference 2 provides a very valuable introduction to the meaning of these resource curves, and Refs. 31,33, and 34 discuss estimates of how much is there.

But the price which one pays for energy, discussed in Fig. 28, will influence to a great degree the amount of a resource that can be discovered and used. Often we forget that our world is a finite one, and we assume that resources are plentiful, as long as the price can go up. Certainly higher prices often do lead to more exploration and discovery, but this cannot go on forever, especially as the energy cost (and resulting pollution) of recovery rises. Indeed, many accepted models of resource economics assume the infinite or nearly infinite world principle, and ignore what the physical world tells us. Reference 167, from a major bank in California, virtually ignores energy in its many lavish pages of evaluation of the economic future for 1974 in California, mentioning only that "energy prices will rise." This is another example of the way in which we ignored the physical nature of energy, and perhaps hints at how our basic thinking helped allow an energy crisis to occur.

At the same time, many forget that items 1 through 8 in the Fig. 28 "price list" represent real physical costs, with subjective values and politics entering mostly in number 9. While new technologies can reduce the costs of numbers 1 through 8, the new technologies themselves demand inputs which are also subject to the same physical constraints, hence, it may be unrealistic to assume that "we will always find a way" to have cheap energy (at increasing rates of usage). Note that rising prices often lead to substitution of one fuel for another, as new sources or methods become economic. But, again, this process cannot continue indefinitely, and it should be explicitly stated what will happen.

Figures 29 and 30 remind us that both investment in energy and transportation of energy cost dollars (and energy). It is difficult to realize that energy facilities take years to build; even then, energy must be moved over great distances, often with resulting environmental damage, because "energy is where you find it," while people usually live in concentrated urban areas.

One important principle mentioned above should be kept in mind: energy costs now go up as energy is used faster, even if there is plenty of energy in stored fuels in the ground. While Hubbert's Pimple (Fig. 27) shows how much coal there is, the slope of the curve tells *how fast* coal use is rising, but shortages of coal mines, coal miners, envestment, unwillingness on the part of mine owners to use the *time*, technology and money required to ensure the safety of the miners and health of the environment, or shortages of water or railroad hopper cars, or shortages of clean air (e.g.) too many smokestacks in a given area), in fact, restrict the *rate* of coal use even though there is plenty of coal!

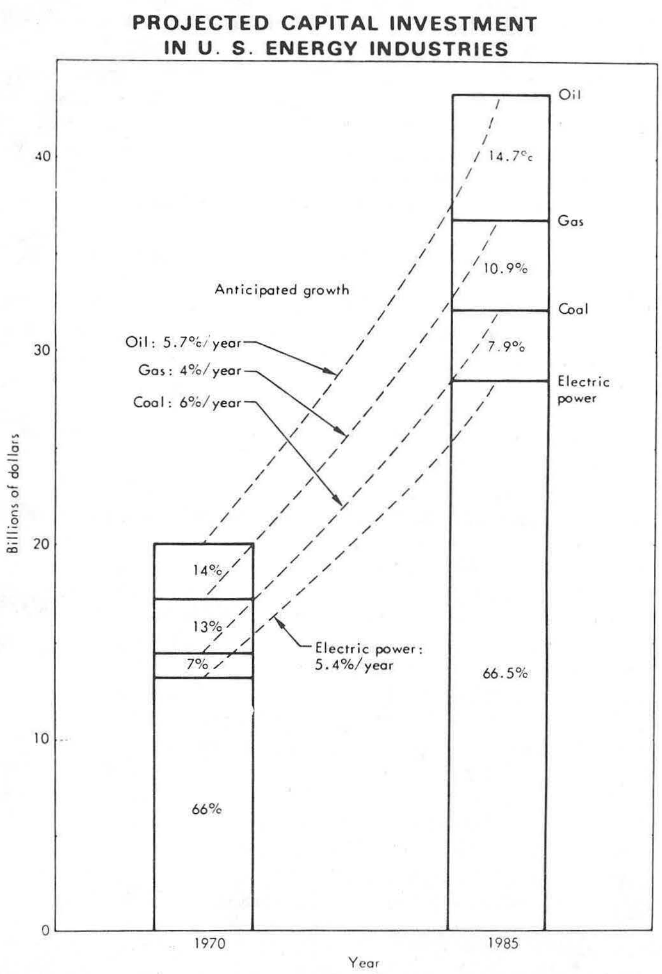


Fig. 29. Building the energy system costs! (Ref. 38). (XBB 744-2666)

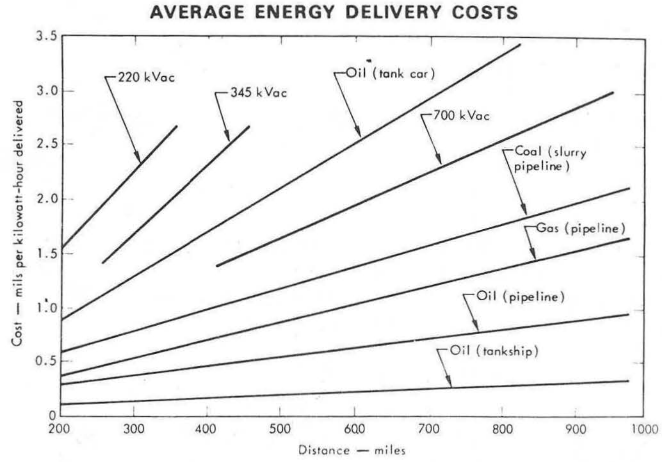


Fig. 30. Moving energy costs too! (Ref. 38).

(XBB 744-2692)

Finally, account must be taken of the energy inputs required to produce a unit of available energy; energy in the form desired. Odum (Ref. 8, also in Ref. 21) has emphasized this "net energy concept" and explainers should be careful not to fall into the trap of putting in more and getting out less. This warning also applies to those who claim "infinite resources" from the sea, that "we have only begun to tap the earth's crust." As always, a strict accounting of real costs, including machines, men, energy, and environmental spoilage, must accompany any honest evaluation of "how much."

More recent work on the energy cost of energy (506,512) caution us about the folly of estimating the size of resources in energy units. Shale oil, gas or oil from coal, and uranium enrichment all demand energy that must be supplied before the fuel in question can be used.

"HOW MUCH D'YA WANT FOR IT?"

Figure 31, a drawing by Kenneth Boulding, illustrates what, in the ideal case, would be the role of the free market and economics in determining how energy is bought and sold, and ultimately used (150). Rising prices lead to lowered demand and at the same time increased supply. Rising supply, beyond demand, leads to falling prices and increased supply. Surprisingly, in the USA energy prices in real (non-inflated dollars) fell from World War II until about 1970. According to this model, changes in demand and/or supply are correlated with changes in prices.

When the level of supply or demand is sensitive to changes in price, the relationship is determined "elastic." If steep price increases do not bring about reductions in consumption, if sharp price drops do not increase usage, if sharp price rises do not make increased supply available, or if falling prices do not inhibit the producer's desire or ability to make supplies available, then the relationship, for the given price, supply, and demand levels is called "inelastic." Many "solutions" to the energy crisis state simply that "rising prices will discourage consumption and encourage production." But it is important to explain what the physical and technological mechanisms of this response will be, and in particular, to evaluate *who* will or will not respond to price changes. Can the poor use less? Do the rich care? Do dollars find oil, or do the dollars first have to become drilling platforms, petroleum engineers, and good luck? And, most important, how long does the market or price mechanism take to provoke the desired change, if at all? Many of these questions are discussed in Refs. 100,106,107,115, and 155.

Missing too, from a simple "free market" description of energy are the effects of government or private policies regarding taxes, depletion allowances (tax breaks for fuels actually dug up and sold), pollution and other costs to the general public ("externalities") borne by the seller or user of energy, and many other rules or restrictions which may influence energy demand. For example, scrap iron dealers are charged higher rail freight rates than shippers of iron ore. (308). Thus the price of scrap is higher than otherwise, so that it is not as competitive with ore as it might be. Since scrap requires considerably less energy to re-refine, and the whole process results in less pollution and less solid waste, the advantages of scrap re-use and recycling in general and implications for total energy demand are lost, due to a freight ruling that appears to have little to do with energy or pollution. Explainers who wish to explore the economics of the energy system are forewarned to take a deep breath and expose themselves to some economics and related political subjects.

The various forms of environmental impacts (Table 4) both direct and indirect, are very important to any discussion of energy, and one should not overlook those impacts, even where quantifications or cost/benefit is difficult or controversial as in the case of nuclear power. Although energy itself is consumed in cleaning up pollution (especially the mess made by energy consumption), recent studies (Ref. 805, and Table 5) suggest that ultimately this clean-up bill will *not* amount to more than a few percent of total energy consumption. Increasing efficiency of energy use also cuts pollution, as do other measures listed below under conservation. (See also Refs. 253,159,819,810,828, 830.) What is important to understand about energy use and the environment is that all power pollutes; pollution exacts a real cost on our health, welfare, property, and in the long run on the economy (Fig. 32). Since nearly all activities introduce some foreign substances into the environment or change rates of *flow* of substances, it is difficult to imagine eliminating pollution entirely. But economists suggest that up to a point it *is* worthwhile for society to force individuals to "clean up" pollution, pay a tax on pollution, develop anti-pollution technology or cease certain polluting activities. Auto makers and energy producers (and consumers) have a nasty habit of complaining loudly about the dollar cost of cleaning up while ignoring the dollar and non-dollar value of a clean environment, especially where health is concerned. Because few producers or consumers would voluntarily clean up pollution, economists suggest that government standards and enforcement is necessary. (See the excellent book by Barclay and Seckler (150) for more on the economics of pollution.)

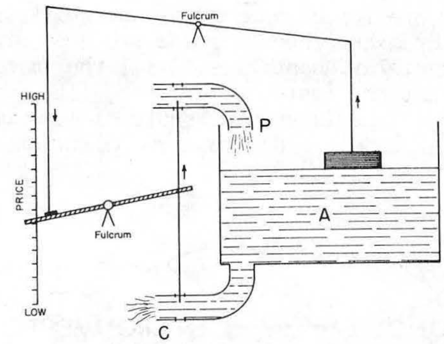


Fig. 31. How the free market might operate. A is the stock, P is production, C is consumption. What if the tub overflows, or the valves do not work? (From "The Shadow of the Stationary State," by K. Boulding, Ref. 28.) (XBB-747-4338)

Table 4

ENVIRONMENTAL IMPACT OF ENERGY SOURCES

	COAL	GAS/OIL	URANIUM
PRE-CONVERSION			
DEFACING LANDSCAPE	X	X	X
MINERS' HEALTH	X		X
WATER POLLUTION	X	X	X
CONVERSION			
PARTICLES, NO_x, SO_x, CO_2	X	X	
MERCURY	X	X	
LOW LEVEL RADIATION	X		X
RADIATION ACCIDENT			X
HEAT	X	X	X
POST-CONVERSION			
SOLID WASTE	X	X	XX
PLUTONIUM DIVERSION			X

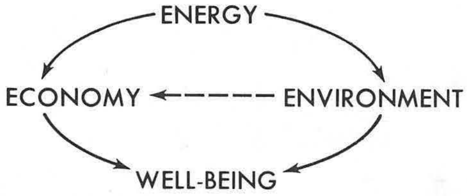
Table 5

National Petroleum Council estimates of 1980 energy consumption to meet environmental standards

	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] Total projected energy consumption for the intermediate case in 1980 is 102,581 trillion Btu.

And additional caveat about discussing pollution is important! It is the *rate* of adding pollutants in a given area, measured as a resulting concentration there, that is important. As the numbers of factories or autos in an area increase, so does the *rate* of polluting. Then more abatement must be applied to every polluter in order to maintain a given degree of "clean" environment. But pollution control on an individual source rises spectacularly in cost as the amount of abatement and new technology required rises, as Cook's diagram (Fig. 33) shows. Sometimes too, abatement itself adds to the problem as when by-products like sulfur, limestone, or other chemicals are produced are collected in unwieldy quantities. Still the important lesson is that the faster we pollute, (the more the economy grows--the larger the share of our wealth we have to expend in order to keep pollution constant. (Ref. 820, Fig. 33).



XBL 759-4095

Fig. 32. This simple drawing by J. Holdren suggests that the links between energy and well-being are several. While energy use makes a positive contribution through the economy, it has a negative impact through unabated pollution, which hurts well-being as well as hampering many economic activities.

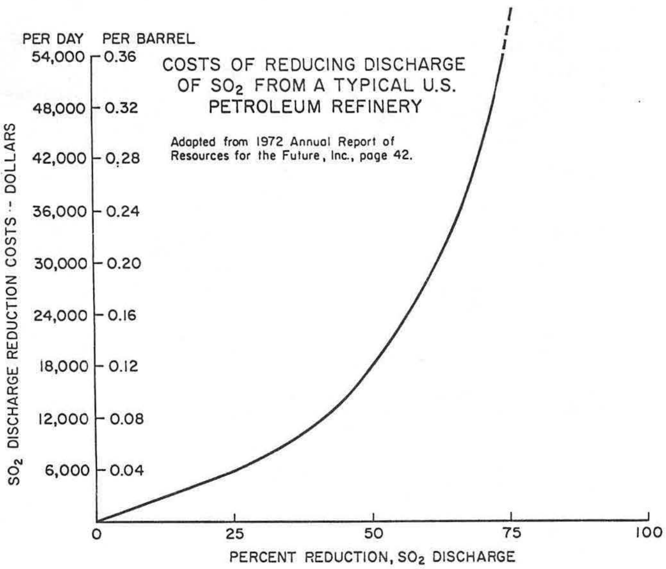


Fig. 33. Diminishing returns on pollution control expenses warn us to be careful with energy waste! (From Cook, Ref. 159, used by permission.) (CBL 754-3164)

Three important subjects that have roots in world history are the history of fuel use (and substitution), (Fig. 34) the geographical distribution of energy resources, (Fig. 35) and the recent rising international trade in fuels, especially oil (Fig. 36). The character of a people is very much influenced by fuel availability and distribution, and the history of fuel use reflects changing social conditions, values, and technology. The cost of preparing energy, such as refining, the cost of mining, transportation, and conversion, must all be considered in understanding the economics (5,9,11,12).

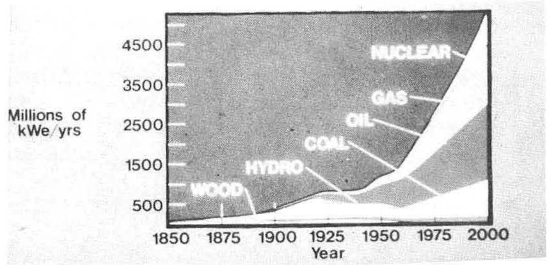


Fig. 34. History of fuel use in the U.S.A. (From General Electric Co.) (XBB 747-4340)

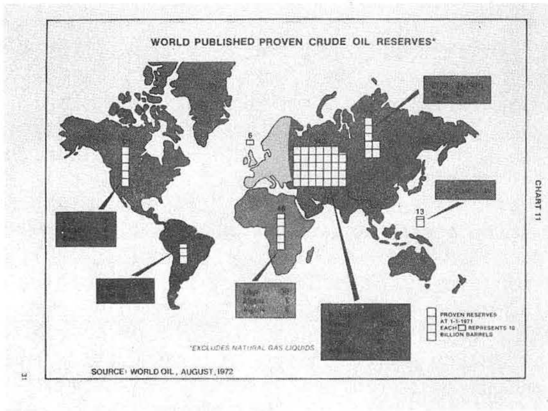


Fig. 35. Who has the oil? (From Shell Oil Co., Ref. 28). (XBB 747-4341)

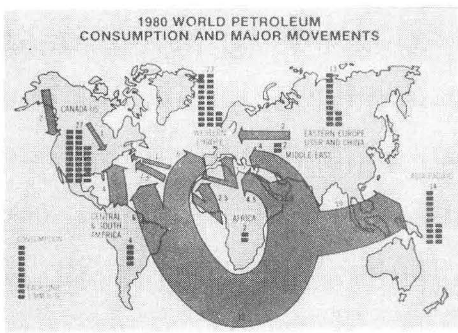


Fig. 36. Who sells to whom? (From Shell Oil Co., Ref. 28). XBB 747-4342)

A careful reading of the National Petroleum Council Summary (110) produces the prediction that, "The more ya want, the more ya gotta pay." While many call this "bloody murder," they often forget that rising demand rates, as well as cumulative usage, do use up the energy fuels that are cheap financially, environmentally, and geographically, as well as physically. Then we have to do more to produce the same: drill farther, drill in far-off places (the Arctic), make deals with governments that might want to limit demand by high prices, and so forth. This is illustrated in the data given by NPC, adapted here to illustrate the findings of the NPC. Note in Fig. 37 that higher demand brings on the "need" for higher prices. The NPC estimates were made in 1972, before the embargo. While prices have risen, the effect illustrated in Fig. 37 remains. Economists say that the marginal or incremental cost of oil is rising, so that "the more ya want, the more ya pay per unit." This interaction is typically found in markets where scarcity and rising physical costs finally offset economies of scale and efficiencies of technology. We might still argue a lot with the oil companies, but we cannot argue with nature, too.

To illustrate the point about rising costs and cumulative usage, I show three samples of shale, containing 90, 30, and 15 gallons of crude oil per ton of rock (Fig. 38). All audiences agree: "Take the 90 gallon stuff first." They shudder when they are reminded that when that is gone, they will have to move much more rock and water (with high environmental hazard and lower net energy gain) which *has* to cost more, even with a Second Coming.

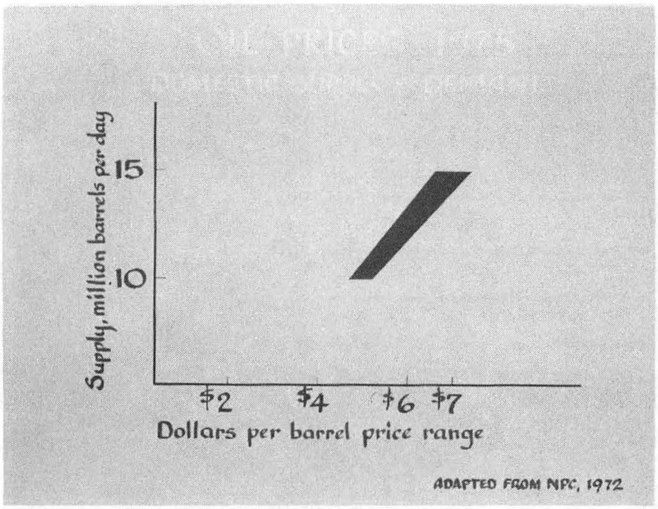


Fig. 37. Supply vs price in 1975--before the embargo (Ref. 110). (XBC-744-2390)

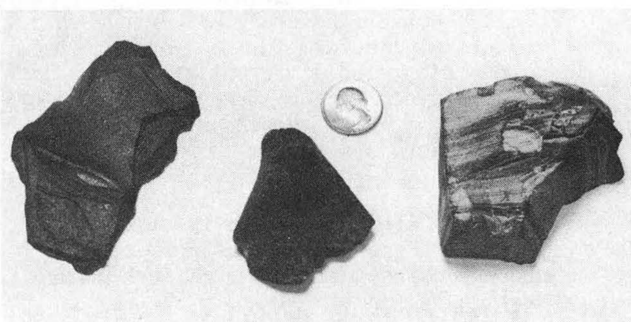


Fig. 38. Three pieces of oil-baring shale, with 90, 30, and 15 gallons of oil per ton of shale respectively from left to right. Which would you mine first? What would you do with the leftover part? (BBC-746-4202)

WHO HAS ALL THE ENERGY?

Understanding the energy supply system is an important part of preparing to explain energy. Since total direct and indirect expenditures for energy add up to about 10% of GNP in the USA in 1972 (and more in 1975) we can say that the energy system is in fact the largest industry, charged with running the rest of the country! Note that we include "indirect energy use costs" (use of energy for products and services), a point we will amplify later (157, 267, 270), but not environmental costs. The pies (Fig. 39 and 40) show the energy sources for the USA for 1972, and for the World in 1968.

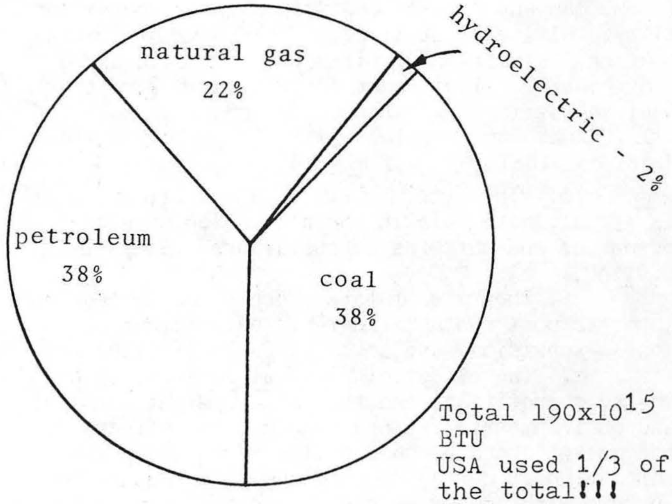


Fig. 39. World energy supply as estimated in 1968.

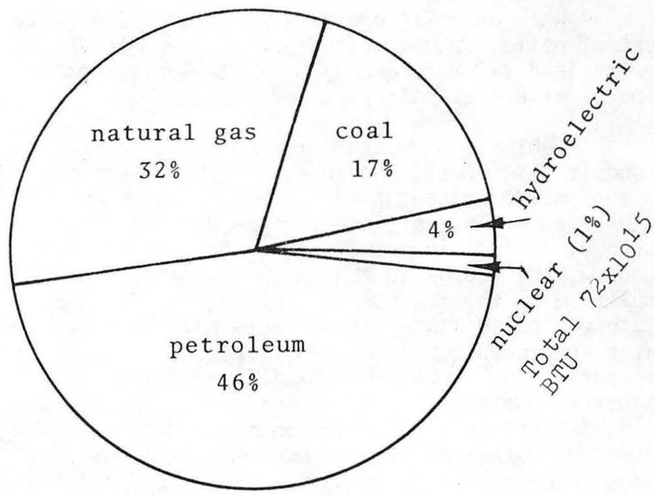


Fig. 40. U.S. energy supply for 1972 (from Refs. 25, 101).

The fuel industries and electric utilities, some of whom also buy or sell natural gas or water, are engaged in all forms of energy activities, including exploration, recovery, processing, conversion, transmission, distribution, retail sales, and environmental clean-up activities noted in Fig. 28. In addition to the very interesting technical and physical problems inherent in recovering energy (32, 618, 625), these industries face controversy on various aspects of public and private energy policy. Explainers might consider such issues as:

1. "Incentives" needed to encourage energy recovery and development (100,113). Should the price of energy be the only incentive for companies to harvest and sell fuels?

2. Competition and structure in the energy industries (122).

3. Government's role in watching over, regulating, and aiding the energy industry (121, 102, 106, 107, 201, 186).

4. Integrated ownership/organization of the energy facilities: a) vertical integration, wherein one company owns or controls a fuel from extraction to ultimate retail sale, b) horizontal integration (actually diversification) wherein a company controls significant activities in competing fuel industries, say uranium and coal, as well as oil (Exxon, for example). (Ref. 122, plus many Hearings, 188)

5. "The Free Market." What is it, and what is its ultimate role in the allocation of energy resources and patterns of energy use? (See Refs. 150,100.)

6. The role of taxes, depletion allowances, import/export quotas, indirect (environmental) costs, subsidies, and so on (176-179,119,120).

7. The effect of physical constraints on costs, competition, and the market. Might physical and environmental factors preclude the effects of the market, such as competition, from being important under certain conditions. Does nature cooperate with economic, and exponential man? (See Refs. 819, 821, 153, 127.)

8. Promotion of energy use (201, 827).

Reference 813 contains an interesting statement of policy from a united group of energy industry leaders. References 100 - 214 analyze other aspects of energy policy.

Tables 6 and 7 give some idea of the economic size of the energy industry as compared to the entire United States economy. The energy industries employ far fewer people per dollar of revenue, cost or investment than the rest of the economy, and trends in the energy industry as exemplified by the figures in Table 8, are for fewer employees per dollar. (These facts will be discussed later when we discuss conservation). It is important of course, to have an economically efficient energy industry, but these employment figures should be kept in mind by those who see the energy industry growing relative to the rest of the economy. If we use too much energy, that is, if we use energy inefficiently we inflate the energy industry by giving up jobs, output, and welfare in the rest of the economy.

Electric utilities have grown rapidly in the past three decades, in fact, more rapidly than the rest of the energy industry as a whole. Most are investor owned, though there is a significant number that are publicly owned, such as the Los Angeles Municipal Department of Water and Power, and the federal Tennessee Valley Authority (Fig. 42). (References 4 and 7 discuss many of the institutional aspects of utilities, as well as the technical aspects of electric power.) Explainers should gain an understanding of the regulated monopoly nature of private utilities, and the various economic and physical costs that determine prices for electricity. The system of rate structure should also be investigated. The most notable feature of present day rate structures is that larger users usually pay significantly less per unit of energy, reflecting apparent lower generation costs when the system is used fully. But this rate structure is under scrutiny from several directions (186,187,182). Similarly, it is now suggested that useage of electricity be more expensive during time of peak useage, when generation is more expensive (187,176).

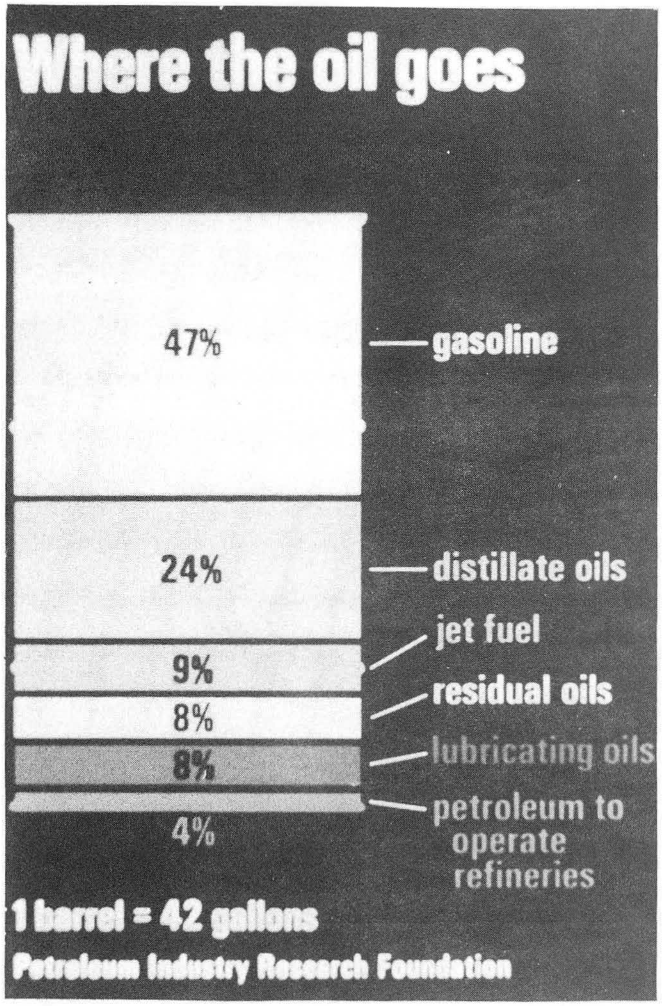


Fig. 41. One example of how the energy industry, in this case the oil industry, processes fuels, converting crude oil into a variety of useful liquids. The coal and nuclear industries also differentiate among kinds of energy content of fuels. (Used by permission of Petroleum Industry Research Foundation, New York.) (XBB 747-4345)

Other aspects of electrical generation are changing. For example, the mix of fuels used to generate electricity in this country as shown in Fig. 43, has changed since 1972 when the graph was drawn, and continues to evolve. Most are surprised by the relatively small share of hydropower, the large share of coal. The portion of electricity generated by natural gas is falling rapidly, while the small contribution generated by nuclear power is rapidly growing. Reference 801 compares many of the environmental effects of alternate methods of electric generation.

To most listeners, the surprising aspect of the generation of electricity is the large price in fuel paid for a unit of electric energy (Figs. 45 and 46). Basic physics works here, saying that when

Table 6. Energy-1974

National Income	4% of National Income[1]
Value Sold	9% of GNP[1]
Personal Consumption	7% of PCE[1]
Indirect Costs in Personal Consumption (in goods and services)	4% of PCE[1]
Investment of Energy Industries	22% of Non-Residential Gross Domestic Investment
Employment:	3% of Total Employment[2]
Extraction, refining, pipelines, utilities	1.75% of Total Employment[2]
Retail, wholesale dealers	1.25% of Total Employment[2]

Sources: [1]J. Holdren, private communication.

[2]Reference 100: Data are for 1971.

Table 7. Investment and Employment, Some U.S. Industries
Capital Investment per Employee 1971

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

Source: Edison Electric Institute, 1973.

Table 8. Some Statistics from Electric Utilities

	Capacity kW	Output 10^{12} kWh	Revenues $ 10^6	Construction $ 10^6	Employment* 000's
1961	190	.80	$12,200	$ 3,300	343
1971	370	1.62	$24,700	$12,000	394
1973	440	1.85	$31,700	$13,900	415

*Of the total number of employees, roughly 25% were engaged in construction.

Source: Edison Electric Institute, 1973 and 1974.

we heat a gas to turn a turbine to make mechanical energy from heat and electrical energy from mechanical energy, the ultimate best efficiency depends on how hot we can heat the gas, usually steam, and then how cool we can make it after it has pushed the blades of the turbine. The efficiency in this written as $E = 1 - (T_{cool}/T_{hot})$. Note that an efficiency of one is impossible because we can't get T_{cool} to be absolute zero, and we can't get T_{hot} to be very high before the system wants to fall apart from heat. In order to cool the steam, and send it around again, we have to either run the steam pipes through cooling water, which conducts away the heat and condenses the steam, or run the steam pipes into contact with a pond from which water evaporates, or vaporize water directly, or cause air to be conducted through the system in such quantities as to cool the steam (see Refs. 4, 7, and 814). Figure 47 shows the cooling water inlet for a nuclear power plant. The result--only about 32% of the energy in the fuel actually winds up as electricity. Furthermore, 10% (average) of the remaining electrical energy is lost in transmission (4). Thus, today Fig. 46 represents a valid picture of approximately how much of the heat energy originally present in, say, coal, winds up as light bulb in a home far from the power plant. Note that the bulb itself only converts 6% of the electricity it receives into light. On the other hand, heat is itself "low grade" energy, while electricity is high grade, in the physical sense that we can then convert nearly all of it to nearly any end use. Once we have paid the physical (thermodynamic) penalty to convert heat to work, we can keep that work as electricity. For some end uses, such as light, motors, and electrical separation of chemicals (electrolysis), the price is necessary and well worth paying. But, as Berg points out (252), some uses of electricity, especially for resistance heating, squander the high grade thermodynamic quality of electricity.

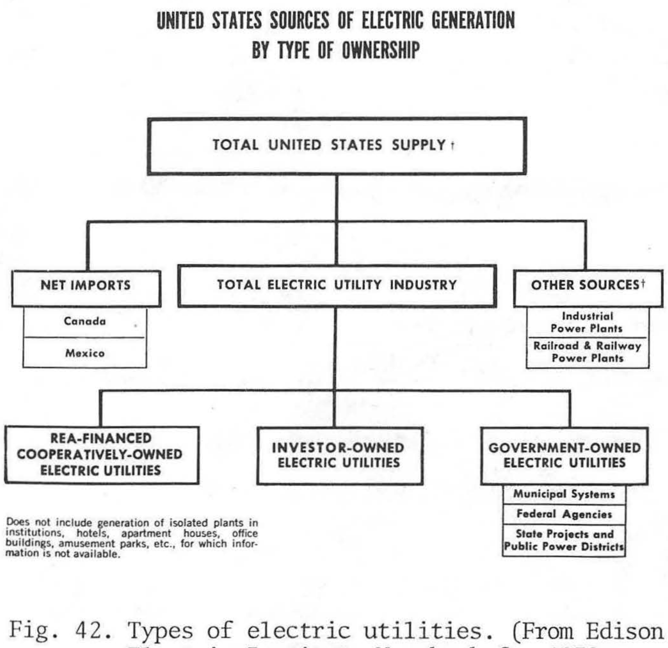


Fig. 42. Types of electric utilities. (From Edison Electric Institute Yearbook for 1972, used by permission.) (CBL 747-4876)

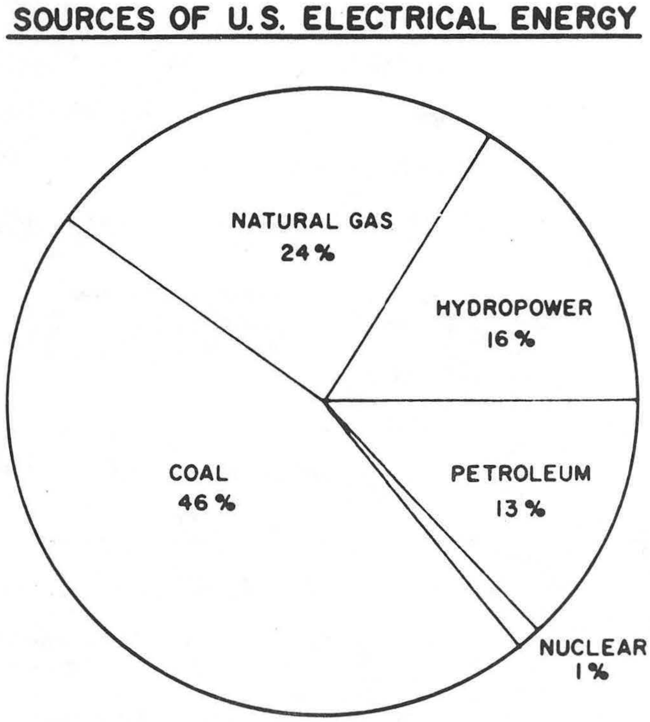


Fig. 43. Sources of energy used to generate electricity in 1972. (XBB 747-4350)

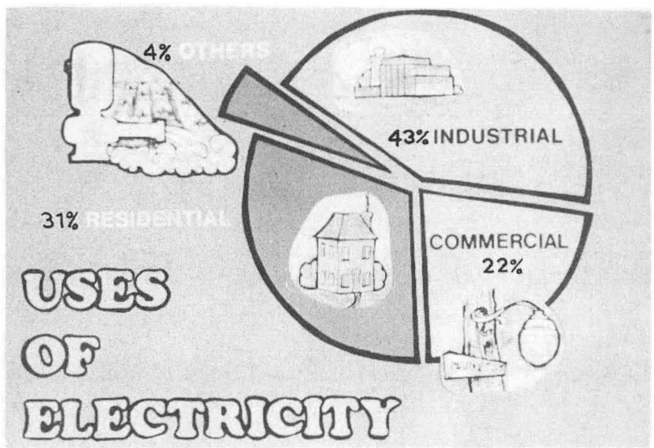


Fig. 44. Uses of electricity in 1970. (From General Electric Co.) (XBB 747-4350)

The electric system has certain problems. First, sites for power plants and space for transmission lines are hard to win, and even today fuel is still a small fraction of the cost of electricity the system itself being expensive. Raising capital is difficult for utilities, especially as their share of construction grows, in comparison with all investment in the USA. Vigorous battles are being fought in various states over new rules governing utilities (see especially the paper by Chicetti, in Ref. 186, and the papers by Ralls in Refs. 276 and 118).

But the most frustrating characteristic electricity utilization is the difference between times when demand on the capacity of the system (the rate at which the system can supply energy) is low, and when it is high, or exceeds the system capacity. When this happens the system may buy or borrow power from another system, release water it has previously pumped uphill ("pumped storage"), reduce voltage to everyone ("brown-out") or, in the most unfortunate situations, shut down ("crash down") in certain locations. Figure 48 shows typical loads for a utility; here air conditioning is seen to be mostly responsible for the need to build a large reserve. This difference between capacity to generate power (a rate limit) and limitations on the system due to unavailability of fuel (an amount limit) should be made clear. The cost of maintaining a large generation capacity for use at only a few times should also be considered (133,186).

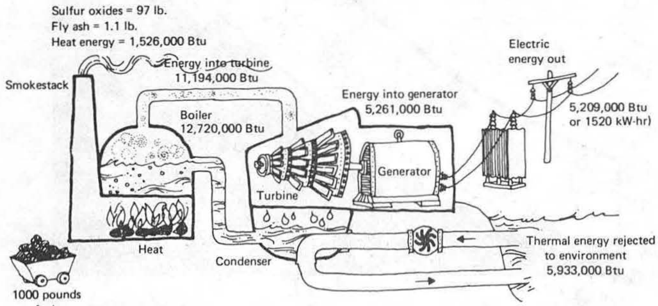


Fig. 45. The flow of energy in a steam electric plant. The fuel heats the steam in the boiler, the steam rushes under pressure through the turbine, turning the blades (which turn the generator), but the steam must be cooled in the condenser to make everything work. You can only loose! (From Priest, "Problems of our Physical Environment," Addision-Wesley, Reading, Mass., 1973.) (XBB-747-4343)

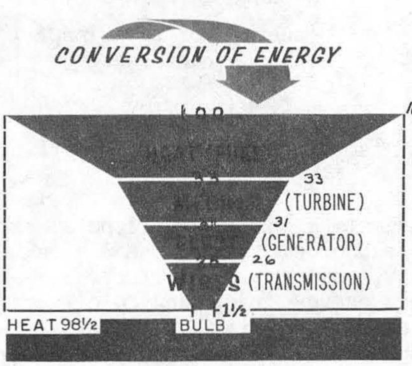


Fig. 46. Ultimate conversion of fuel at the power plant to light in an incandescent bulb. (See also p. 209 in Ref. 11.) (XBL 742-729)

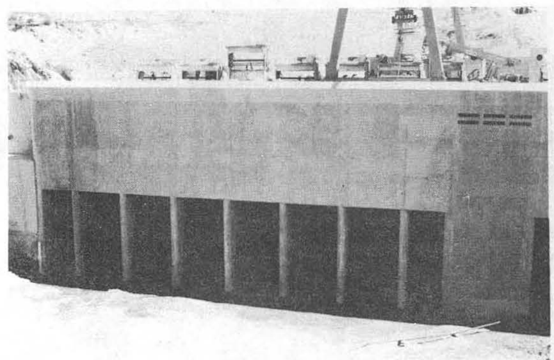


Fig. 47. 700,000 gallons of Pacific Ocean are pumped through these intakes every minute to absorb heat at the rate of 2000 MW at the Diablo Canyon Nuclear Power Plant in California. (BBC 747-4889)

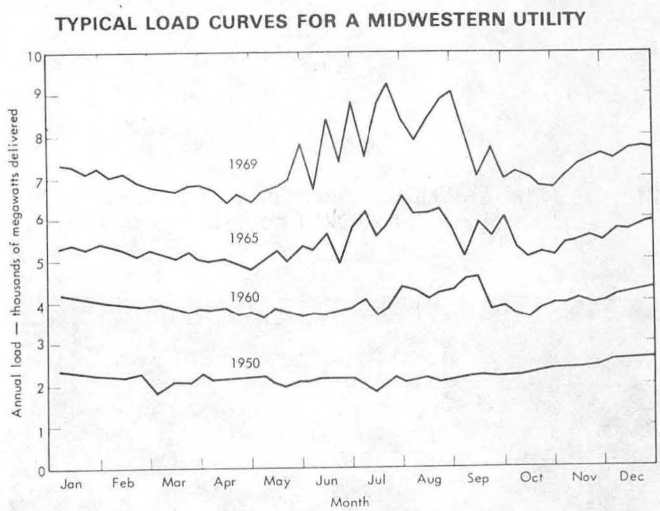


Fig. 48. Airconditioning use accounts for much of the growth in summer peak loads for the electric utilities. (From Ref. 38). (XBB 747-4344)

WANT MORE?

Attention is now focusing on the evolutionary nature of the energy system, its growth, and penalties or benefits of that growth (Fig. 49). We have difficulty in perceiving the consequences of exponential growth, as illustrated in Fig. 50. Yet, most economic systems follow this kind of growth, with energy use growth related to both the enabling causes and the results of economic growth (30,38,150,166 a,b, 818,819). Note that energy use grows per capita, that is, faster than population, reflecting rising standards of living, new technology, the falling price of energy (at least until 1970) and also the effects of waste, congestion, and suburban lifestyles. But exponential growth (like compound interest) can quickly grow beyond all bounds. The doubling time, or interval required for a rate or amount which increases at a certain percentage every year, to double, is given as (70)/(annual percentage growth). As much energy capacity must be added in addition to replacement of worn out capacity in a single doubling time as already existed at the beginning at that time if growth is to be maintained. As much fuel is used in one doubling time as in all history previous to that period if the growth had been constant. Note in particular that electricity use grows faster than total energy use, with a doubling time of about 10 years (Fig. 51). How long the growth can be maintained, how desirable this state is, and what the alternatives, costs and consequences might be are highly controversial subjects (see especially 133).

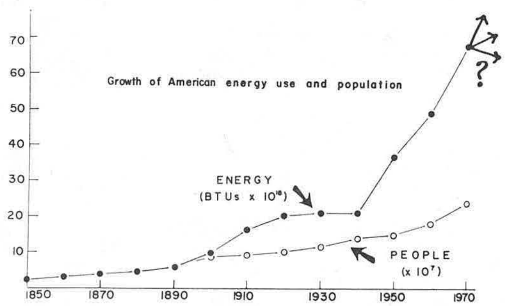


Fig. 49. The growth of American energy use and population. (From ORAU Workshop, Ref. 25).
(XBB 747-4347)

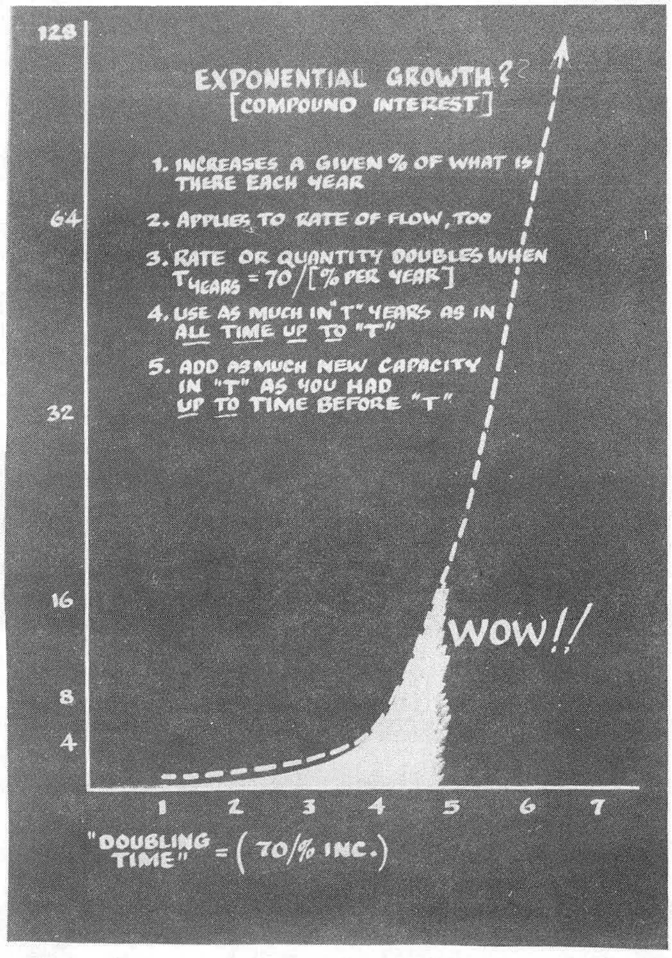


Fig. 50. The curve for exponential growth.
(XBC 744-2386)

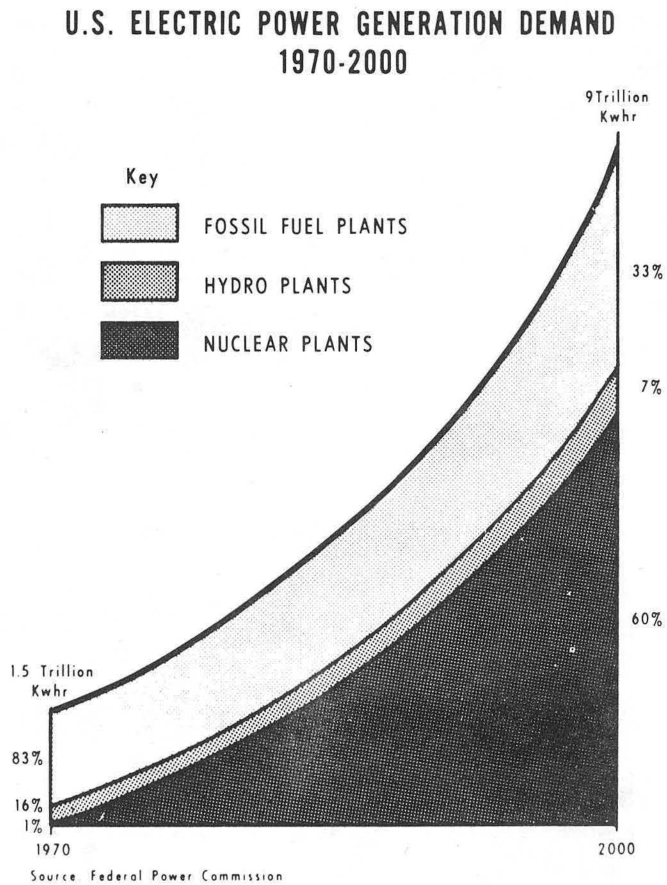


Fig. 51. Does the expected growth in electricity generation remind you of Fig. 50? (From Ref. 32).
(XBB 747-4348)

In projecting future demands analysts will often separate growth into several factors. Broadly put, the consumption of all fuels is broken down by each fuel, each gross end-use (farming, driving, etc.), the technology of the use, the rate of consumption of that end-use (how much per capita) and the number of people in the consuming population. We can write:

$$\text{USE} = \left[\Sigma(\text{outputs per capita}) \times (\text{inputs to each output}) \times \begin{Bmatrix}\text{energy for each input} \\ \text{plus direct energy}\end{Bmatrix}\right] \times \text{POPULATION} .$$

The first factor is often termed "affluence" (816, 817).

Estimating changes to (inputs) is difficult because technologies change, and even "energy" might vary, as, say, manufacturers of a material develop an energy saving device or turn to an energy-intensive source of raw materials. The SST, for example, would have consumed 2-2½ times more energy per passenger mile compared to a 747, assuming standard load factors. Given the growth in air transportion assumed (as late as 1972) to be continued well into the 1990's with a fleet of 300 SST's predicted as profitable by the Department of Transporation, oil consumption in the U.S.

would be 500,000 barrels per day higher than if all the SST passenger miles were flown on 747's (see Ref. 329). Thus we must be careful with technology (see also Ref. 127). Another factor is saturation, discussed in Refs. 384 and 393 for many kinds of consumer's items. Per capita consumption of energy depends on the average number of people (or homes) with various appliances, and the number of people using each appliance. Saturation in ownership means 100% of all homes have a certain appliance, say a vebelfetzer. Projected future growth depends on how many homes will get certain energy using devices which are not near saturation: electric resistance heating, air conditioning, heated swimming pools, recreational vehicles, third autos, and, to a smaller degree, washers, dryers, and electric ranges. (Refs. 39, 40, and 48). These factors are life style, and they depend on affluence, i.e., per capita personal income, which depends, of course, on everything else. Furthermore, it is not clear how fast per capita use of other inputs to life style will rise: travel, synthetic goods, processed food, and most important, throw-away packaging using aluminum, paper, and plastics. (Ref. 75, 76, and 305 discuss future scenarios in materials and energy).

If we lump these things under "affluence", we arrive at a very famous equation:

Energy use = population × Affluence per capita

or, $E = P \times A$.

The meaning and value or importance of changes in either right hand term are the subject of famous literary debates (803, 817, 816). Following Holdren, and Ehrlich, we can write

$$(E + \Delta E) = (P + \Delta P)\ (A + \Delta A)$$

where E is the energy used in a year, $E + \Delta E$ is energy used in a certain time later. Writers "argue" whether population growth or affluence is the "villain" in rising use of energy or environmental insults. But if we examine carefully this product, we see graphically the following (Fig. 52):

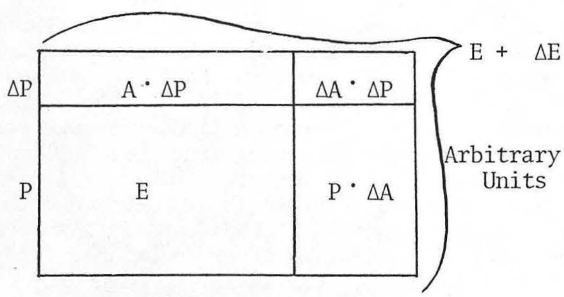


Fig. 52. Illustration of $E + \Delta E$ derivation.

I purposely draw the case $\frac{\Delta A}{A} > \frac{\Delta P}{P}$. Note that the change in energy, ΔE, comes from three terms. A large population gives big changes to small or large changes in affluence because all terms are multiplied together. Merely assigning percentages to population growth or affluence growth as "causes" of energy growth is misleading. The real relationship includes four terms, $(P)\cdot(A)$, $(\Delta P)\cdot(\Delta A)$, $P\cdot(\Delta A)$, & $(\Delta P)\cdot A$. Population growth is slowing dramatically, though "zero-population growth" is still decades away. Nevertheless Ref. 258 quotes a revised "traditional" energy use forecast based upon 260,000,000 people in the year 2000 in the U. S., rather than more. In view of the preceeding note of caution, we see that slowed population growth will have a beneficial effect on the energy system, since lower demand allows us to ignore the most dirty or expensive fuels, thus lowering average energy costs for all (see also Ref. 253).

But population growth itself can have a significant multiplying effect on per capita energy use. (See especially Holdren in Ref. 253).

1. More people ⟶ congestion, urban sprawl, more distance to cover ⟶ more energy for transportation per capita.

2. More people ⟶ higher gross demand for resources ⟶ higher demand for the most energy consuming and marginal resources or synthetics.

3. More people ⟶ higher demand from agriculture ⟶ more energy (fertilizer, machines, transportation) per acre or per ton of food.

4. More people ⟶ more everything, even if affluence tries to stay constant ⟶ more pollution (for a given technology and abatement) ⟶ more technology and abatement to maintain the same level of "clean air, water, land" ⟶ more energy, materials needs to maintain same quality of life.

In other words, more people at a given level of affluence, more mess, more energy just to keep up. Or, population growth (and affluence growth) multiply themselves and create greater "needs" to keep running.

I did not postulate readjustment in technology or lifestyle or affluence to offset population increases, or any other permutation of these items. But it should be clear that the various inputs to life interact, and population size is an important multiplier in this interaction. Technology could reduce the impact of affluence, but, then again, if population were lower and technology more provident, impact and energy use would be still lower.

There are a variety of energy forecast methodologies (Fig. 53) discussed in Refs. 161 - 163, and 210 but the forecasts are usually extrapolations of present trends, often in great detail, so that the forecaster estimates growth in each consuming sector and then projects the total demand, looking to the energy industry to see if requisite fuels can be obtained. Demand reduction can occur in many ways:

1. Sudden reduction in demand due to shortages, conservation, climatic beneficence or economic collapse.

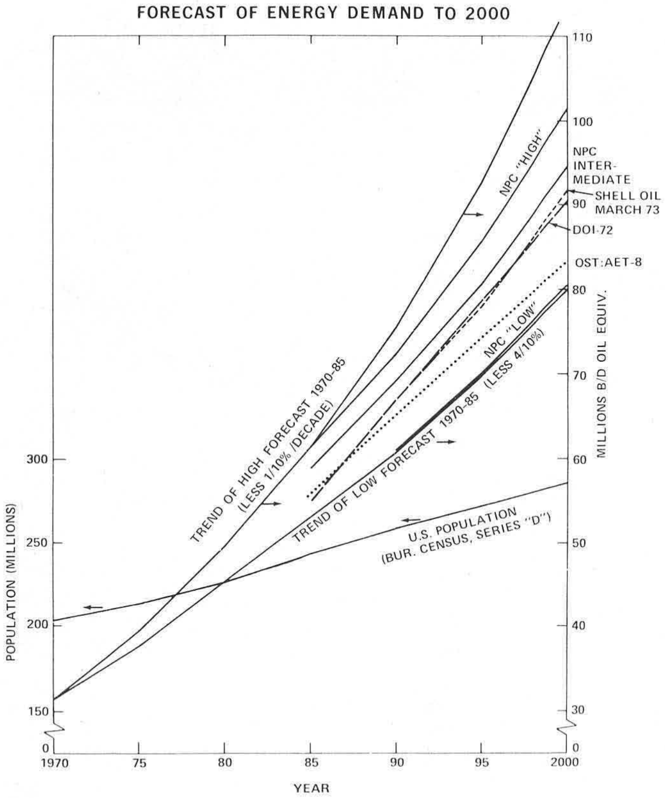


Fig. 53. A comparison of energy demand forcasts. (From Ref. 35). (XBB 747-4351)

2. Stabilization in demand: i.e., if expected rises in demand are just cancelled out by conservation, the net change will be zero. Some conservationists will look dismayed, not realizing that conservation did take place. The head of the California Public Utilities Commission, Mr. V. Sturgeon, did report to me that electricity demand in California had indeed dropped by X% in the spring of 1974 compared to 1973, instead of rising at the historic 7% rate. Based on these figures the reduction in demand was really (7+X)%. How son the growth returns in 1) or 2) is always an open question.

3. "Slowed Growth" (see Refs. 100 and 208). In slowed growth the yearly growth percentage is lower than in traditional forecasts as efficiency measures, market-price effects, and life style changes evolve to increase energy productivity. As Summers (24) points out, all of these demand patterns succumb eventually to exponential growth, when and if that growth returns or quickens. For more discussion of growth curves see Ch.5 in Ref. 11 and Refs. 164, 165, 260.

Energy industry people attempt to predict the amounts of various fuels that might be available at a given time and price. A notable study by the National Petroleum Council (110, 161) fills several volumes and treats the energy supply situation in great detail. But most studies state explicitly or implicitly that the effects of changing technology, rising efficiency, environmental restraints, rising prices, consumer awareness, or changing lifestyle are not included. One can, however, take a critical look at projections, realizing that it is possible to postulate several energy futures, with energy consumed by different sectors at various efficiencies. One should not postulate a priori that downward adjustments in energy use automatically imply adverse economic conditions or changes in lifestyle, as stated in the NPC study. One might instead compare various energy futures and energy use technologies, as well as the possible shifts in consumer patterns or even lifestyles, and quantify the differences, pointing out costs and benefits from various levels of energy use. The Energy Policy Project of the Ford Foundation, (100,101), for example, examines three scenarios, and in its final report makes clear the various assumptions and data used.

While energy conservation and efficiency is significantly overlooked in most studies written before 1972, many recent studies (257,258) allow for the effects of conservation. Reviews by the Exxon and Shell Oil Companies (109,257) explicitly allow for possible effects of energy conservation. Similarly the "Project Independence" movement formed by the Nixon-Ford administrations to eliminate the dependence on foreign sources of energy also looks at Energy Conservation. While I am not implying that these studies are right or wrong in their approaches to physics or policy, they should be noted as among the first from the energy industry or the U. S. Government which now do project energy savings as part of the "conventional" future scenario, something the conservationists called for years ago.

At the same time economists are busy trying to predict the effect of inflation and price rises for particular forms of energy; will rising prices dampen growth and encourage conservation? (See Refs. 210 - 214,156.) While many industry and government sources assume little effect from rising prices, a growing body of literature is accumulating which seeks to study these effects. We are also asking how changes in energy prices will effect various income classes, in particular, the poor. Conclusions seem to point to price rises which have caused a slowing trend in the growth of demand. Tyrell, Chapman, and Mount, for example, studied not only energy prices, but personal income and appliance prices as well in analyzing changes in electricity use. The assumptions shown in Fig. 54 might result in the different levels of consumption as indicated (309-14). While these results are still under much discussion, we see that perhaps we ought to explore the full implications and prices of several energy futures. If rising prices do not dampen growth in energy use then we must be able to predict what consumers and businesses will give up in order to be able to afford as much energy per capita as the high projections of Fig. 53 and 54 imply.

One overlooked part of the energy system is the importance of the cost of energy on our lives. Figure 55 illustrates the relative amounts of energy that various American income families buy, and the fraction of their incomes that they spend for energy. While it may be no surprise to see that the poor tend to spend a larger fraction of their incomes on energy than the rich, the rich far out-consume the poor due to indirect consumption, that is, in products and services (40,122).

Herendeen and his co-workers are looking at the energy pie from a dollars-per-Btu point of view, tracing the detailed flow of energy and dollars in the economy. Usually the cost of energy is buried in the goods and services we enjoy, but some services, materials, or goods are energy- intensive, and energy-expensive. (See Table 9).

While the price of energy usually adds about 5% (or less) to the cost of most things, the energy cost for airline travel, aluminum, or many chemicals can be as much as 15% of cost of producing the product (155). Figure 56 shows Hannon's results (266) for labor and energy requirements for things in 1963, and indicates how we would decide the effect of adding more demand for some things, less demand for others. Put in a dollar's worth and see what it buys in energy and jobs. Direct energy purchases, incidentally, buy fewer jobs than nearly anything else.

Herendeen's results (Fig. 55) and Table 9 suggest that we can estimate our "energy cost of living" by figuring what we buy, what services and transportation we use, and what energy and materials went into them. The energy cost of gifts, for example, is discussed in Ref. 270.

Other research is directed towards possible changes in consumer habits as rising energy prices push up the cost of certain goods over others: plastic furniture, for example, would rise in price relative to hand made wood furnishings as petroleum prices moved up. Possible effects of energy taxes on prices and patterns of consumption are also studied, and this topic is the subject of many sharp debates. Researchers use a technique called input/output analysis to see just how much labor, energy, and capital is required to produce a given product or service. Producers will begin varying inputs or production methods as energy costs rise; many observers see a greater demand for labor as a possible result. Reference 268 discusses more of the conclusions of input/output work in addition to those noted here.

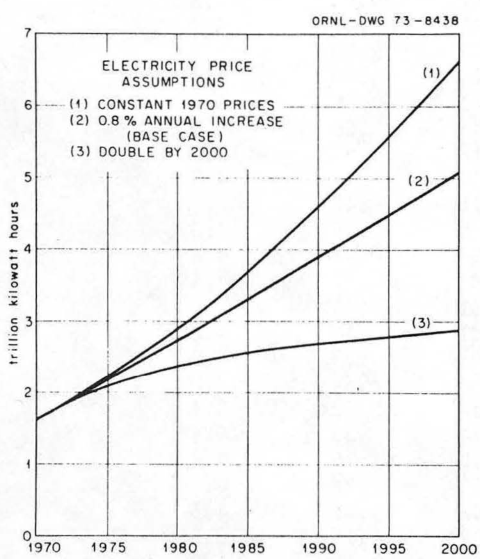


Fig. 54. A forcast of the effects of price increases on electric power demand. (From Ref. 214).

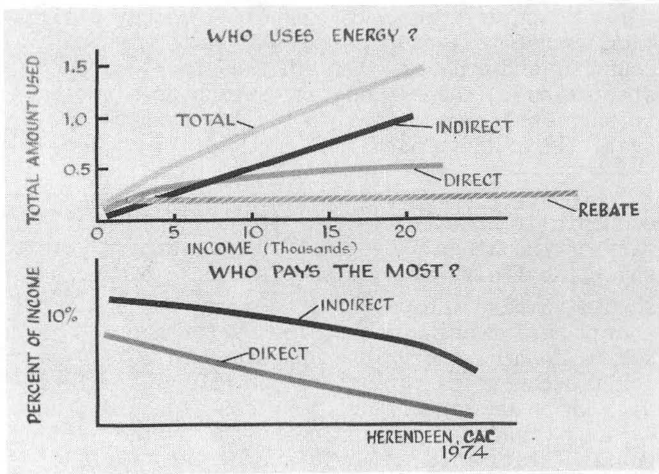


Fig. 55. Use of energy by income and percentage of income. (Adapted from Ref. 157.)

(XBC 745-3349)

Many suggest that the trend to a "services" economy, rather than a production economy, will require less energy. But if service industries are housed in energy inefficient buildings, and dependent upon trucking and large autos, the total energy picture might not change.

The relation between the GNP of a country and its energy use is interesting. Many state as proven fact that energy consumption and standard of living are directly related (see Ref. 82 for example). A closer look, however, reveals much variation in physical factors such as efficiency, climate and demography, resource availability, as well as factors such as price and life style. (Many of these factors are discussed in Ref. 100.) Since, in addition, there are many factors in industrial production besides energy, it is naive to represent this correlation of GNP and energy use as an iron-clad destiny. Perhaps the relationship indicates instead of kind of evolutionary path taken by nations as they rely on their cheap energy resources as the primary tool of economic and social development. Recent trends in the USA of changing energy consumption per unit of GNP (Fig. 59) also serve warning to approach this relationship cautiously (253). I emphatically recommend a multi-dimensional approach to the relationship of energy use and society, a relationship that is often maligned and over-simplified by looking at this graph.

One technical example illustrates the dangers inherent in correlating the energy input 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. If one counts all the inputs to steam electric generation in Sweden, one finds the balance shown in Fig. 60. The similar balance for the USA is shown in Fig. 58. (Ref. 70) The differences in energy utilization is striking: In Sweden, 53% of the output of thermal plants is used as industrial or residential heat or electricity, while in the United States, very little of the waste heat from power plants is utilized. This large scale difference in technical energy utilization is not reflected in the GNP statistics of a country, and only shows up in the gross energy statistics to the extend that Sweden does not have to burn fuel to get some of its low-temperature heat. (From Refs. 63-65 and Fig. 23.)

However we choose to pursue energy and economic growth, it is clear from Fig. 62 that many of the other nations of the world have yet to enjoy the fruits of wise energy use. Explainers should compare the per capita energy use and total energy among various countries. Reference 305 gives a breakdown of energy use and standard of living for two countries, Great Britain and New Zealand, with which we can compare American standards, and various organizations including the United Nations publish statistics on world energy use. (Ref.34) Those who are skeptical about the reality of the energy crisis today ought to consider the implications of world industrialization and the growth in energy use tomorrow (Fig. 63). If all nations today consumed energy at today's per capita rate (in the U.S.) world energy consumption would be six times higher, based on 3.5 billion people at 12,000 watts per capita. This effect can be seen visually by filling in the entire graph in Fig. 62 If the world of the year 2000 kept our pace (25,000 watts per capita by traditional predictions) then its probable that 7 billion people would use nearly 25 times what 3.5 billion use today. Figure 63 shows projections of world energy demand. Note how the U.S. share falls as most countries try to catch our per capita usage. These numbers are so staggering that we are forced to consider all of the political and economic ramifications they contain, asking both "Where do we go from here?" and "How do we get there?" In addition, one should observe that as world resource prices rise in response to demands from the most industrialized countries, the developing nations will be caught in a squeeze between expanding population, rising prices, and reduced access to the very elements that the industrial countries were nourished on! (See Ref. 34 and speeches in Ref. 26.)

Table 9. Btu Content and Energy Value Content of Selected Goods and Services: Partial List

PRODUCT	ENERGY CONTENT (Btu/$)	GALLONS OF GASOLINE EQUIVALENT	ENERGY VALUE CONTENT (¢/$)
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
Metal Doors	109,875	.88	6.7
Cooking Oils	94,195	.75	7.1
Fabricated Metal Products	91,977	.74	5.8
Metal Household Furniture	91,314	.73	5.9
Knit Fabric Mills	88,991	.72	6.5
Toilet Preparations	85,671	.70	5.1
Blinds, Shades	81,472	.65	6.3
Floor Coverings	79,323	.63	5.8
House Furnishings	75,853	.61	5.3
Poultry, Eggs	75,156	.60	7.3
Electric Housewares	74,042	.59	5.6
Canned Fruit, Vegetables	72,240	.58	5.2
Motor Vehicles & Parts	70,003	.56	5.9
Photographic Equipment	64,718	.52	3.8
Mattresses	63,446	.51	4.5
New Residential Construction	60,218	.48	4.5
Boat Building	60,076	.48	4.9
Food Preparation	58,690	.47	4.8
Soft Drinks	55,142	.44	4.5
Upholstered Household Furniture	51,331	.41	4.1
Cutlery	50,021	.40	4.0
Apparel, Purchased Materials	45,905	.37	4.0
Alcoholic Beverages	43,084	.34	3.0
Hotels	40,326	.32	5.4
Hospitals	38,364	.30	5.4
Retail Trade	32,710	.26	4.4
Insurance Carriers	31,423	.25	4.4
Misc. Professional Services	26,548	.21	4.3
Banking	19,202	.15	2.5
Doctors, Dentists	15,477	.12	1.9

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

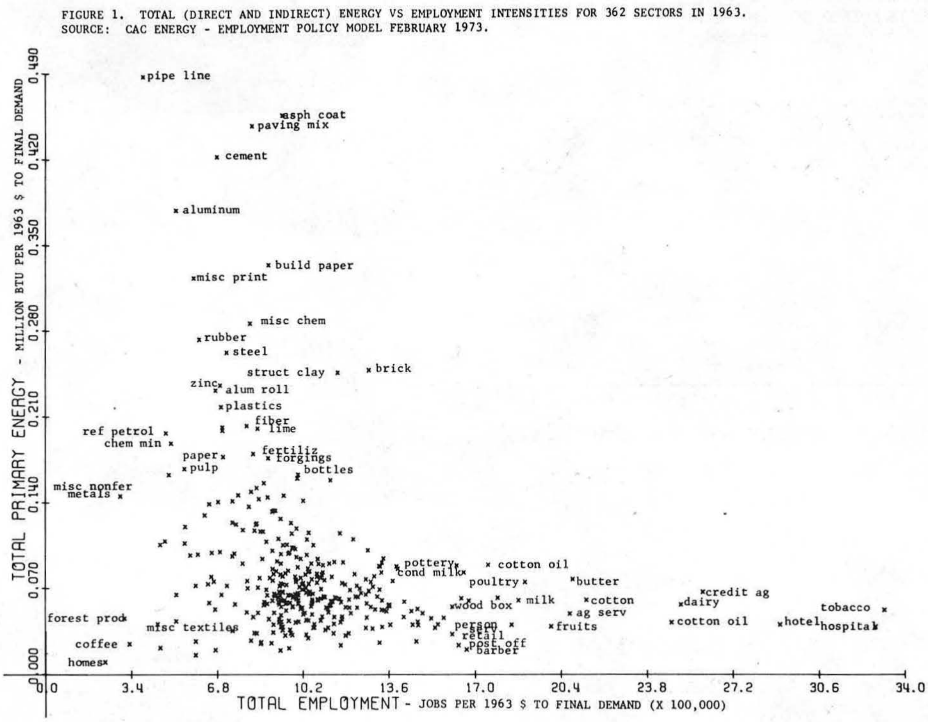


Fig. 56. Actual labor vs energy content of goods and services in 1963. (From Ref. 266).

(XBB 744-2413)

Fig. 57. It took this much energy to produce a buck's worth of GNP in 1970. But we can do better. Dollars are just paper; energy is real! (Author's appologies to Schultz, GNP in 1958 dollars, data from Ref. 34.)

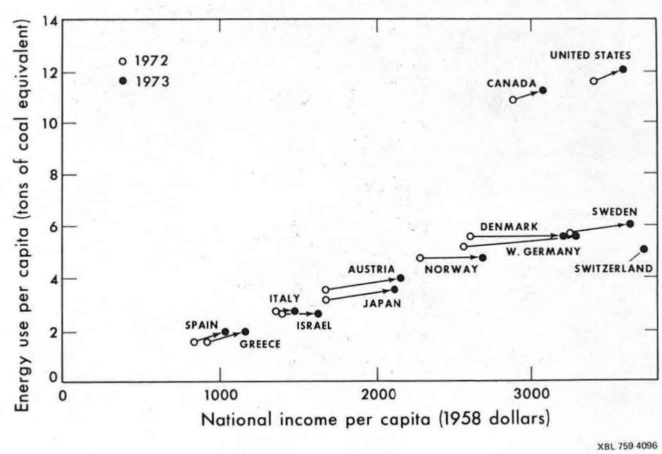


Fig. 58. Energy use and the national income per capita displayed for some important industrial nations. Note how the U.S. and Canada have high use of energy per dollar. (From Ref.253).

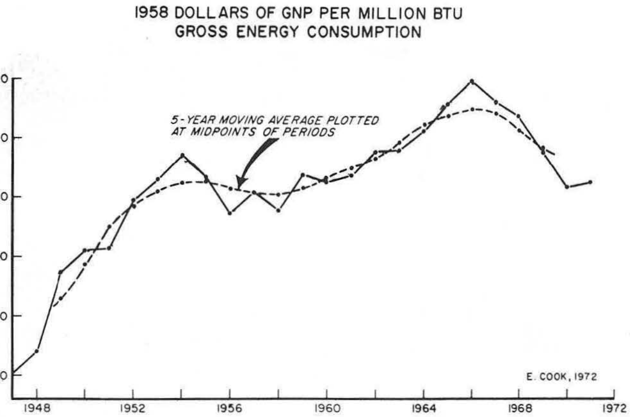


Fig. 59. Relationship of energy use and the GNP.

(CBB 7410-6796)

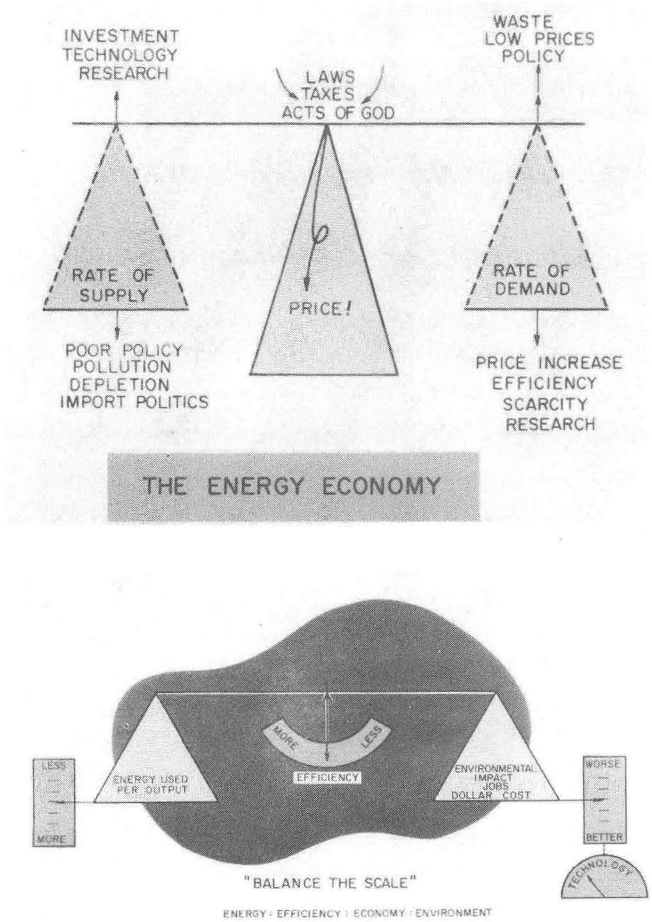


Fig. 61. These two symbolic scales suggest that the so-called energy use-GNP relationship needs further refinement. Too many other factors are as important as gross energy inputs to economic well-being.

(CBB 746-4197)

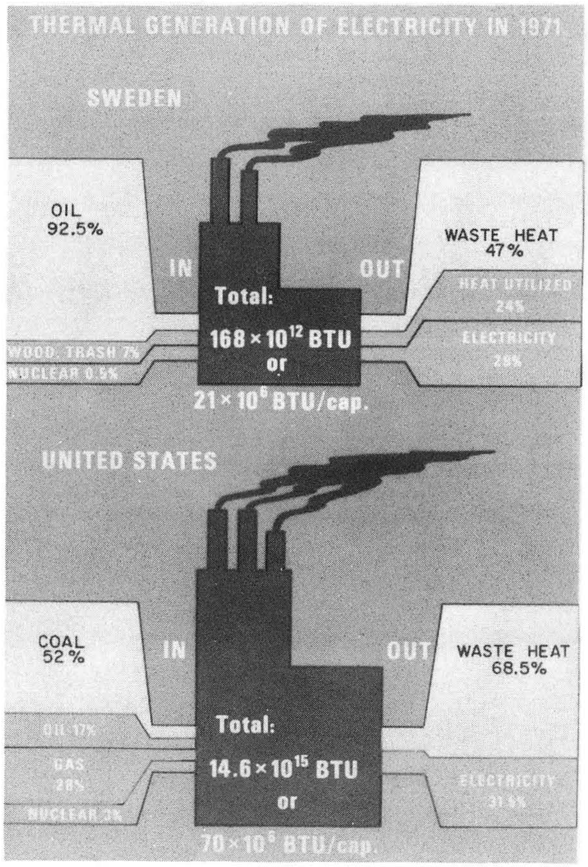


Fig. 60. A comparison of thermal generation inputs and outputs in Sweden (above) and the U.S.A. (below). (From Ref. 70). (CBB 755-3827)

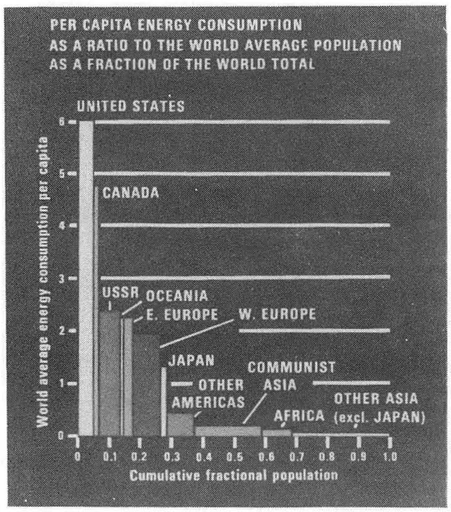


Fig. 62. Average per capita energy use represented by height, population by width. Guess who uses the lion's share? (CBB-756-4277)

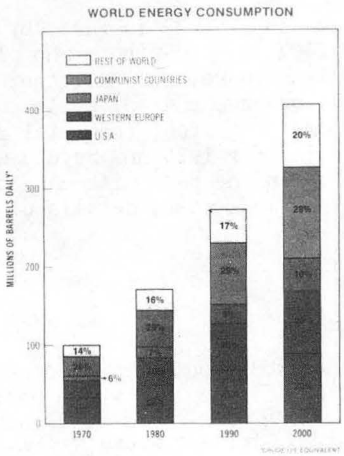


Fig. 63. Growth in world energy use. Our share falls as they catch up! (From Shell Oil Co., Ref. 36). (XBC 742-689)

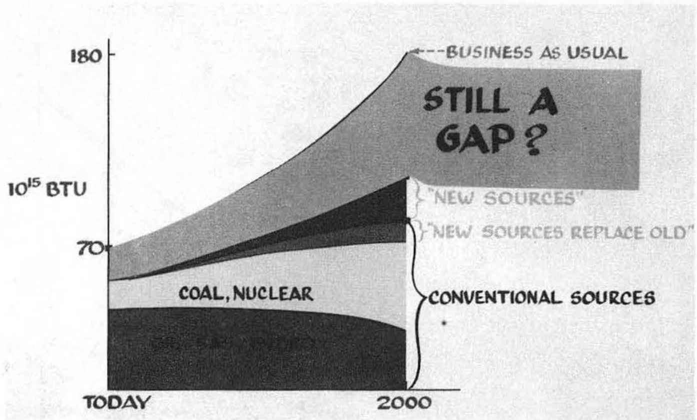


Fig. 64. We try harder...but there is still a gap. Import? (XBC 744-2384)

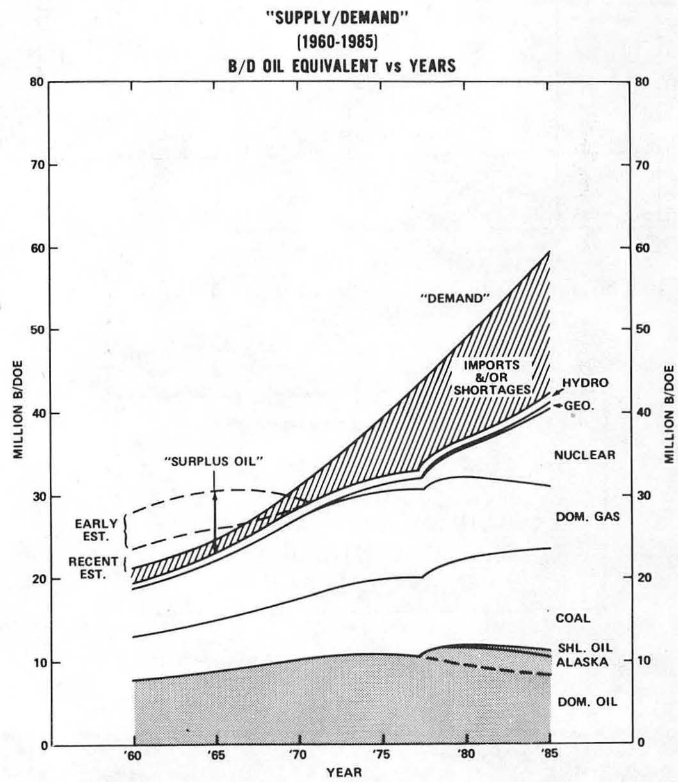


Fig. 65. The future: bleak. (Joint Committee on Atomic Energy, Ref. 35). (XBB 747-4360)

FILLING THE SUPPLY PIE TOMORROW

All energy futurists seem to agree on one point: new sources of energy will have to be developed, no matter how fast or slow energy use grows– maximum efficiency with no supply is no comfort. Nor is abundant, but polluting energy fuel. But "abundant cheap energy" (32) is not necessarily as desirable a goal as "reliable, clean, safe, efficiently used" energy.

In my view, based on information contained in Refs. 3,11,100,150 250-287, conservation plays a very key role in easing the pressure for energy, keeping prices reasonable, and allowing time to develop "new sources." (Figs. 64, 65). Conservation also allows the role of certain "new" technologies, like solar energy, energy from wastes, and wind energy, to assume a proportionally larger role than in the full growth futures predicted a few years ago. In the Joint Committee on Atomic Energy scenario (Fig. 65), nuclear energy plays an important roll, with "imports or shortages" filling the gap. What the JCAE overlooks is that shortages will not come about if the demand fails to materialize, i.e., if the nation does in fact mobilize to meet the challenge of energy conservation. The study by the Ford Foundation Energy Policy Project (EPP) (100) looks at not only the traditional and conserving ("technical fix") scenarios, but also a "zero energy growth" future, zero population growth having already been assumed. (Fig. 66). Since only a minority of writers and workers seem to have accepted the inevitability of an end to growth in the rate of energy use, population, and eventually, in the rate of economic expansion, the debate over "limits to growth" is in its infant stages and makes many tempers run high (166a, 818). What is clear, however, is that one cannot expect technology to violate physical laws in order to satisfy what we deem today (or tomorrow) to be socially necessary. For today, however, the impact of growth, especially concerning population growth and the rise in standard of living in underdeveloped countries, has become bound up in the details of energy use (and abuse).

The criteria for allocating research funds in the search for energy sources have been widely discussed (501,503,505), and the five conditions of Fig. 67 come into play at all times. In addition, most policy-makers ask whether a new form of energy conversion will be easily adapted to our presently existing hardware.

Amidst the criticism that we have "all our eggs in one basket"--the nuclear fission basket--there has been renewed interest in other forms of energy conversion, as shown by the variety of baskets in Fig. 68. Note that the gas and oil eggs

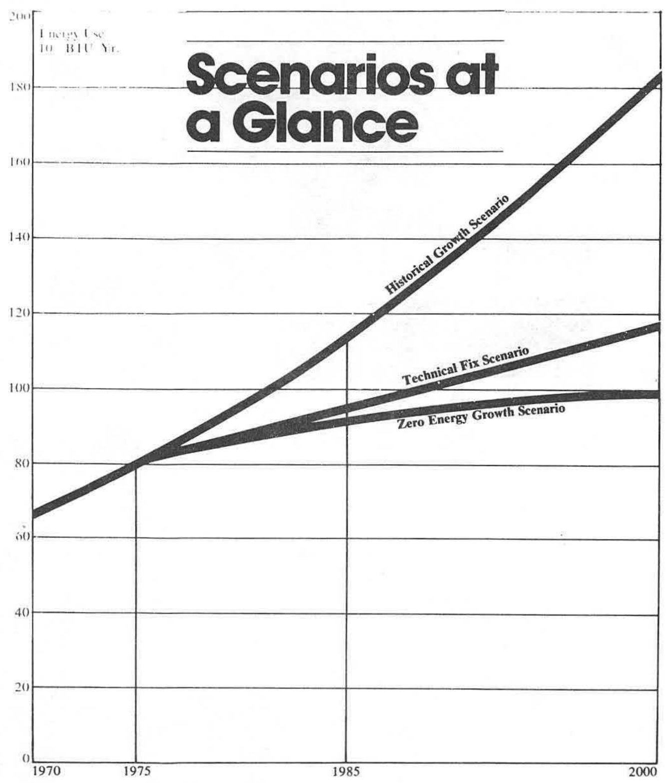


Fig. 66.Ford Foundation scenarios. (From Ref. 100).

EVALUATING NEW SOURCES:

1. COST
2. SIZE OF SUPPLY
3. RATE SOURCES CAN BE USED
4. ENVIRONMENTAL IMPACT
5. WHEN AVAILABLE?

Fig. 67. Choosing which pies to bake.

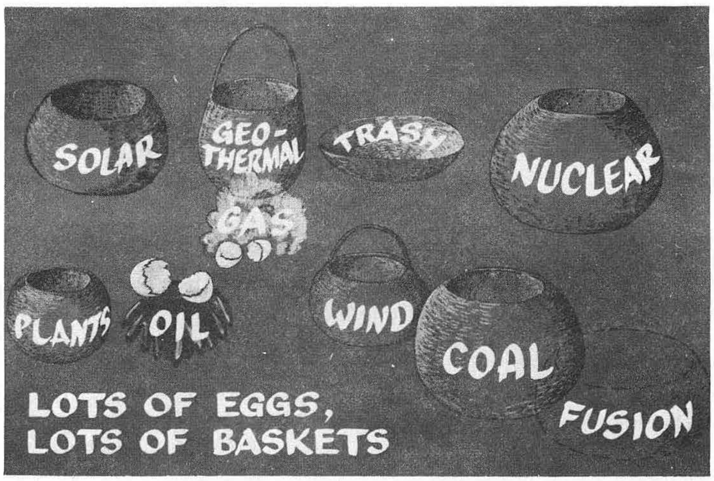


Fig. 68. Lots of eggs, lots of baskets. But the oil and gas eggs are broken!

have been broken, suggested, in fact, by the work of Hubbert (33,24,, 2) and others who claim that while these fuels have not run out, their rates of domestic production have peaked. While competition for research funds is fierce, the total private and federal funding for 1975 and beyond will be much broader than in the past with many projects studying, for the first time, details of energy consumption.

Nuclear Fission

The most talked about form of energy conversion is nuclear fission, in which heat from the fissioning of certain forms of uranium (see Fig. 69) is used to drive a steam system and produce electricity. While nuclear power thus generated only provides about 5% of all electricity in the US today, that fraction is growing fast, and traditional forecasts place the nuclear share of electricity at around the 50% mark by the year 2000 (553,567,570).

Nuclear energy is heralded by its proponents as safe, economic, reliable, and environmentally clean: There is virtually no air pollution, much less solid waste by volume than from coal-fired electric generation, and nuclear plants are generally quiet and attractive.

In the nuclear basket, Fig. 72, we see three eggs whose initials stand for the three most commonly discussed kinds of nuclear reactors. Light Water Reactors are the kinds most commonly built today, but they use only the 0.7% of natural uranium which is of the right (fissionable) type (U-235). One by-product of these reactors is plutonium, which fissions, and which can be included in the fuel cycle at a later time. LWRs produce more waste heat per unit of electricity than the best fossil fuel plants.[7] A more advanced form of reactor, the High Temperature Gas Cooled Reactor (HTGCR), utilizes a slightly different form of uranium, or thorium, in a different fuel cycle, but produces more useable fuel (as a by-product) than the LWR and operates at a higher efficiency. The LMFBR, Liquid Metal Fast Breeder Reactor (5,701,6), or "breeder", converts unusable

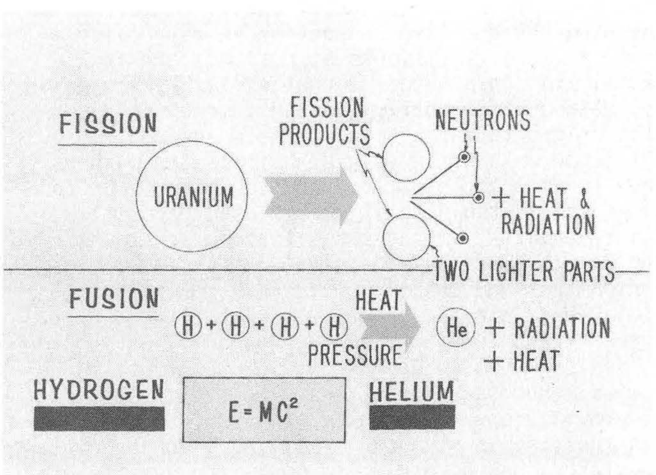


Fig. 69. Fission and fusion compared. (XBC 746-4285)

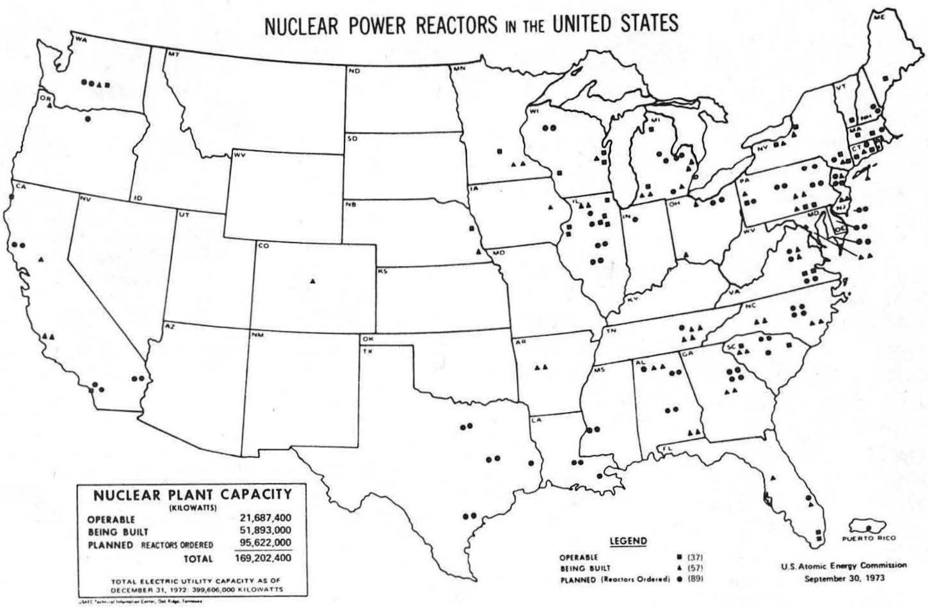


Fig. 70. Where the nuclear plants are/will be.

(XBB 744-2412)

Table 10. Fy 1976 Energy Research and Development Admin. Budget, Millions of Dollars

Nuclear Fission Power	2342
Theoretical and Experimental Physics	367
Nuclear Fusion -- Magnetic & Laser	208
Fossil Fuel	332
Solar	57
"Conservation" (of which 10% end-use)	$35 ($100)
Geothermal	29
Advanced Systems (MHD, Fuel cells, etc.)	23
Weapons	1026
Total Classifiable items	4419
Other	556
Grand Total	4975

Source: Nuclear News, April 1975, and J. Holdren, private comm. The figure for Conservation was magnified recently by Congress and appears in parenthesis.

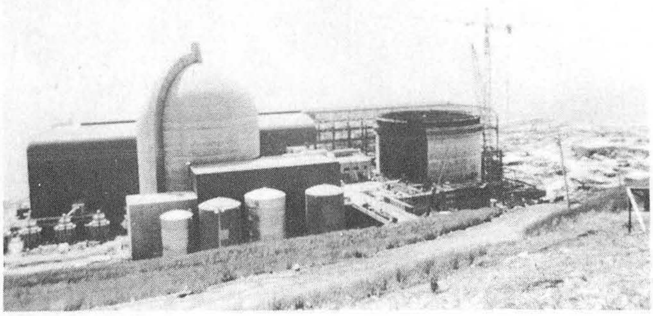


Fig. 71. The P.G. & E. nuclear power plant under construction at Diablo Canyon on the central California coast. The two units of this plant will each have a capacity of 1000 MW and are scheduled for completion in 1976 and 1977. (XBB 747-4363)

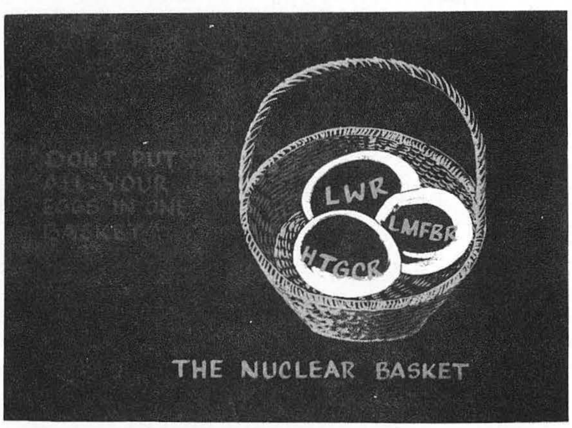


Fig. 72. The nuclear basket. (XBC 746-3686)

U-238 to plutonium while "burning" U-235 or plutonium, and actually makes more usable fuel than it burns.[8] The breeder reactor is the center of a very hot controversy over its economics and priority, though construction of a full-scale test breeder began in 1974. Explainers who touch on the issues of nuclear power should read relatively unbiased accounts of nuclear power, as in Refs. 6, 9, and 11, as well as accounts of the advantages and disadvantages as seen by the nuclear industry (553) and its critics (550). Attention should be paid to the careful accounting of the economics of nuclear power, especially with the large amount of capital required to build a plant (569,570f, 570j).

Nuclear fuel is considerably cheaper per unit of generated electricity than most fossil fuels, and nuclear fuel is plentiful. But the cost of fuel is only a part of the cost of generated electricity. The cost of nuclear electricity is particularly insensitive to the cost of the raw uranium ore (555, 569). The cost of building a nuclear power plant is higher than that for a comparable fossil fuel plant, and utilities have to compete today (1975) in a tight money market, financing more of their growth from today's utilities rates. Still, growth in nuclear power is impressive, as over 100 nuclear power plants have been operational, under construction, or ordered. (Ref. 570d,j). Experiments are taking place to test the feasibility of floating nuclear power plants, and some have suggested the clustering of reactors into large "nuplexes," where fuel enrichment, reprocessing, and storage would be combined on-site with multi-million kilowatt clusters of power plants. A typical single reactor produces electricity at the rate of 1000 MW. An accelerated program would allow for the substitution of nuclear plants for anticipated fossil fuel power plants and even the substitution of electricity for fuels in home heating, transportation, and industry, as discussed in Ref. 567, and in the Atomic Industrial Forum paper (277). One cautionary note, however, the demand for money, engineers, workers, and even materials limit the rate of expansion of nuclear power, especially as costs for plants continue to rise.

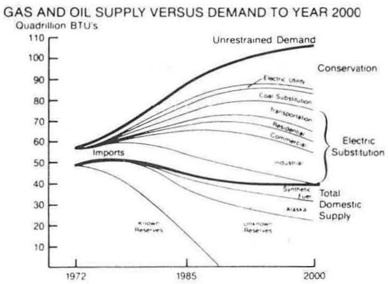


Fig. 73. Westinghouse Corporation solution. Substitute electricity wherever possible. But at what total cost? (From Ref. 567; used by permission).

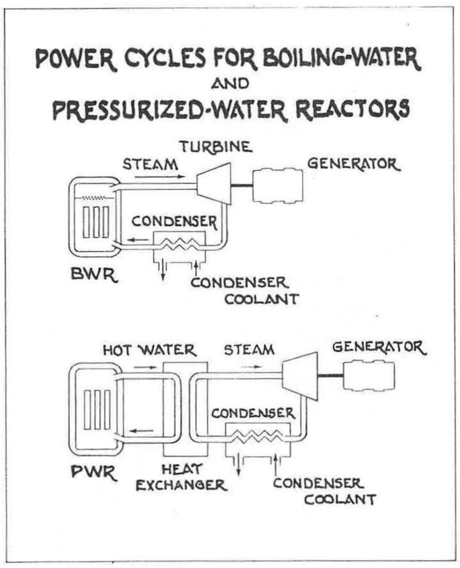


Fig. 74. Two types of light water reactors. (From Ref. 3). (CBL 747-4985)

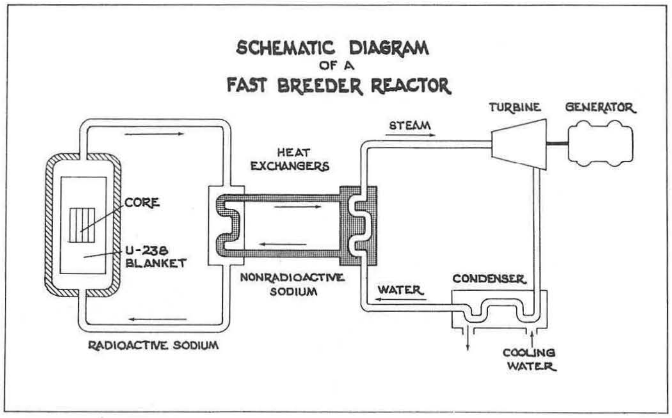


Fig. 75. A breeder reactor schematic. The uranium in the blanket is converted to plutonium while the fuel in the core "burns." (From Ref. 3). (CBL 747-4879)

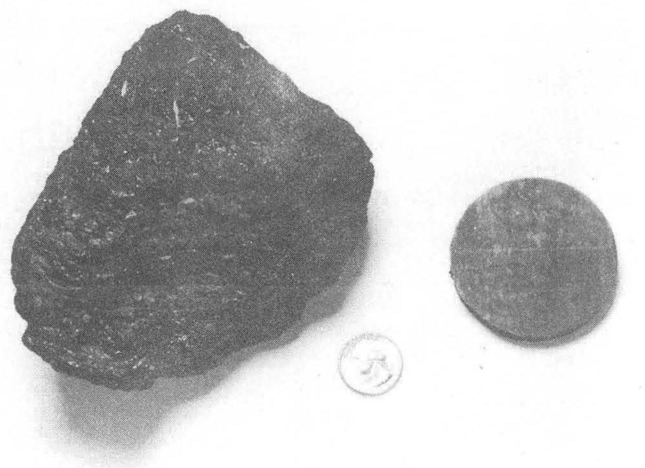


Fig. 76. Compare one pound of uranium (right) with one pound of coal (left). The uranium is pure metal, 0.7% U-235, and would generate about 21,000 times as much heat as the coal. If the naturally occuring U-238 were used in a breeder reactor, it would generate over a million times more heat than the coal. But these figure do not include the energy cost of processing uranium or coal. If only it were that simple! (BBC 746-4210)

The safety issues for all fission power plants revolve around certain well-defined questions and the most often discussed include: (Fig.77)

1. How probable, or improbable is the release of radioactivity due to accidental overheating of the reactor and failure of the backup cooling and containment systems? (551,558,563-65).

2. How meaningful are our calculations in 1? (564,565).

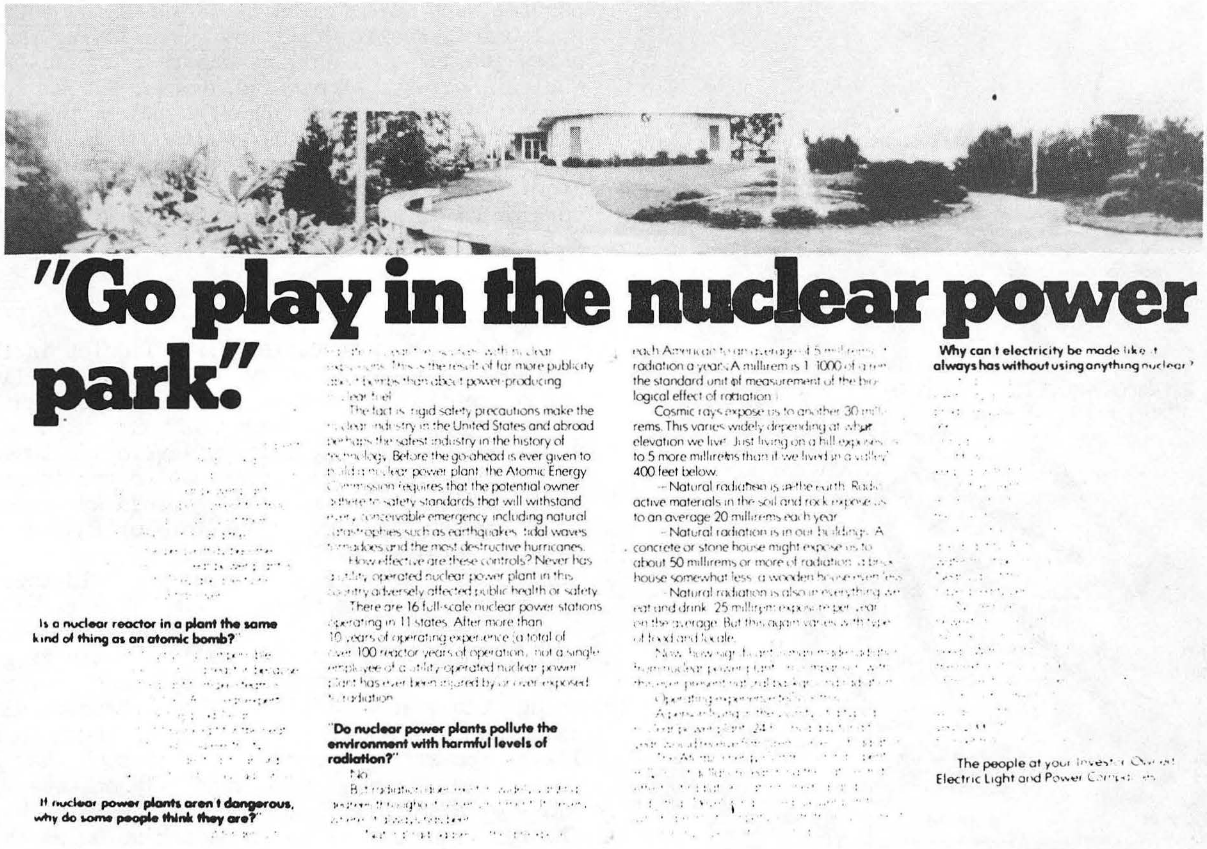


Fig. 77. Nuclear safety means a lot more than what this ad talks about. (From "the people at your investor-owned utilities.").

(XBB 747-4364)

3. How safe is the fuel cycle (outside of the reactor) against accidents in shipping or reprocessing, or theft? (554,561). (Fig.78).

4. What are the best means for disposing of the wastes which, while small in volume (compared to the ash from coal giving the same amount of energy), are intensively radioactive, so radioactive that they must be kept out of the biosphere for centuries? (566,570e,f).

5. How vulnerable is the entire fuel cycle to sabotage and/or human error? (556).

6. Where should nuclear power plants be located? (See Refs. 560, 562 and 568).

I have omitted routine releases of radioactivity from power plants, which have been reduced to levels satisfying nearly everybody (568,826). The subject of routine releases, and the fact that nuclear power plants do not blow up like an atomic bomb should not be taken as sufficient proof of the safety of nuclear power.

Though there is much discussion and controversy, scientific or otherwise, as to the answers to these questions, the hardest topic to evaluate is perhaps the risk/cost vs. benefit analysis inherent in any social decision to adopt a technology. Particularly difficult is the weighing of an improbable event with potentially catastrophic consequences against every day, less consequential but probable danger, such as the damage to health from fossil fuel emissions (568,826).

The nuclear industry has pointed out that delays in the granting of permits and licenses, as well as labor and material shortages or engineering delays stretch the time needed to build a nuclear plant to nearly 10 years. Yet the licensing and permit hearings are the step at which the public is supposed to be able to express its feelings on the site, safety, or necessity of a particular power plant. Often critics of proposed nuclear power facilities have pointed to mistakes in utility need projections, or possible conservation measures that would postpone the need for a particular power plant (212 and 259). Indeed two stories from the Wall Street Journal (Fig. 79) tell of the high cost of a new power plant in New England ($750 per kW of capacity) on the one hand, and money not invested because slower growth in demand erased the "need" in Arizona, on the other. Thus a big factor determining the ultimate role of nuclear power will be how much, how soon, and at what cost. The reader is urged to contact reactor manufacturers, local utilities, environmental groups, and others for more views on the pros and cons of nuclear power. These issues are being given wide ex-

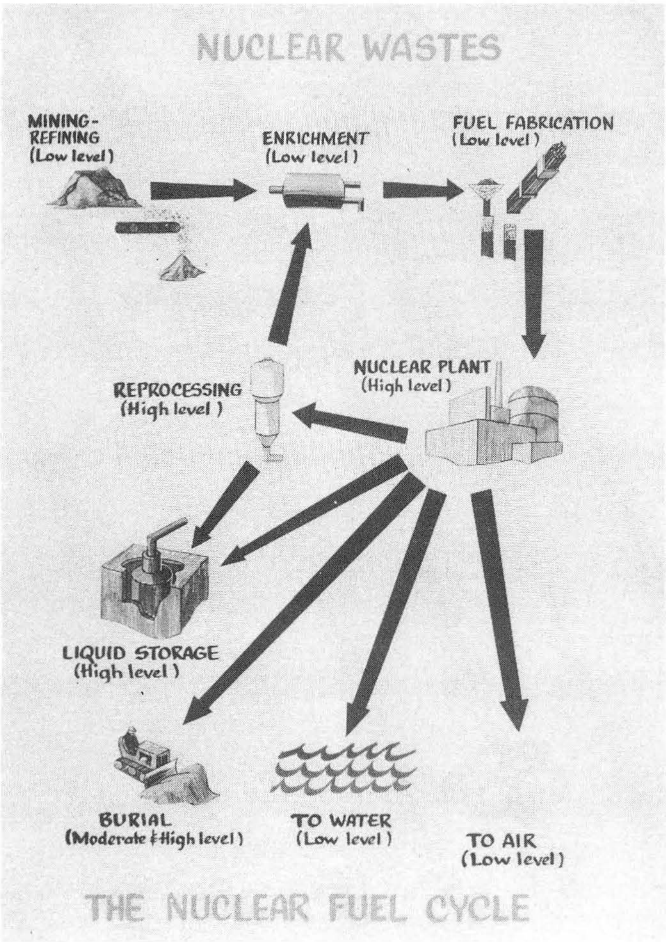


Fig. 78. The nuclear fuel cycle. But the leaks are a concern. (CDB 746-4193)

posure, both scientifically (Science, Nuclear News, Nucleonics, Public Utilities Fortnightly, to name a few journals, as well as papers from the American Nuclear Society, Atomic Ind. Forum, Union of Concerned Scientists, and others), and in the media. Witness the full page ads, radio and television commercials, pamphlets and utility "bill stuffers," stockholders magazines, and so forth. (For discussion of the role of "Experts" see Steinhart in Ref. 132.)

Nuclear Fusion

Nuclear fusion differs from fission in that the joining together of two or more of the lightest atoms provides the energy to make large quantities of heat (Fig. 69). The recent oil embargo has inspired a new effort towards developing fusion (which has yet to be carried out in the laboratory), which would produce more energy than was needed to start up the process. In one form of fusion, a very high temperature gas, or plasma, of deuterium (a form of hydrogen) is compressed and held together by intense magnetic fields (Figs. 80,81). When the fusion reaction ignites, heat can be removed and used to make electricity. The difficulty is getting the plasma hot enough and dense enough, for a long enough time, and fulfilling these three conditions simultaneously. A newer approach has been to use lasers, powerful sources of light, such that the laser beams converge simultaneously on several sides of a small pellet of deuterium (Figs.82,83). The resulting implosion of deuterium holds the matter together long enough for the fusion reaction to ignite, and the heat generated is used for electricity. This reaction too has not occurred yet with a net energy surplus, and work now mainly awaits the perfection of the most powerful lasers ever constructed. "Will it ever work?" can be asked, too!

Utility to Build $1.7 Billion Plant In New England

Westinghouse Will Supply $100 Million of Reactors To New England Electric

By a WALL STREET JOURNAL *Staff Reporter*
WESTBORO, Mass.—New England Electric System said it plans to build a $1.7 billion nuclear power station with total capacity of 2.4 million kilowatts.

The utility hopes to build the station in Charlestown, R.I., at the oceanfront site of the abandoned Charlestown Naval Air Station. It is negotiating with the Navy to buy the station, which has been declared surplus.

A spokesman said the company has other potential sites in Rhode Island, Massachusetts and New Hampshire but considers Charlestown "our prime site."

MORE? IT WILL COST!

Arizona PS to Reduce Spending Through '76 By Some $63 Million

By a WALL STREET JOURNAL *Staff Reporter*
PHOENIX – Arizona Public Service Co. said it will reduce its capital spending $63 million through 1976 by delaying for one year the in-service dates of generating units under construction at two power plants.

"New, updated studies show that we can defer the completion dates of these projects without affecting our ability to meet the needs of our customers," said Keith L. Turley, president of the utility. He added that the company was "pleased" to make the reductions when financing costs are at record levels.

Expenditures will be reduced $13 million, to $174 million, this year and will be lowered $34 million in 1975 and $16 million in 1976, the company said. Transmission lines and substations associated with the generating units also will be delayed, it added. The generators affected will produce a total of more than one million kilowatts.

Arizona Public Service said the new studies indicate that future peak demand will be lower than earlier estimates.

LESS? UNIT PRICES WILL NOT RISE SO FAST.

Fig. 79. Two items from the Wall Street Journal.

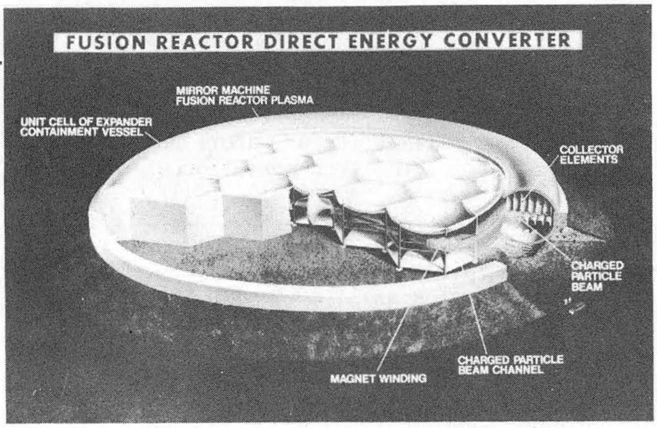


Fig. 80. A possible fusion reactor using magnetic confinement. (Courtesy of Lawrence Livermore Laboratory). (XBB 747-4365)

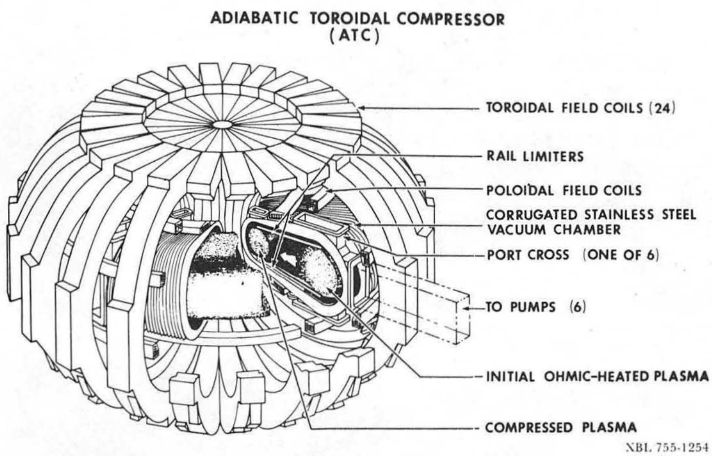


Fig. 81. What the inside of a plasma fusion machine might look like.

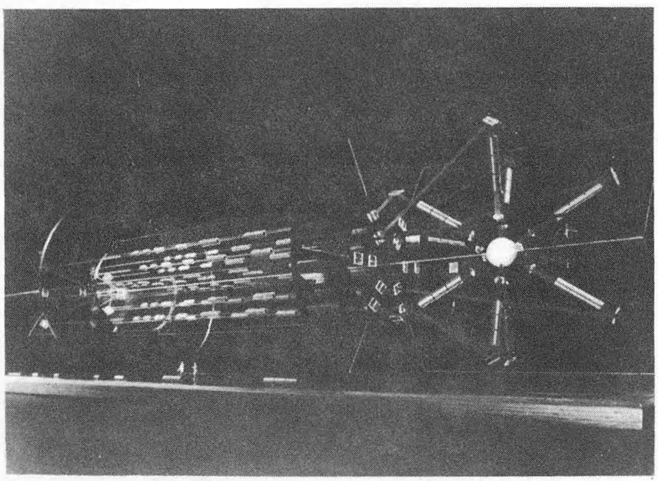


Fig. 82. A model of a possible laser implosion fusion reactor. Light from the left is amplified, reflected into the ball near the right, and implodes a pellet of deuterium located inside. (Courtesy of Lawrence Livermore Laboratory). (XBB 747-4366)

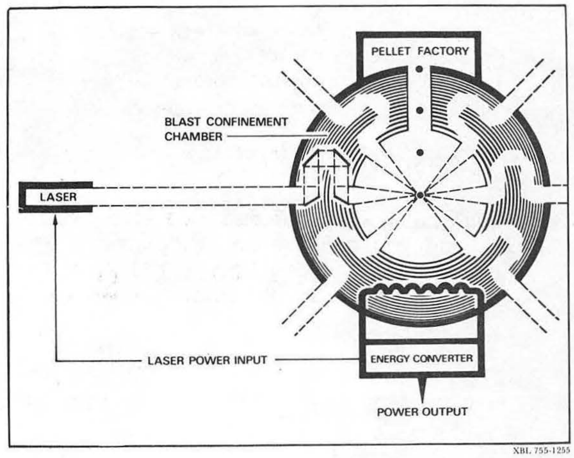


Fig. 83. How laser fusion will work.

Since deuterium exists in nature as a small fraction of all the hydrogen in water, the fusion egg is particularly limitless, as the world's oceans contain enough deuterium for millions of years worth of power. However, four points should be accentuated in any discussion of fusion:
1) critical materials needed for fusion machines may be someday in short supply,
2) the cheap fuel costs will be overwhelmed by undoubtedly expensive investments required to build fusion reactors, 3) a nearly infinite supply of fuel does not allow us to increase the rate of usage indefinitely, because fusion, like all other energy forms we have considered so far, converts energy to heat (see below), 4) and fusion, while free of many of the hazards of fission, nevertheless produces radioactive tritium, and the metals that line the walls of the reactor become highly radioactive. Fusion may be a cheaper lunch than fission, but it is not free (See Refs. 580, 582-585, and especially 6).

Fossil Fuels

Since fusion is not here today, we might look into the other eggs in the basket (Fig. 68). The search for advanced methods of recovering and converting fossil fuels faces many problems. Coal is plentiful, but strip mining and deep mining both are wrought with environmental and safety hazards that cannot be overlooked. Worse, much of our coal contains sulfur, which creates another environmental hazard when the coal is burned. Techniques for converting the coal to liquid, or combustible gas, like ethane or hydrogen, are being examined (617,622, 627, 823). Furthermore, work is proceeding in the removal of the sulfur dioxide and other chemicals emitted by burning coal, and in removing particles and ash that also result. Since the coal egg is the largest fossil egg, this work could have a big payoff, though social issues concerning the problems of coal miners and mining areas of the USA should also be examined[9] (671,626).

Any discussion of oil (see above) must address itself to problems of how much oil is available at a given price, and how fast the oil can be pumped at a given price. A look at the Hubbert Diagram (Fig. 85) drawn for oil alone suggests that oil

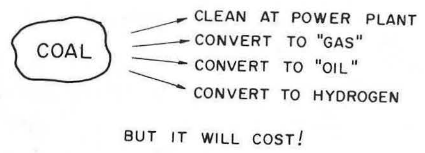


Fig. 84. "Coal has two problems: You can't mine it, and you can't burn it," says S. David Freeman of the Ford Energy Policy Project. But coal is abundant. (XBB 745-3347)

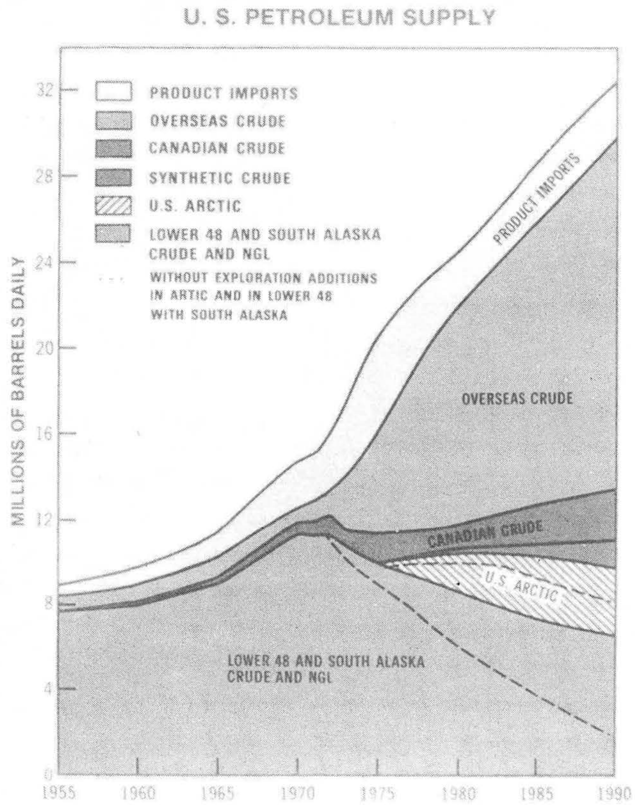


Fig. 85. Prospects for oil. Note the similarity to Fig. 27 if you ignore imports. (XBL 741-497)

use has peaked but will not cease for many years--the figures for natural gas (Fig. 86) are similar. Industry spokesmen tend to be optimistic about "how much" but also remind us that the cost of additional supplies will rise. Probably Alaskan oil, offshore oil, and increased recovery from old wells can at least maintain a stable rate of domestic supply at around 10 million bbl/day or more for some time, but the economic reports in the Wall Street Journal or Business Week remind us that domestic production of oil in the USA has fallen for more than a year. Higher post-embargo prices will certainly aid the oil companies' attempt to boost the rate of production, but as Hubbert implies, there is a point of diminishing returns. Finally we should not forget that increasing rate of supply only hastens depletion.

Still, oil offers some hope in addition to coal. Increased exploration and advanced recovery techniques to recover oil from sand and shale (Fig. 87) may prove helpful in the long run, as these supplies are potentially large (615, 519, 629, 630). No free lunch here, however, since some shale rock contains as little as 15 gallons of oil per ton (Fig. 38), so that shale mining will involve large areas of land and, in particular, problems concerning the availability of water, and, its possible pollution. The transportation of oil poses some problems too; the famous oil spills, the issues of where to put pipelines, and special deep water ports to handle supertankers are still being debated. And in spite of energy shortages, plans to build new refineries still meet with stiff opposition from local residents on environmental grounds.

Increasing natural gas supply may be the most challenging egg in the basket (620, 624, 625, and 631). Figure 87 indicates that a combination of synthetic gas (SNG) made from coal or even oil, or liquid natural gas (LNG) would extend the peak of natural gas use a few decades. Since an extensive pipeline distribution system for gas already exists in the USA, it would seem advantageous to develop new sources or forms of this fuel.

The "net energy" mentioned earlier must be considered when dealing with advanced fossil fuel sources: Do exploration, recovery, conversion, and transportation costs add up to more useful energy than is ultimately recovered when the fossil fuel is used?

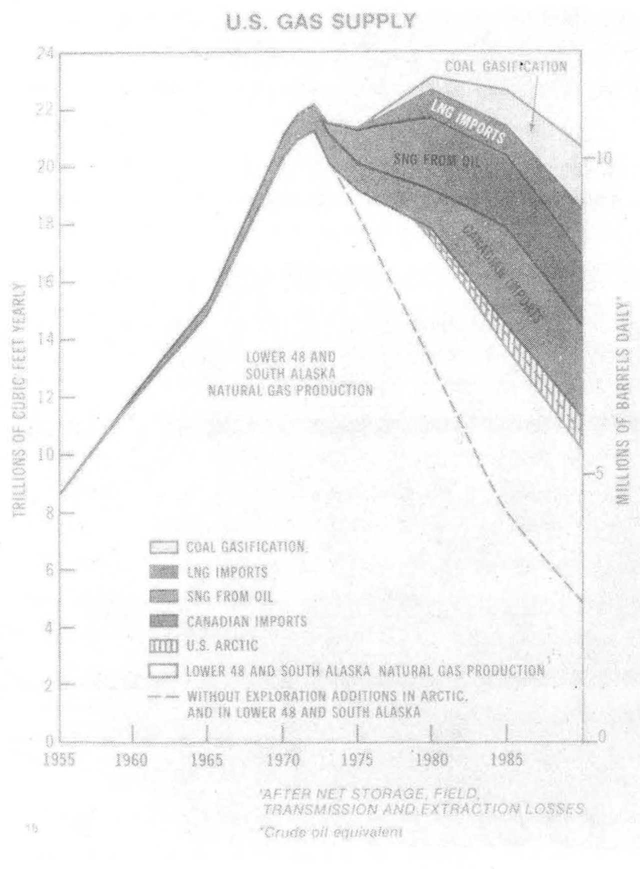


Fig. 86. Prospects for natural gas. Note the similarity to Fig. 27, and how we try to stretch out the time of peak usage. (XBL 741-496)

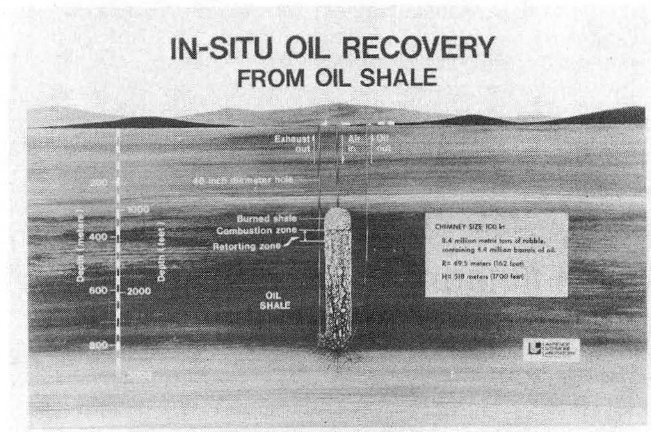


Fig. 87. One concept for oil from shale. But be careful about the environmental impact and net energy recoverable. (From Lawrence Livermore Laboratory, Ref. 624). (XBB 747-4367)

We must not forget that the energy cost of these fuels rises with the real cost. Cook, for example, (Fig. 88) shows how the cost of drilling a well rises exponentially with depth. In addition much of the energy content of shale oil and coal will be consumed in converting these to synthetic gas and oil, as these figures show! Vyas and Bodle estimate the following net energy output from various synthetic fueld processes. Their estimates do not include energy expenditure for capital equipment or harvesting (earth moving, crushing, water supply) nor are transportation energy requirements given. Figures are percentages of Btu-inputs (from Ref. 630).

In summary, we can look to continued use of fossil fuels, but rates of use of oil and natural gas will probably not rise significantly over the peaks of the 1970's. Imported oil and gas as well as synthetic fuels will play an important role in energy balances. Coal, while large in supply, will rise in useage as environmental, logistic, and financial factors permit.

Solar Energy

Since the fossil fuels, as forms of stored energy, are being used up quickly compared to the millions of years they took to be formed, much attention has been focused on "renewable" or continuous energy sources: solar energy, tidal energy, windmills and hydropower.[10] Hubbert and others point out that nearly 50% of the ultimate hydropower only generates a relatively small shae of electricity (15% in the USA in 1972) its full expansion might mean the loss of wild rivers and scenic valleys without making a dent on electricity supplies. Hence the interest in solar energy which is non-polluting, abundant, and apparently free. We should emphasize apparently free, for with solar energy it is the conversion and storage facility that costs (700-715).

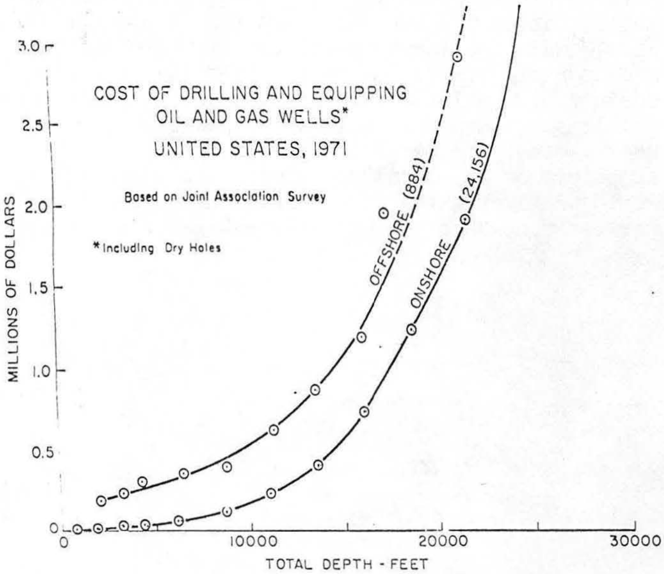


Fig. 88. Energy, materials, and dollar costs rise spectacularly with scarcity. (From Cook, Ref. 159, used by permission). (CBB 740-6794)

While economics and materials considerations have hampered the development of certain forms of solar energy, this renewable source should not be omitted from an evaluation of the energy future, especially since heating and cooling of buildings can be available soon and at economic savings over the lifetime of the building being affected even before we consider employment, pollution reduction and energy demand reduction benefits from using solar energy. Other pathways to solar energy include 1) use of concentrated solar heat to run central steam systems for producing electricity, 2) bio-conversion, or processes that use plants or

Table 11. Comparison of processed gas energy content.

	Process				
	Lurgi-Gas		CSF-Coal Process	Coal-Methanol	Shale-Syncrude
% of Btu's recovered in desired form	56.2% Gas	59.7% Gas	32.2% Fuel Oil 21.5% Ga~	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%

plant materials to make fuels or split water into hydrogen and oxygen, and 3) direct conversion of the sun's light to electricity, probably from solar cells similar to those found on space-craft.[11] Since solar energy systems do reduce pollution (including heat added to the earth's surface) to almost nil, solar energy has advantages beyond those that simple dollar economics might show.

Wind as a source of energy was all but abandoned by western society in the 20th century, fossil fuels having become too cheap to justify new investments in windmills and storage devices. Now the situation has reversed, and many small (kilowatt) and a few large (megawatt) wind generators are appearing (710). While the fact that the wind doesn't blow all the time creates obvious storage problems, wind power, like solar power offers the user a great degree of independence from energy suppliers or the local power grid. To some it is worth whatever extra investment is required to harvest renewable resources (see Figs. 93,94).

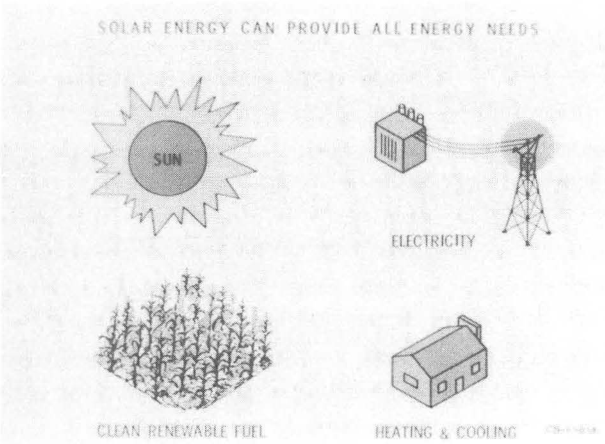


Fig. 89. Various ways to harness solar energy.
(XBB 747-4369)

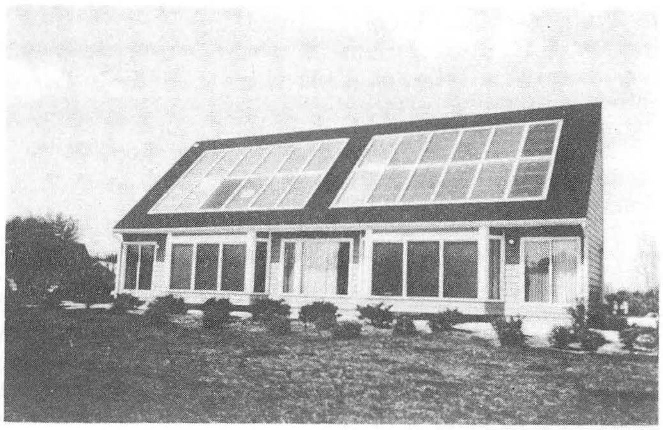


Fig. 90. The solar house "Solar One" at the University of Delaware (see Ref. 180b). This house gets heating, cooling, and electricity from the sun. (Courtesy of M. Telkes, Institute of Energy Conversion, University of Delaware). (XBB 747-4370)

That solar energy uses renewable resources presented an economic dilemma until the U. S. Congress indicated its willingness to phase out certain tax anomalies (e.g., the depletion allowance) for the fuel extraction industries (see Ref.179 for an excellent discussion). The difference between non-polluting, renewable sources of heating, cooling and work and pollution-ridden fossil fuels are certainly not shown in the prices of fossil fuels, which rarely include pollution or health costs in their price.

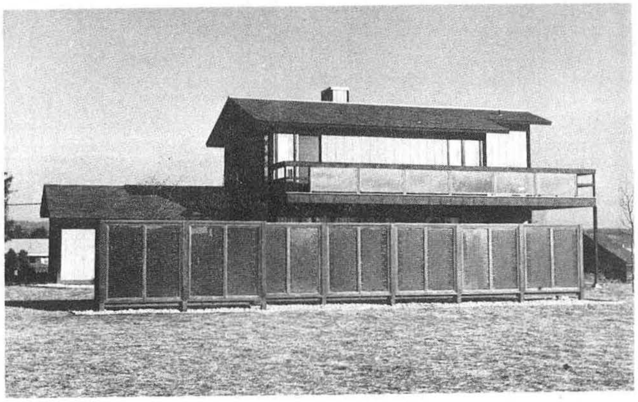


Fig. 91. The house of the future. This innocent looking structure is actually a low energy house, constructed by the Pennsylvania Power and Light Co. near Allentown, Penn. Solar energy falling on the vertical panels is used along with a heat pump for heating. Low energy automation keeps curtains closed when the sun goes down. The heat circulation system (see Fig. 92) keeps heat in the house by recycling heat from various sub-systems, making this house also a total energy house. Someday we'll all live in these kinds of houses. Eat your heat out Edison!!

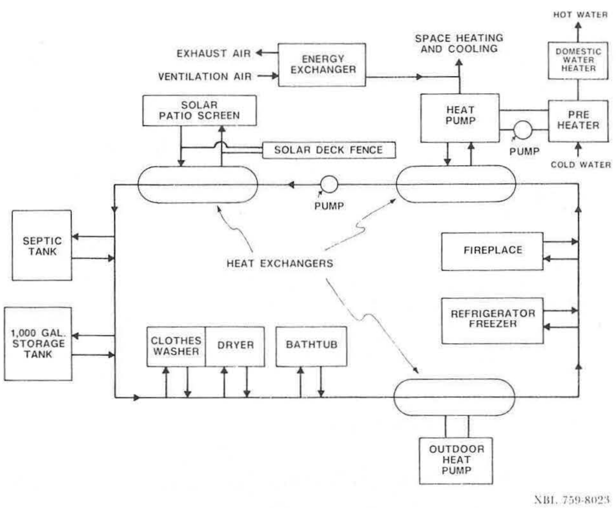
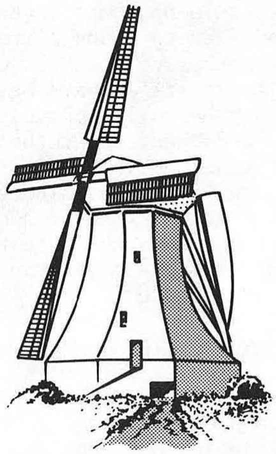
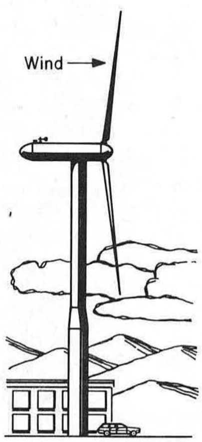


Fig. 92. Schematic for house of the future.



XBL 753-2478

Fig. 93. It worked in the olden days!



XBL 753-2480

Fig. 94. A modern windmill design. (From Ref. 710).

Geothermal Energy

Increasing attention has been focused on geothermal energy, especially in the western United States, where already a large fraction of the electricity used in San Francisco is generated by the system run by the Pacific Gas and Electric Company at The Geysers (Fig. 95). Basically, one captures underground heat that results from a thinning of the earth's crust that allows the hotter interior materials to come within a few miles of the surface. By finding naturally occurring steam, by using hot water existing underground, or by pumping water into hot dry rocks, one captures some of this geothermal heat and uses it to run steam systems. But, even geothermal energy faces certain environmental problems, such as the hydrogen sulfide gas common to many underground water formations, the caustic minerals in the water, or the radioactive gas radon, which geothermal wells may contain. These issues should not be overlooked in a discussion of geothermal power (601, 604, and 4).

Table. 12. World geothermal power production, 1971.

		Electrical Capacity, MW	
Country	Field	Operating	Under construction
Italy	Larderello	358.6	
	Mt. Amiata	25.5	
U.S.A.	The Geysers	192	110
New Zealand	Wairakei	160	
	Kawerau	10	
Japan	Matsukawa	20	
	Otake	13	
Mexico	Pathé	3.5	
	Cerro Prieto		75
U.S.S.R.	Pauzhetka	5	
	Paratunka (freon plant)	.7	
Iceland	Namafjall	2.5	
		790.8	185
			Σ=975.8

Table 13. Geothermal energy resources potential.

Year	1975	1985	2000
Power (thousands of MW)	0.75	132	395
Electrical Energy[1] (millions of MWH)	5.913	1,041	3,114
Oil Equivalent[2] (millions of Bbls/day)	0.024	4.213	12.60
Foreign Trade Impact[3] (billions of dollars/year)	0.051	8.919	26.67

1. 90 per cent load factor
2. 3,412 BTU/KWH and 5,800,000 BTU/Bbl of oil used at 40 per cent conversion efficiency
3. $5.80 per barrel ($1.00 per million BTU)

*Hickle Report

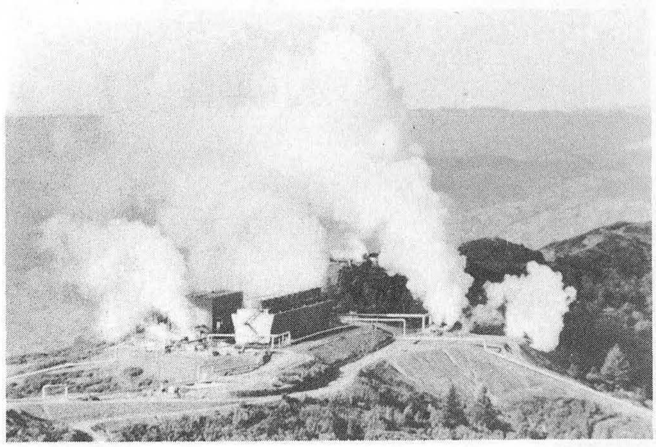
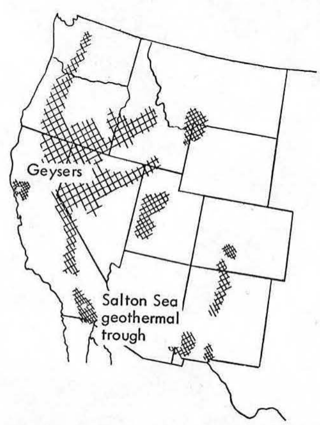


Fig. 95. Geothermal power, here nearly 1000 MW, is alive and well at the Geysers in California. (Courtesy of Pacific Gas and Electric Co.) (XBB 747-4371)



Existing and potential geothermal areas of the western United States.

Fig. 96. Some places to look for geothermal power.

(XBB 747-4372)

Other "Non-Scheduled" Energy Sources

While we have not exhausted the list of possible new sources of energy, we have mentioned the most promising ones that are receiving attention at present. One additional source, the recovery of fuel from sewage or solid wastes, is receiving wide attention and actually represents a kind of leak plugging (623,627-628). This idea solves a solid waste disposal problem, and adds to the supply of fuels that can be burned to make electricity or cooked to make a liquid or gaseous portable fuel.

The idea of capturing energy or fuel which would otherwise be thrown away is usually termed "total energy." Figure 97 shows one system similar to that in use in the town of Vasterås in Sweden. In Fig. 97 solid waste is burned in a power plant (perhaps mixed with coal) and both electricity and low temperature space heating (or industrial heat) are produced. similar to the diagram (Fig. 60 illustrating electric power conversion in Sweden.[12] In a different kind of total energy system (Fig. 98) a factory generates its own electric power, using the waste heat for process heat, and selling any surplus electricity to the local utility (a strange twist!). Berg (22) discussed some of the problems such systems face. References 301, 315, 250, 576, and 377 discuss total energy systems (see also footnote 12).

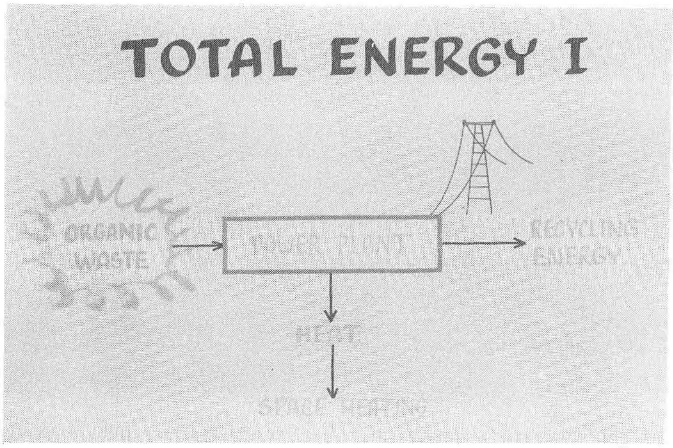


Fig. 97. Electricity from solid wastes. (XBC 744-2519)

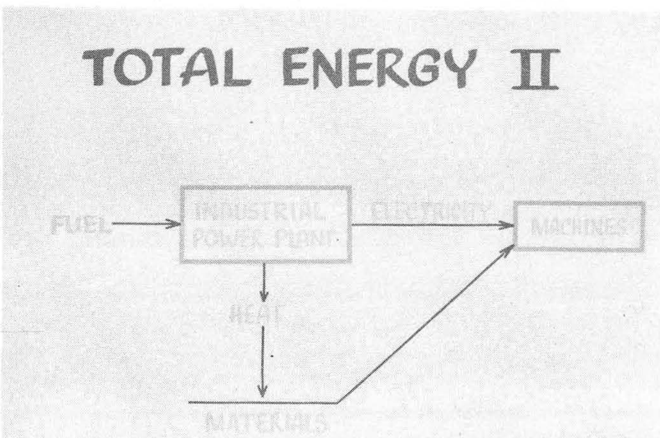


Fig. 98. A system for manufacturing heat could also produce heat for space comfort. (XBC 744-2318)

Explainers should no doubt investigate less familiar sources of energy, and certainly many ideas not treated here may prove to have much merit (515, 112). Still, we will always be hounded by questions such as "When will we have...?" "Why do we not have...?" and "What about the pill that turns water into gasoline?" The first two questions are, of course, legitimate and sincere, but the third represents a common kind of question asked of the author. It represents the hope that science and technology may someday break the very rules upon which they are founded!

ANOTHER LOOK AT ENERGY USE: CONSERVATION

The energy pies (Fig. 99) show American consumption by various end uses and economic sectors. Explainers should point out that the pies do not tell the whole story, since no efficiencies or prices are given for the various forms of consumption, nor do we see the end products or services we get. We tend to overlook the fact that the object of heat (or cool) is comfort, and that industrial heat is used for production. By contrast the amounts of energy consumed say very little about what actually happens, and this point is often overlooked by explainers. (See earlier discussion of efficiency, where it was indicated that the temperature of heat/cool used is an important parameter of how much fuel must be consumed.) Table 13 shows the information from Fig.99 sorted by energy quality or temperature.

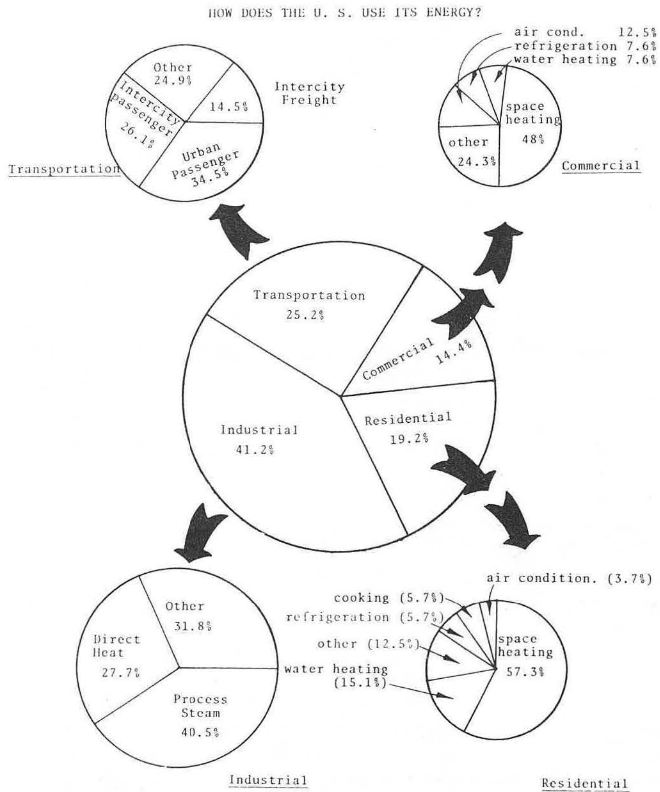


Fig. 99. How the U.S. uses its energy. (From Ref. 25). (XBB 747-4355)

We should also recall from Fig. 61 that energy is but one input to the economy as a whole. This is symbolized by Fig.100 in which we see that various goods and services demand different amounts of labor and energy (and capital, land, design, pollution, and so forth). Increasing the efficiency of energy use moves the average energy requirements for a unit of goods/services towards the lower part of the figure, and, as we see below, to the right (more "jobs"), not by increasing sweat or hard labor, but by substituting other economic factors for energy, factors which directly and indirectly employ more manpower.

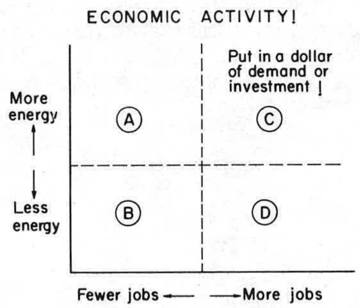


Fig. 100. How the economy uses its energy. (From Ref. 25). (XBB 744-2413)

We can also ask ourselves about the role of efficiency in energy use by breaking down for example the energy requirements of the automobile by physical processes, as is done in Fig. 101 Note that both First and Second Law efficiencies are represented here. Or, we can look at efficiency of energy use in the economy from a task or output point of view. Figure 102 for example, shows the varying energy requirements of many familiar passenger transportation modes per passenger mile, which, after all, is one measure of the utility of transportation. Changing the physical efficiencies of automobile energy use involves engineering as well as economics, and such changes can reduce the physical requirements of a given propulsion system. At the same time, changes in social behavior and values could change the size of cars people dirve, the number of miles they drive, the kinds of trips they take (long or short, downtown or out in the country), or change the number of people who participate in each trip. Certainly we should recognize the differences between purely physical-economic changes in physical efficiency and the more broad changes in social use-efficiency of automobiles which energy conservation might usher in. Both Fig.103 and Table 14 suggest a version of the song, "It Ain't How Much Ya Use, It's The Way That Ya Use It." We must examine the quality of energy use as well as the quantity of energy use, but this idea was overlooked in nearly every traditional energy survey or forecast until recently. When Cook, for example, redrew his original spaghetti bowl (159) shown in Fig. 24, he changed the overall (First Law) efficiency of energy use from 50% to 33%. As we examine the details of energy use, we will find that conservation means "doing better" rather than "doing without."

Table 14. A.P.S. 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 and other		4	-
Feedstock	———	5	-
Other		5	-
		100	

a. Sources: Reference 11 and 80. "Work" is defined as "infinite-temperature" energy by the APS study.

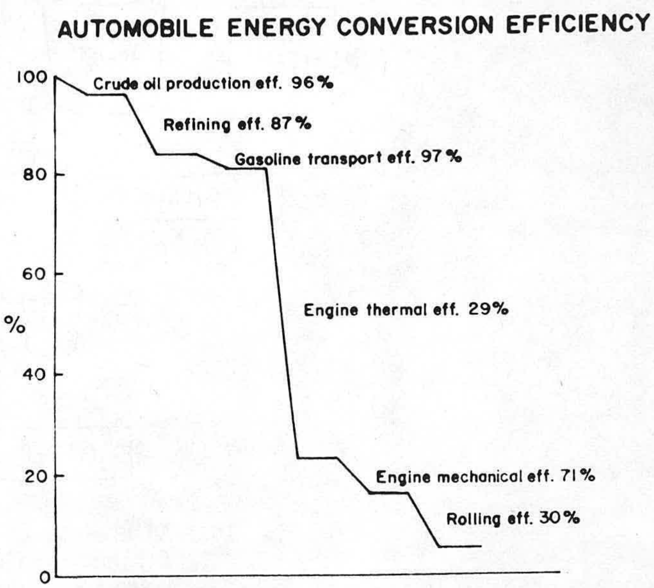


Fig. 101. Where the gas goes. (From Ref. 25).

(XBB 747-4346)

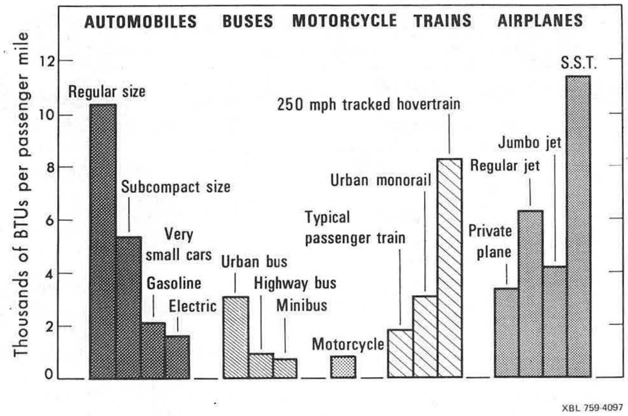


Fig. 102. Energy consumption of various transporation modes. (From Refs. 261, 333).

The energy buckets in Fig. 103 designed by Yegge (25), remind us that we can carefully examine the energy system to see what leaks exist. Since 1971, increasing attention has been paid to the idea of energy conservation, or, better put, increased efficiency of energy use. Under careful implementation, the payoffs are not only improved efficiency but lower costs, reduced pollution, increased employment (see below) and most important, lower investment requirements for the energy industry, and thus slightly lower prices, which are very sensitive togday to demand and capital requirements. This suggests a rather touchy topic, that "we are all in it together;" that the price Mr. Brown pays for gas for his Volkswagen depends on the number of miles Mr. Green drives his Cadillac. Thus energy utilization is a topic that should be discussed from all points of view, including political and social perspectives.

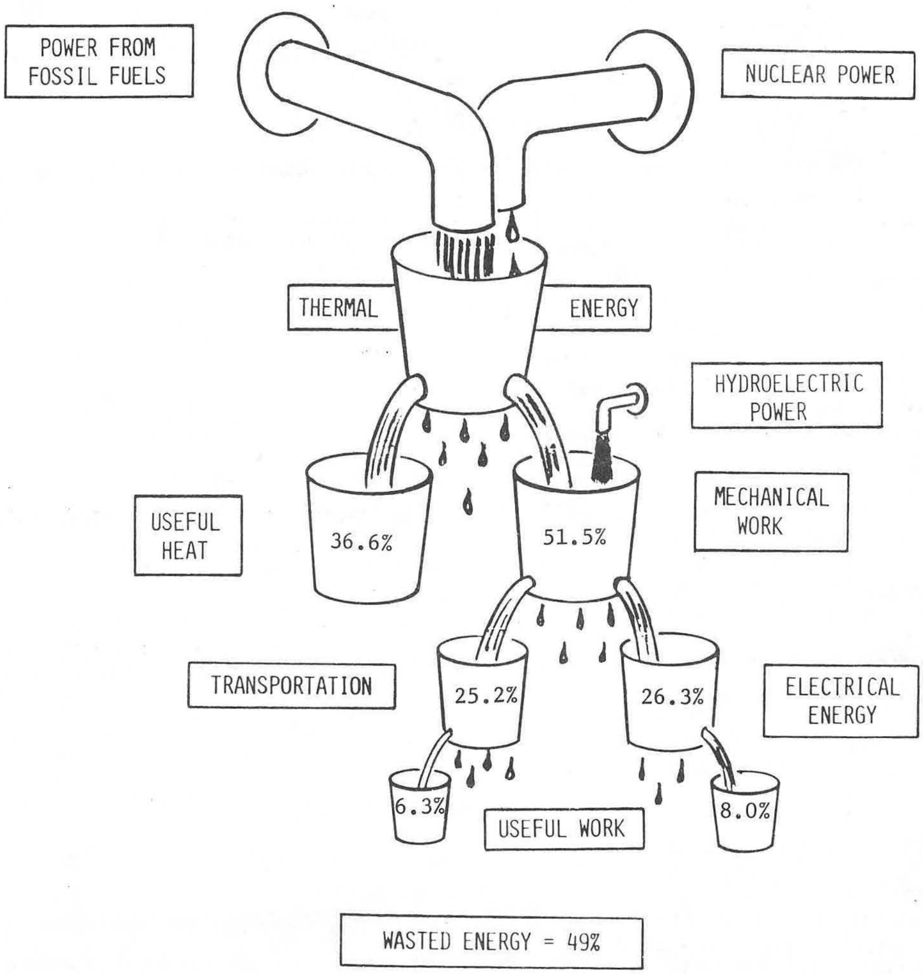


Fig. 103. An example of energy flows; the "efficiency" values are probably taken from Cook (Ref. 24) and should be adjusted downward. (Original drawing from J. Yegge, Ref. 25). (XBB 747-4354)

EFFICIENT ENERGY PIES

The theory of energy conservation involves many factors besides the potential energy saved. The cost curve (Fig. 104) shows symbolically that today's energy use, based on older, lower energy costs no longer gives the lowest total output cost of a product or service. Increasing energy efficiency lowers total costs (268). Since many inputs go into the output obtained from energy use (Table 14), the object of energy conservation is to readjust the mix of inputs in order to lower the energy costs and dollar costs as well. The Energy Dollar (Fig. 105) illustrates energy saving, with "indirect" energy referring to energy expended in creating the energy saving system, such as energy for manufacture of insulation. Note in Fig. 106 how money saved from conserving energy is redistributed; some is reinvested in the improved system, used for maintenance, labor, taxes, or interest, and the rest is respent or invested in some other activity (253, 268, 288). A theoretical balance sheet for making a comparison is shown in Fig. 107 Note too that since the dollars left over will be spent for something, care must be taken in re-spending if the object is to reduce energy consumption (see Ref. 266). Since there is less labor (and usually more pollution) in a dollar's worth of energy purchased directly, than in a dollar's worth of nearly anything else (253, 266, 267, 270, and 271), one can expect a slight increase in employment and decreases in pollution as energy is used more efficiently. But one must take care with the bookkeeping to foresee hidden consequences of shifting energy use. Banning television viewing after 10 pm, for example, might encourage more evening drives in the family car.

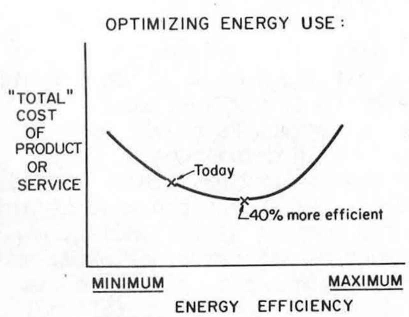


Fig. 104. Re-optimize inputs, reduce energy costs, reduce total costs. Fight inflation! (From Ref. 253). (XBB 745-2993)

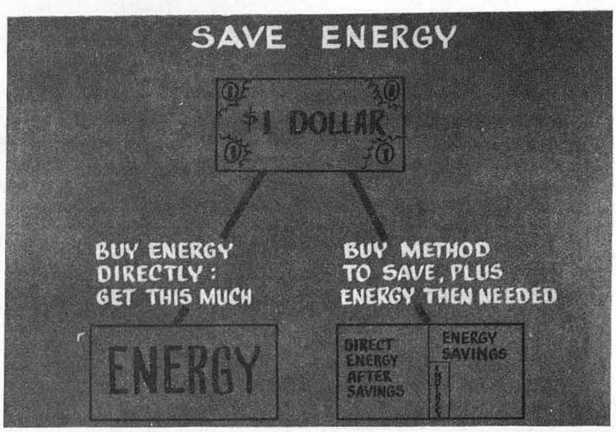


Fig. 105. The energy dollar: Find its most effective use. (BBC 758-6016)

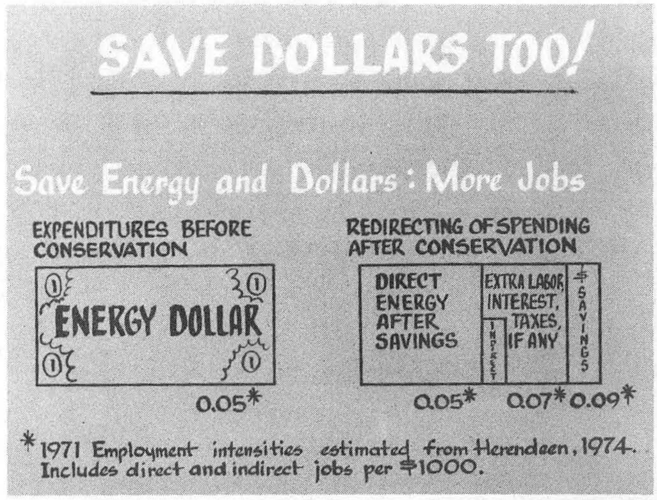


Fig. 106. The economic dollar: Save money, create jobs, clean the air. (CBB 758-6015)

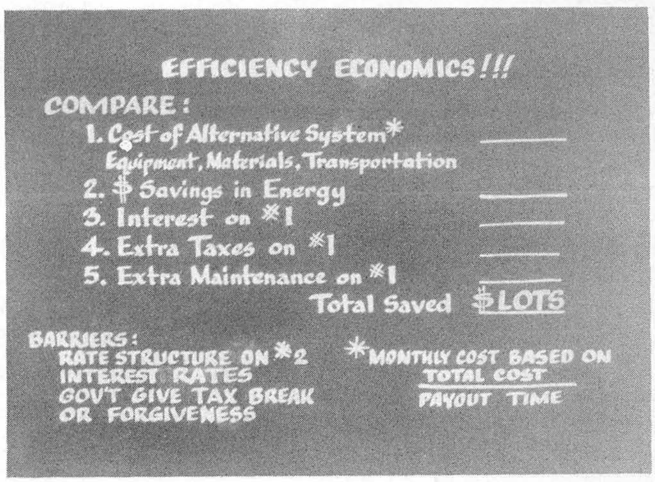


Fig. 107. Compare and save! (XBC 745-3345)

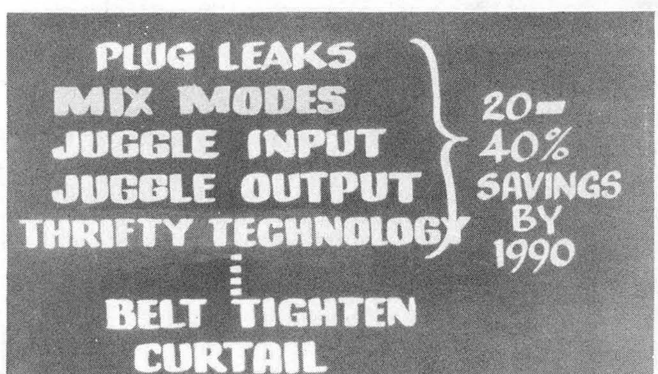


Fig. 108. Many ways to save energy. (XBC 744-3343)

The kinds of energy conservation shown in Fig. 108 can be explained as follows (253, 288):

Plugging Leaks: Preventing heat and cooling losses in life-support systems, correcting energy systems that are not running at designed efficiency, and eliminating unutilized or underutilized energy by retrofit in all energy systems. Examples include insulation in buildings, heat recovery in industry, improved maintenance of all energy systems. Leak plugging techniques are generally implemented once, and then remain passively effective.

Mixing Modes: 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 heat pumps for industrial heat, electric ignition of gas water heaters, improved propulsion systems in transportation.

Juggling Inputs: Change in 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. Recycling is a form of input juggling. Solar energy substitutes capital and materials for energy. Many energy conservation options listed under thrifty technology actually substitute investment capital, design, and, indirectly, labor for energy expenditures. Returnable beverage containers substitute capital and labor for the extra energy and material requirement of throwaways.

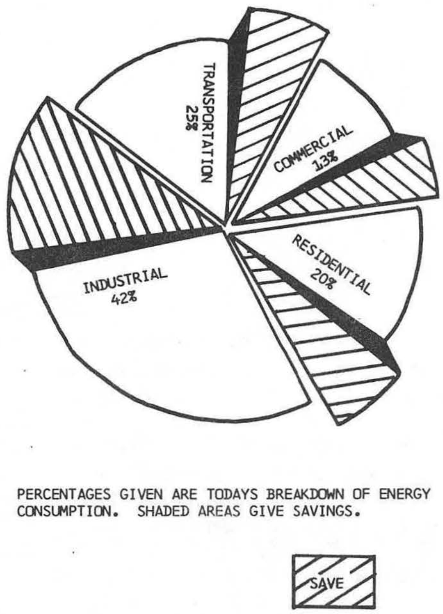
Juggling Outputs: Changes in lifestyle, consumer preferences, investment practices, or shift from manufacturing to services in the economy that lead directly to lowered energy requirements. Smaller cars, changing housing patterns, increased lifetime of consumer durable goods, changes in recreation or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

Belt Tightening: Involves turning off lights, heat or cooling, changes in thermostat settings, driving more slowly, carpooling, increasing load factors in public transporation. Belt-tightening involves small but important changes in energy use which cause minor inconveniences or changes in lifestyle and habits. "Belt tightening," unlike leak-plugging, must be actively pursued by individuals or firms.

Curtailment: Conservation by cessation of a particular process, including driving bans or factory shutdown, often by rationing or allocation of fuels.

The ideas assembled in Table 15 and summarized in Fig. 109 are compiled from a variety of references with some of my own judgments added. They have been shown to be cost effective, meaning that the total or life-cycle cost of the energy-efficient suggestion is less than that of today's "business as usual" practice. Again, the goal of each of these measures is to provide the same (or greater) output for fewer energy inputs.

UNITED STATES ENERGY USE
POTENTIAL SAVINGS



PERCENTAGES GIVEN ARE TODAYS BREAKDOWN OF ENERGY CONSUMPTION. SHADED AREAS GIVE SAVINGS.

Source: "Energy Conservation:Hidden Barriers, Hidden Benefits"(L. Schipper) and references contained therein.(Paper number UCID-3725, Lawrence Berkeley Lab, or ERG-75-02, Energy and Resources Group)

XBL 756-1653

Fig. 109. A pie diagram showing energy use and potential savings in the various sectors. (From Ref. 253).

Notice that the object of house heating, for example, is comfort, not just heat. Thus, one can measure the effectiveness of the measures listed here by studying in detail comfort needs and use patterns in housing and buildings, as indicated in Ref. 408. Using the energy consumed as a direct measure of the comfort is misleading, especially because construction standards, climate, and other factors vary from place to place and time to time. Explainers might consider evaluating not the cost of gas heat per Btu, but rather the full cost of comfort (fuel, furnace, insulation) per cold night. This method emphasizes what you get (comfort) and what you pay (dollars, energy, design, etc.) Thus energy is one of the inputs to home heating, not really an output in this method of analysis (Figs. 110,111).

Air conditioners are a particularly frustrating energy consumer. They pour most of the salt on the blackout wounds during the summer (see Fig. 48). Increased use of inefficient air conditioning leads to heavy peak loads for electric utilities in the warm months, and ironically, the energy consumed plus the heat removed from all the indoor spaces, contributes to the heat of the outdoors; this is responsible for part of the rise in temperature in places like New York (806,812).

But Ref. 392 discusses fully the available air conditioning technology which, if systems were

Table 15. Raising energy productivity.

Summary of Studies

	CONCEPT	TYPE	POTENTIAL SAVINGS[1]	OTHER EFFECTS[2]	FIRST COST OF SYSTEM	LIFE COST[3]	RELATIVE EMPLOYMENT[4]	REFERENCES IN BIBLIO
RESIDENTIAL[5]	Insulation (homes)	Plug Leak	5%	Lower fuel prices Lower summer air condit. needs	↑	↓	↑(manufacture, installation)	127,385 396
	Air Conditioning (homes, offices)	Thrifty Technology	1%+	Lower summer peaks Fewer brownouts Slower elec. growth	↑	↓	↑(manufacture)	392,407
	Building Design (lighting, appliance efficiency, heat pumps)	Juggle Inputs[1]	5%+	Lower needs for heating and cooling	= to ↑	↓	↑(construction, design, materials fabrication)	383,387 389,396 398,400 406,408
	Solar Heating/ Cooling	Thrifty Technology, Juggle Inputs	3 to 5%	Could replace anticipated strains from growth in electric heating and cooling	↑	= to ↓	↑(manufacture, construction)	700-715
INDUSTRY	Industrial Heat Treatment, Process and Materials Improvement	Juggle Inputs, Plug Leaks	5 to 10%	Less vulnerability of industry to fuel costs or interruption	= or ↑	↓	↑(equipment, mfg., increased labor)	250,251 252,262
	Returnable Cans, Bottles vs. Throw-aways	Juggle Inputs	.2%	Typical of the kind of choice we could make	↓	↓[6]	↑	302,303 305,306 309-312 316,317
	Recycle Paper Primary Metals and Plastics	Plug Leaks, Juggle Inputs	3%	Stabilize resource prices, eliminate solid wastes	~	↓	↑	300,313 280,761
	TOTAL ENERGY (also applicable to RESIDENTIAL)	Plug Leaks, Juggle Inputs	5 to 10%	Lower energy consumption, same use!	~	↓[7]	Unknown (probably ↑ due to on-site maintenance & monitoring	305
TRANSPORTATION[8]	Mass Transit for 50% of Urban Passenger Miles	Mix Modes	2%	Less congestion & inconvenience	↑	↓	↑	333,336 340,341
	Smaller Autos More Efficiency	Mix Modes	3 to 5%	Less congestion & inconvenience	↓	↓	Slightly ↓	334,338 343,343
	Shift Freight and Passengers to Rail	Mix Modes	1%	Less congestion	↑	=	Unknown	334,341
LIFE STYLE[10]	Urban Design	All					Unknown	
	Consumers Demand Changes	Juggle Output					Unknown	100,266 268,275 270

[1]Percent of total 1972 US energy consumption. To get percentage of sector or fuel use, consult (40). Figures overlap so they can not be added together. Estimate based on "how much we would save today if we had done it this way" approach.

[2]See references for further discussion.

[3]Life costs include interest, upkeep, taxes. Estimates vary with interest rates, payout time.

[4]Compare with Ref. 123 and Ford EPP results. Since employment per dollar of demand in energy sectors is low, nearly every switch of energy dollars elsewhere raises total employment. Employment shifts, however, are knotty problems and the intangible expenses incurred here are not included.

[5]I ignore thermostat setbacks, though they are effective as are other belt-tightening measures. See 388,402.

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

[7]Design important.

[8]Speed limits, good driving habits, technological improvements save more than clean air devices raise consumption. Compare 342.

[9]See Ref. 330 for indirect energy needs of automobiles.

[10]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. 268 and 270.

LEGEND
↑ Higher
↓ Lower
~ Varies
= Same

designed efficiently and only the most efficient window models were used, could save not only 1% of all energy consumed in 1972, but as much as 7,000 MW of peak-load. (Ref. 60 estimates a savings of 1,000 MW in California; Ref. 827 estimates a saving of 7,000 MW for the entire U.S.). Consumers buy the cheaper, inefficient models, not realizing that higher electricity prices, plus higher consumption, cost them more in the long run than if they had purchased the efficient models. In commercial buildings as much as half the heat removed on a summer day comes from lights in the buildings (346), suggesting that we might be wrongly designing our total system. In Refs. 394 and 399 the notion of energy efficiency standards for home and commercial air conditioning are discussed.

Studies are now also indicating that the industrial energy requirement for similar products or materials can vary greatly according to engineering and process design (309).[17] In transportation, the energy use is usually compared for various modes and conditions, such as urban versus rural. The energy requirement is evaluated per passenger mile (Fig.102) or per ton mile, and many authors include the effect of load factors (331). In the commercial sector, which includes businesses, offices, schools, and other public structures, most of the work centers on lights, heating, cooling and design. References 975, 403 and 408 contain much valuable work on possible savings of up to 50% of the energy used in large buildings.

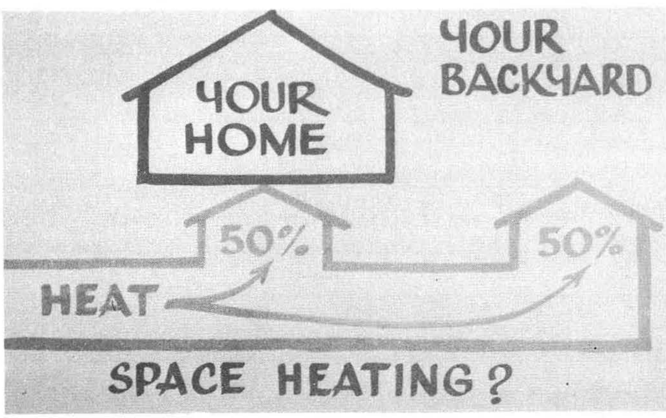


Fig. 110. We heat the outdoors only too well!

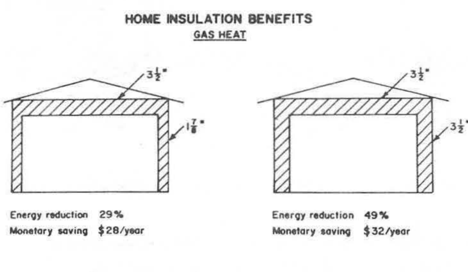


Fig. 111. An example of money and energy savings by installing various amounts of insulation. New York climate, 1972. (From Ref. 285).

Nearly all forms of peak plugging, input juggling, mode mixing, and thrifty technology have the ultimate effect of requiring more non-energy inputs at lower overall energy cost, financial cost, with more employment the direct result. In addition, less pollution usually results. Finally, energy expenditures and energy capital investments are themselves surprisingly less labor-intensive while more energy- or capital-intensive per unit of energy bought or per dollar of investment. The savings in cash and capital saved from energy expenditures through conservation in general buys goods and services with higher employment intensities compared to energy, (Tables 6 and 9, Fig. 56). Another hidden benefit of energy conservation is that demand for capital to harvest energy eases, freeing billions of dollars for other investment or for consumption, often with higher labor impact but milder effect on the environment (253, 288). Conservation also slows the rise in the energy and pollution cost of energy while allowing us to minimize our dependence on sources that are environmentally messy (shale oil, strip-mined coal), politically shaky (imports), or technologically and socially uncertain, such as carelessly used nuclear power. These benefits of efficient energy use, which are unfortunately rarely felt directly by the energy user, might justify government policies that speed up or bolster ordinary economic incentives to conserve (for a detailed discussion see my reviews, Refs. 253 and 288).

Few energy surveys to date, however, have considered all effects of various levels of energy use. In fact, the NPC survey assumes that less energy use leads to less employment and more pollution, but this study did not explicitly study energy use patterns, and considered only energy shortages. Certainly more refinements in these relationships are needed, especially quantitative, but these general observations suggest that one can entertain seriously the notion of energy conservation and increased efficiency, albeit very carefully: "It won't hurt, after all!" Indeed, the popular conception that conservation means doing without, as far as consumers are concerned, seems inaccurate, especially in view of the chart that outlines some of the major changes in energy use efficiency usually considered.

It is important here to emphasize that we are talking about higher energy productivity when we use the term "conservation," because conservation means using resources optimally, or at lowest total cost. What Table 15 really implies is that energy use in the USA in 1975 was far from the economic optimum, as symbolized for a single system in Fig.104. Many energy enthusiasts confuse economic conservation with curtailment, as Fig. 112 almost perversely implies.[13]

Certainly a few of the changes shown here do imply changes in lifestyle regarding transportation and, to a certain extent, the use of materials. For recycling represents a change in inputs from energy intensive material production to more labor intensive recycling, and recycling depends on organizing and planning so that materials are not irretrievably dispersed. Similarly, shifts in employment are to be expected as the economy becomes more energy efficient. Explainers should discuss all con-

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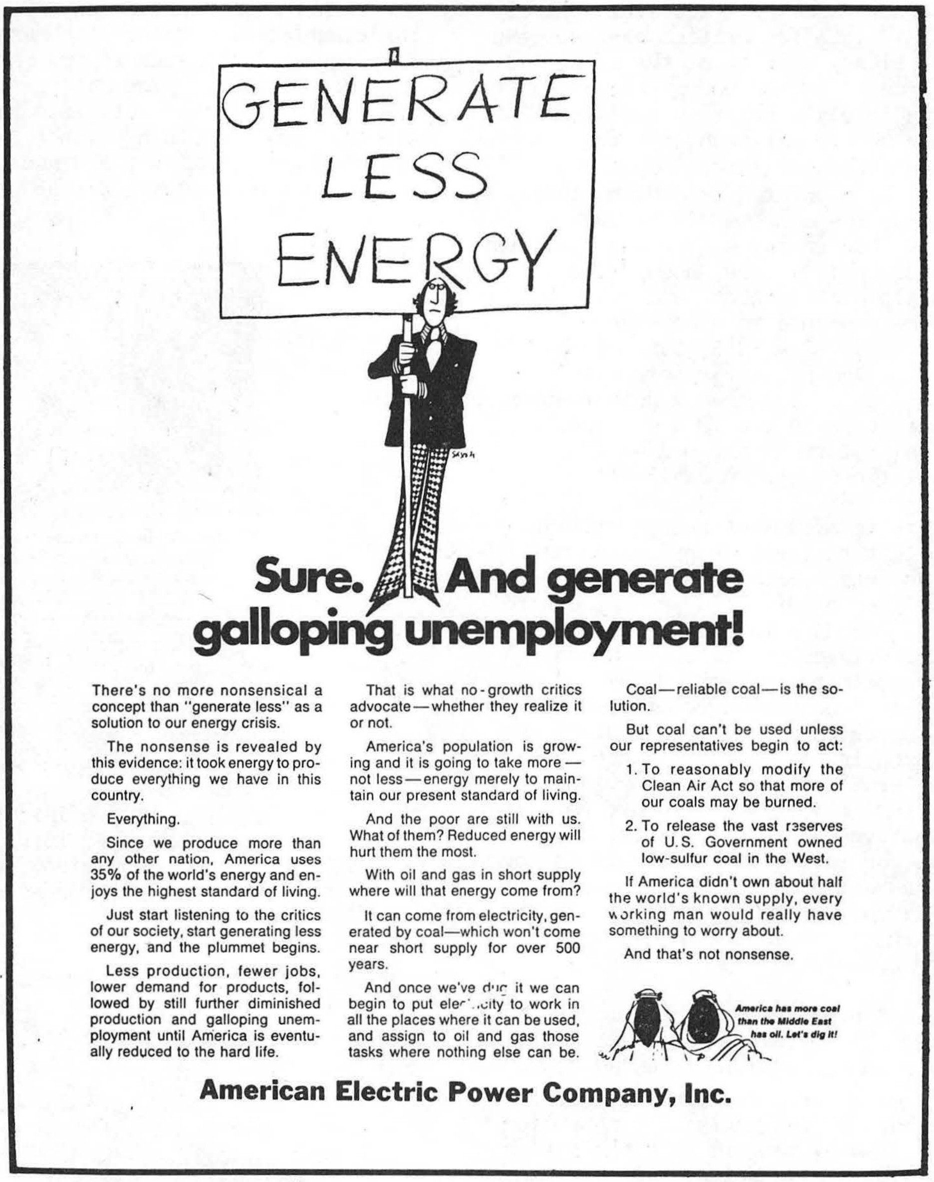

Fig. 112. Many people still identify curtailment with honest conservation. See Note 13.

(CBL 745-3205)

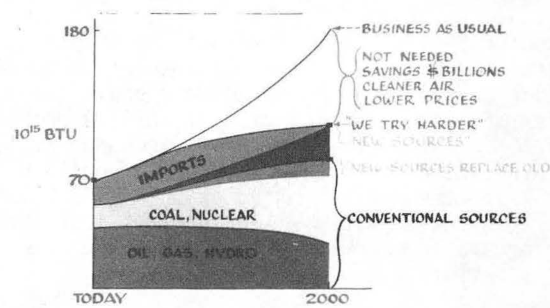

Fig. 113. If energy use efficiency did increase, the economy would provide all the goods and services in the "business as usual" energy forecast—and more. Employment would be higher, pollution lower, and energy less scarce. Compare with Figs. 5 and 64.

ceivable implications of each of these suggested measures, as well as any other changes in energy use that might reduce the demand for energy. We could challenge the outputs, i.e., the lifestyle that demands quick-order hamburgers, the preparation of which consumes the energy worth of two pounds of coal per hamburger!* There are many examples, of course, of the "effluent society", but I leave these choices to the reader.

Some barriers to conservation come from many social and political customs and institutions, often not obviously related to energy use (253). Some spokesmen for the energy industry, too, are

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*Bruce Hannon, private communication. This figure estimated for hamburger produced by a national drive-in chain, includes the energy cost of the packaging.

skeptical of big energy savings (see statement of Mobil Oil in Ref. 101). A few critics even see the call for more efficiency as part of the so-called conspiracy that brought on the energy crisis. Another thorny issue involves shifting employment patterns, as would be brought about if, for example, returnable bottles were used instead of throwaways. In the past many pointed to studies that showed weak consumer response to rising energy prices, especially when energy was such a small part of the average budget (108). Few, however, could foresee the possible consequences, and benefits, of an active policy designed to encourage efficient use of energy (100, 103, 254, 255, 256) by consumers and industry. And no energy forecasters foresaw the public outcry for energy conservation at all levels that followed the 1973 oil boycott, or the pressure to "return to the old ways" regarding lifting of the 55 mph speed limit!

Other barriers to efficient energy utilization include the fact that energy prices do not include full environmental costs. Some prices are propped up by cartels, others held down by controls. Worse, most energy use as a function of useful output depends on the original stock of equipment, such as buildings, climate systems, autos, or machines, which cannot be exchanged or re-optimized with each energy price change. More dismal is the problem of misplaced incentives: appliance manufactures, auto makers, home builders, or landlords don't pay user's fuel fills, so they have no direct incentive to invest in energy efficiency. Any selling advantage due to the extra savings can be obscured through advertising (false or honest, see examples provided), marketing practices such as "rebates," or the general lack of information on energy use and economics.

One point often overlooked by the many critics of plans for energy conservation is the effect of reduced energy demand on lowering somewhat prices for all consumers of a given fuel in the long run. Just as many are hurt by the wasteful consumption of a few, so too can many benefit from the savings of a few. The possible consequences, benefits and costs of an active public policy designed to encourage efficient use of energy should be explored.

At the same time, most studies are cautioning about the degree to which the response to higher energy prices or to the calls for conservation can be expected, especially in situations involving retrofitting, as in the case of insulation added to older homes. The public should discuss the side effects of energy conservation as well as possible means to encourage it; popularly discussed (255, 265) are various tax, rate, and price penalties to discourage consumption on the one hand ("stocks") as well as tax subsidies, low interest loans, and price breaks to encourage conservation on the other ("carrots").

Minimum efficiency standards have been discussed in many state legislatures, especially regarding appliances and home insulation, which are usually provided by a builder who has no economic interest in raising his costs in order to cut the long run cost to home owners or society (see Rauenhorst in Refs. 394, and 253). The social, psychological and institutional issues of energy conservation are indeed many. Some private utilities, for example, have undertaken massive advertising campaigns telling subscribers essentially not to buy the utilities' products, gas and electricity! These same utilities were encouraging the use of electric heating and appliances with no mention of efficiency only a few years ago. (Examples of past and present advertizing are shown in Figs. 114-117.)

Fig. 114. Huh? This kind of electrical heat requires twice the total energy of natural gas or an electric heat pump. From a national magazine in 1972.

(XBB 744-4358)

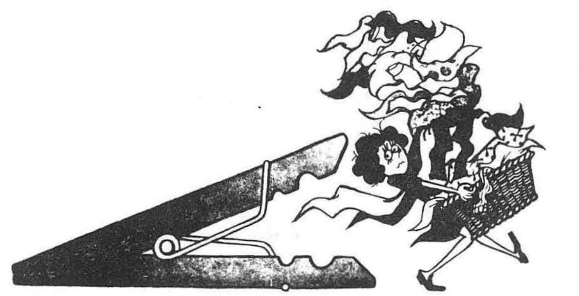

Fig. 115. Ads like these contributed little to efficient energy utilization, and have since been replaced by ones such as in Fig. 116. (From S.F. Chronicle, Feb. 1972). (XBB 744-4357)

HOW BIG CAN THE PIE GET?

With the exception of solar energy (and related forms) every energy technology increases the rate at which heat is produced at the surface of the earth (Fig. 118). Heat is the ultimate pollutant, since it cannot be "abated". In fact, the Second Law assures us that any scheme that pumps heat has to produce even more heat. Today, however, the total rate of generation of heat by man is on the order of 1/5000 of the rate of receiving heat from the sun (812). However, man's production of heat is not evenly distributed, and his rate of production is growing exponentially. Figure 119 shows man's heat production compared with solar

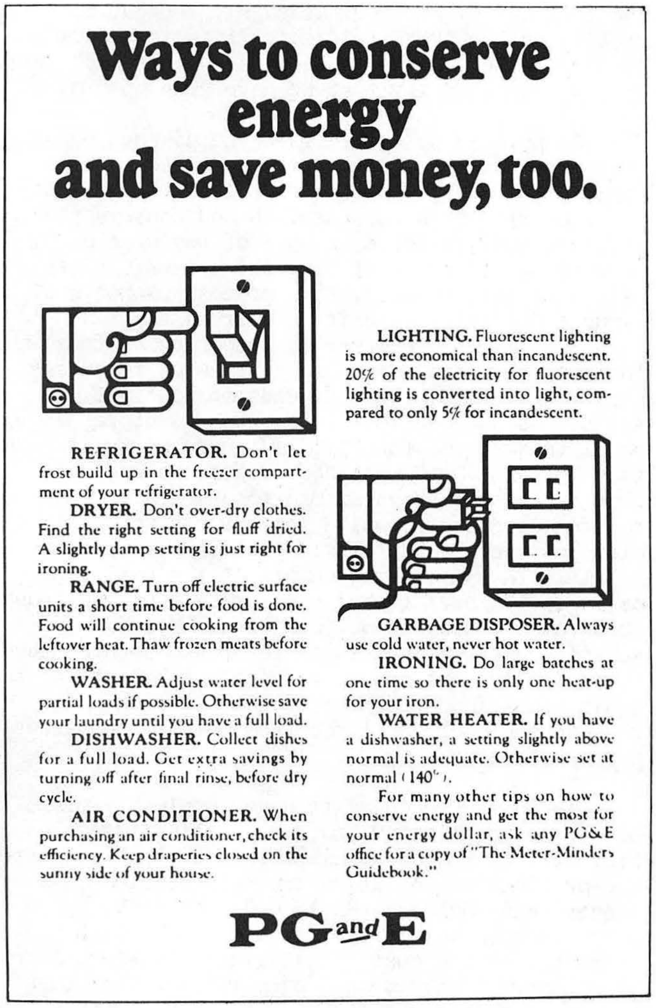

Fig. 116. A healthy carrot. One of a long series of progressive ads dealing with energy conservation (Summer 1974). (XBB 744-4359)

heat in the Los Angeles and Boston-Washington metropolitan areas. As the graph shows, man's energy use in these areas is comparable to solar heating.

The real problem, however, belongs to the future. If we project world energy use (11) to grow at 4.0% per year for a little over 100 years, energy use will be about 50 times greater than it is today. Or, we may wish to simply postulate that in some "advanced" society in the next century a given population, let's say 20 billion people, consumes energy at twice the per capita rate of Americans today--such a society has been discussed by Weinberg and Hammond (cited in Ref. 813). Simple arithmetic shows that total power use is

$$25{,}000 \text{ watts/person} \times 20 \times 10^9 \text{ persons}$$

$$= 5 \times 10^{14} \text{ watts = heat!}$$

which is about 1% of total solar heating.[15] Schneider (809, 813) and other climatologists have expressed some doubt about the ability of the earth to support present day biological and climatic systems when the artificial heating becomes so high. Yet one economist[16] naively used a mistaken piece information to announce that he had heard that the earth could support 1,000 times today's population at the present American standard of living! The heat burden of this would be unbearable, on the order of 10% of solar heating. Air conditioning doesn't help, of course, since that just makes more heat.

The problem of how big the pie can get, as illustrated here by these confusing yet enlightening examples, is called the "Limits to Growth" argument, after the title of a famous study done at MIT in 1972 (281). While this study has sparked much debate, often bitter (see for example 819) two important issues have emerged that should be discussed when explaining energy.

Fig. 117. One carrot: low interest loans for energy-capital investment. (Spokane Chronicle, April 1974). (XBB 744-2408)

Fig. 118. All use of fuel creates extra heat. (XBC 744-2384)

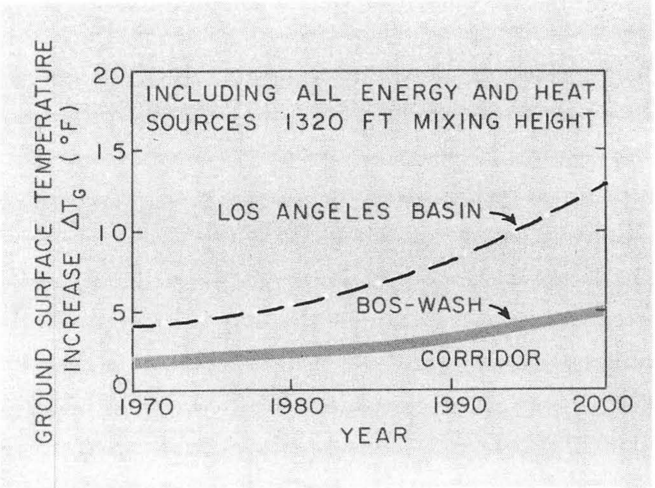

Fig. 119. Still dubious? Jaske (Ref. 800) finds and predicts these temperature rises in the Los Angeles Basin and the Boston-Washington Corridor! (XBC 742-690)

The first issue is the problem called "running out". Physically we cannot destroy energy or matter, but we can reduce the quality of energy irreversibly, and we can take concentrated deposits of minerals, use them and then cast them aside in a less concentrated form--though today the junk heaps are in fact mineable collections of just about everything. When the physical or work cost of getting something, including energy goes up, so does the dollar cost, unless some new technology arrives in time to offset the rise in cost. But technology has inputs that themselves cost in physical and dollar terms, and it is absurd to assume that technology can continually lower the real cost of finding raw materials as they become scarce, because this would imply creating physical order, or negative entropy, out of disorder, which is impossible by the Second Law of Thermodynamics.

Do we ever run out of something, then? Yes and no. No in the sense described above, but yes in more sophisticated analyses. For one thing, we run out of a substance when we have to give up 100-plus units of that substance in order to produce 100 units of the substance: when oil shale requires more oil inputs than it ultimately produces, we would be fools to mine shale! Economists rightly remind us that most substances can be substituted for, especially as scarcity makes prices rise and encourages the search for substitutes. But if substitutes become "economic" only as the price of a substance rise, then the substitutes themselves are scarce. We might then say that we have "run out" of something when we are forced by high prices to do without or substitute; this may occur long before the physical cost is greater than what is produced. Or we can define "running out" as what happens when, given a total ultimately recoverable quantity of substance S in the earth's crust and a small number near zero e, the total amount of S remaining, as a fraction of S_0, is less than e. If prices and costs rise and society uses less of S, there still must come a time when the point 1-e of cumulative utilization of S is passed. Recycling, of course, could stretch the time out by an order of magnitude, but no recycling can be 100% efficient. If society decides to stop using substance S because of its high cost, then we can also say that we have "run out" of S.

As pointed out earlier in the discussion of energy resources, rising prices do lead to more exploration and discovery as well as research and practice with both substitution and conservation (or more welfare for each unit of resource use). Because the energy cost of getting energy rises with scarcity, however, this process cannot continue indefinitely, so it is fair to say that the total ultimately recoverable resources of fossil fuels are limited. How long particular resources last (at a given price) depends on how fast society uses those resources. What is depressing about this part of the "limits" controversy is not that "running out" will destory the world, but that rich nations can afford to use scarce resources carelessly, while most of the world struggles for the crumbs that remain. Today the industrial world is managing on oil at the cartel price of $12/barrel, but this price shuts most underdeveloped peoples out of the market. The scarcity part of the Limits to Growth debate, then, could revolve not around running out but around the equity questions that arise when the rich outconsume the poor and force them out of the market, perhaps forever.

Where many economists have completely misunderstood the "limits" problem is illustrated in Fig. 120. As the above discussion of heat suggested, the problems of pollution are rate problems. As Singer (820) Holdren (821), and Cook (159) have pointed out, the cost of pollution on health and property, or the cost of managing a constant level of background (i.e., abating pollution from each source so that the concentration of pollutants in a region is below some biologically dangerous level) rises non-linearly (out of proportion) to the rate of economic benefits derived from the activity that pollutes. New techniques can always be postulated that increase abatement, but the cost of abatement then rises, as Fig. 33 shows for oil refineries. To assume that technology can always "find a way" that is cheaper is really asking for order from disorder, impossible by the Second Law without an external source of "order", in this case energy and technology. Of course long before a real hardship point is reached some peoples might simply try to ignore the real costs of pollution, as witnessed in the debate over the "Clean Air Act" in the 1970's.

Economically the situation can be analyzed by asking the question "When does the incremental cost of the increased human economic activity that accrues extra pollution exceed the incremental benefits derived by individuals from that activity? When, for example, will the addition of another coal-burning plant into a region cause more damage to health and property than benefits in the form of electricity? Or, when would cost of additional abatement equipment on that plant and the others already existing make it not worth putting up the additional plant? Individual firms or consumers could ignore these questions, passing off the costs into society, but the"buck has to stop somewhere."

LIMITS TO GROWTH ?

they depend on...

RATE OF ---

1. Formation of pollution.
2. Food production.
3. Heat production (climatic change).
4. Demand of energy, water, raw materials.
5. Radiation or radioactive wastes.

Fig. 120. Many scientists are recognizing physical limits to man's activities. Will anyone else understand then?

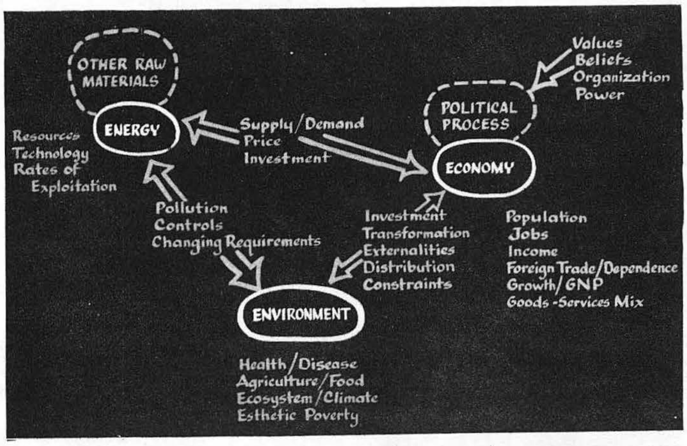

Fig. 121. The mess: The many factors involved in energy choices. There is no shortage of oversimplifications, but no glut of real answers. (XBC 745-3344)

"Limits to Growth", then properly suggests that it is the rate of using energy that may hang us up, not the total supply. Let's not forget, however, that as supplies of minerals become scarce the energy required to produce them will increase: the grandiose schemes to recover minerals from the sea, uranium from granite, and so forth would increase the heat and pollution produced along with a unit of production. But living within the rate limit, a kind of 55 mph "natural" speed limit may mean gross changes in society as we know it, especially since few today are prepared to accept the notion of the finite pie or the zero sum game. And we should realize that there is much debate over where the various rate limits from pollutants lie, in addition to debate among economists as to how fast the economic system can produce the capital, men, and machines that allow the economic pie to grow.

Whether we are worried about the political aspects of the long term implications of "Limits to Growth" or the decision over that nuclear power plant in the next county, it is clear that "Explaining Energy" must involve a lot more than the cold recital of numbers and presentations of endless pie diagrams. Holdren's diagram (Fig. 121) reminds us that energy policy, society's decisions on how to influence energy use, depends on many variables that arise in the political, economic, or social processes that I have not discussed in this manual. My own "energy future" (Fig. 122) is probably an oversimplified statement of what many others would like to see come about. A second glance at Holdren's telling figure (Fig. 121) reminds all of us that the social interactions which have to take place in order to change energy policy are complex and sometimes tinged with "energy Watergates" and all of the most unpleasant odors of any of the world's political systems. Perhaps changes in energy use, or resource use in general, depend more on social and political factors than on individual economics and technologies, as some claim. Even if this is the case, the role of the scientist-economist in identifying as many measurable aspects of energy utilization should not be underestimated.

THE ENERGY FUTURE:

1. Prices reflect true costs.
2. Environmental damage minimum.
3. Maximum efficiency of all uses.
4. Clean supplies, which last longer.

Fig. 122. The author's energy future: Reasonable costs are not cheap, but the energy is there and is clean. Compare with other policy statements.

Nevertheless, it is up to all of us--mostly non-scientists--to judge for ourselves what the "best" road for energy policy to take is. In that sense Porky's comment that "We have met the enemy and he is us" applies, not in the sence that anyone is quilty of something, but that anyone who does not get involved with energy questions might not be fulfilling his/her vital social role. I hope that this manual will aid energy explainers in making that point to everyone, while providing us with safe and sane food for thought, not pie in the sky.

Fig. 123. The problem.

FOOTNOTES

1. I also had occasion to contact various TV, radio, newspapers and magazine journalists, for whom I provided short energy vignettes, examples of which are given in the appendix. My aim was to provide them with a scientifically correct morsel, lest they speculated in public with no way of knowing the real answers. Often I volunteered information during public controversies, such as "throwaway bottles versus returnables", and "should we label air conditioners?". But most journalists were not allowed time to delve into important energy facts. When an important American Mayor called for "public works jobs to take up the slack in employment from energy crisis layoffs," no journalist asked the major where the energy for the public works jobs would be found! Clearly most of us were not ready to think physical overnight, in a world where free lunches come in the junk mail and TV advertising constantly!

"A TYPICAL ENERGY VIGNETTE"

This energy vignette was presented by Jim Steck, Television Station KPIX, San Francisco, in March, 1974.

ENERGY USE AND SPORTS: ANOTHER VIEW.....

While many rightly point out that when energy is tight, some uses, as for motor sports or night lighting, ought to be curtailed. But sample calculations show that it is not the sports even itself, but usually the transportation, by car, to that event that takes all the energy.

At a recent racing event at the Ontario Raceway, 33 cars were each alloted 280 gallons of methyl alcohol. Again this seems like a waste of a large amount of fuel, but consider the energy needed to send 25,000 cars (attendance was 100,000) 20 miles each way to the raceway: About 70,000 gallons of fuel against only about 9000 for the racers, assuming they all used up their allotment.

Ironically, as reported in an issue of Science last December, methyl alcohol offers a prospect as a man-made liquid fuel for the future, to be synthesized out of coal or methane from organic wastes. Thus the day when all cars run on methyl alcohol is not inconceivable!

Indeed, most forms of entertainment and recreation are heavily dependent on transportation by car or airplane for their business; hence the impact of the energy crisis is felt heavily on the skiing and other outdoor industries, although the product/activity itself consumes relatively little energy per participant. Many commercial structures used for sports can be upgraded through better insulation, lighting and cooling to offer large reductions in energy consumed on site: It remains to be seen whether the American people can make similar savings in transportation so that the energy shortage will not deprive them of their good times!

Source: Lee Schipper

2. If cars went 50% more often to buy gas, and 10% of all stations went out of business, and those remaining cut total operating hours from say an average of 100/week to 72/week, or 12 hours a day, closed Sunday, and at any one time only 1 station in 4 was pumping (i.e., gas was sold for 3 hrs. daily out of 12) then there would be 150% as many customers (compared with before lines) but only (.90)·(72/100)·(1/4)=15% as much pumping time, or capacity. Then the ratio of customers to time would go up by a factor of 10: Ten times less "space" at a gas station per customer! Customers would thus arrive at a greater rate than they could be handled, because of this compression.

Of course gasoline advisory services all warned "buy gas earlier", but no one was told that this would not increase the amount of gas, only increase the competitive atmosphere - "Buy early, beat the other guy." Note that actual fuel supply does not figure in this argument, only our perception about that supply - maybe there was a shortage, too!

Actually I believed we had a shortage, but I used this illustration to warn explainers to differentiate between gas lines or oil company "theories" and the energy crisis.

Still, confusion reigned elsewhere. For example, one listener complained that he had cut back on electricity use by 30% but his bill remained the same. While some of this was due to the rate structure, part was the effect of a price increase for electricity. He perceived the results as an indication that conservation would not pay, until the rest of the audience and myself convinced him of how much more he would have paid if he had not conserved!

3. The first law says that energy comes from somewhere and in some form, goes somewhere, into the same or another form. The second law relates to the quality or grade of energy - Dyson, in Ref. 24- discusses these ideas. Basically the second law says that energy is constantly, though gradually being converted into heat. Rub your hands together: chemical - mechanical - heat. Now turn the energy flow around. Hard! Heat moving devices do exist, called refrigerators, air conditioners, or heat pumps, but they require high grade energy in order to pump heat from cold (or cooler) to hot; and the energy these devices use is also turned into heat.

The second law is also related to the concept of entropy, or disorder. Heat is energy, diluted or distributed over many systems especially molecules or atoms which move at random. Other forms of energy are "more concentrated" or ordered. That heat flows "downhill", from hot (hi-concentration) to cold (low concentration) means that nature moves from order to relative disorder. You can clean up ("order") a part of a system, but only by using up some hi-grade energy, and creating more disorder elsewhere in the system. The second law warns us that no matter how hard you try the order gained will be less than the disorder caused elsewhere.

4. More mysterious is the fact that nearly every television ad claimed that their cars averaged better than 15 miles per gallon. Since the national average (Ref. 331) was under 14 MPG, someone was fooling someone. The resolution, of course, comes in the disclaimer, "Of course the mileage you get depends on how you drive and under what conditions", but, ironically, only the Cadillac ads emphasized this clearly.

5. Be sure to count the energy required to make electricity in any evaluation. A recent (May 1974) issue of Consumer Reports ignored this in evaluating energy consumed by dishwashers, and they also ignored a carefully written analyses by Prof. Gene Rochlin and myself explaining what was wrong.

Some statistics even count "electric utilities" as a consuming economic sector, rather than a conversion, and in these statistics energy use in industries, homes, and businesses is deceptively understated. Similarly Mr. Donham Crawford (in Ref. 276) testified to the effect that since electricity accounted for only 10% of end-consumed energy, savings from conservation would not be so earth shattering. Crawford skillfully ignored the power-plants' waste heat, the millions of acres of land consumed by transmission lines, and the burgeoning growth in electricity use, some of which is very wasteful. Figure 124 illustrates a comparison of electric and gas water heating: obviously counting only the energy consumed in the house "favors" electricity, but counting the energy required by the utility that made the electricity, as well as losses in the natural gas delivery system, produces the balance illustrated here. (See Ref. 250 and 401 for more perspectives on water heating.)

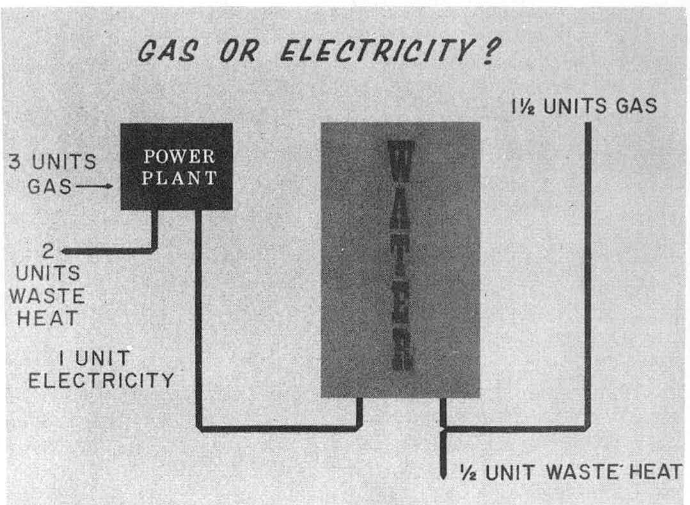

Fig. 124. Efficient water heating.

6. The figure first appeared in Cook's article in the September 1971 issue of Scientific American, "Energy and Power". The revised version shown here was part of Cook's presentation to the "Earth 2020" Lecture Series in California in 1974 and is published in "Resource Conservation, Recovery, and Solid Waste Disposal", Senate Committee on Public Works, 1973. Cook undoubtedly uses First Law efficiency or maintainence efficiency.

7. While uranium mining, processing, and enrichment do consume up to 5% of the energy ultimately

produced by fission, explainers should be careful of claims that LWR fission is a net energy consumer, as this is not the case. Currently we enrich more uranium than we use, especially because of weapons and exports. See Ref. 512 for a lively discussion of the energy cost of nuclear power.

8. The "breeder" does not make energy, it only converts U-238, a form of uranium whose energy cannot be readily recovered, to plutonium (Pu), which can be utilized.

9. I take particular exception to the misleading oversimplifications inherent in a set of ads which appeared regularly in Newsweek and Time Magazine on behalf of American Electric Power Company in Spring 1974. These ads ignored too many factors in appealing for an all out exploitation of coal, a relaxation of environmental standards, and a simplistic plea: "More Energy!" A recent ad implied that more coal-generated electricity would be consumed than the uranium fission would ultimately provide. Nasty!

10. Don't forget the environmental impact of dams, tidal generators, and even windmills!

11. Present solar cells must operate for many years before returning as much generated electrical energy as was consumed (in all forms) during the fabrication. Or, that's why they are so expensive!

12. Some listeners always ask whether the U. S. could run everything on wastes alone. While we could derive a great deal of energy (perhaps 5-10%) from wastes; we could not run a system on the wastes of that system, since we would probably violate both the First and Second Laws. We only have wastes because we process so much in the First place. However, some futurists postulate both a high-recycle, low-waste - input society and power from wastes, even though wastes are minimized in that scenerio. Careful here.

13. If you thought that ad struck a weird tone, the famous "Energy to the Year 1985" prognosis of the Chase Manhattan Bank (108) echoes the theme that energy conservation opportunities were unimportant. In fact the 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 non-essential -- but their elimination would not permit any significant savings." (Ref. 108, p. 52) While it is probably possible to find a definition of "conservation" which fits the Chase description, many physical scientists and economists would be appalled by the Chase analysis, or lack of analysis. In view of the confusion and disruption generated from a sudden curtailment of fuel supply, as was seen during the Arab Oil Embargo, one can understand why some observers actually fear energy conservation.

14. Explainers will be asked "Yes, but what can we do?" References 127 and 222 contain lists of suggestions, but those who do want to encourage conservation and efficiency can consider the following:

1. Lists of belt tighteners and technical fixes are popular, but few people will run out and replace everything they own that is inefficient at once.

2. Hints in transporation are very helpful, especially regarding 55 mph speeds, driving habits, car weight, and so forth. References 89, 93, and 96 discuss these further.

3. Comments about lifestyle must be made carefully, unless you know the audience well. But I usually find at least two or three listeners out of 25 who are fed up with the "no-deposit no-return America."

4. A discussion of how very similar lifestyles and/or levels of affluence might be very different in terms of energy (Ref. 67) is enlightening. Listeners do respond to careful explanation about how (and why) to choose certain products and services over others.

5. Most listeners do not comprehend the difference between first cost (purchase price) and life cycle costs. Explaining this might allow them the chance to purchase appliances, homes, or cars that cost more at first, but less in the long run due to greatly decreased energy costs. I find it particularly frustrating that we are so preoccupied with today's costs, not the long run prices, especially when low prices and shabby quality results in energy waste and pollution. See the discussion of Rauenhorst and Stein in Ref. 394.

Explainer must remember: Audiences might leave impressed by authority, full of inspiration, but still be confused. Nevertheless at a recent program in energy conservation organized by one of the Armed Services, I was approached by officers from all over the country, each eager to tell me how much his program had already saved!

6. Beware of listeners who "heard about" energy sources, energy studies, and so forth. This does not mean "talk down to audiences", but merely be super cautious. Then again, someone might think up a good idea!

15. Hubbert, in Ref. 24, gives three figures for the solar insolation: 170×10^{15} watts received at the top of the atmosphere, 121×10^{15} watts transmitted through the atmosphere and 41×10^{15} of those coupled to the weather and climate.

The latter figure is probably the important one, since it is the climate! The percentage given in the text is based on the 121×10^{15} figure.

16. The economist, Carl Kaysen, had quoted Prof. R. Socolow on the numbers which suggested that the

world could support 1,000 times today's population at today's U. S. per capita standard of living. Socolow told me privately that he did not mean this; yet Kaysen's formulation, stated as a footnote in an article in Foreign Affairs ("The Computer That Cried Wolf", reprinted in Ref. 819) was quoted widely, most recently in a book on limits to growth by W. Beckerman. That neither Beckerman nor Kaysen challenged these figures (or their misinterpretation) is unfortunate. That heat production would rise to about 10% of solar, as I claimed, is calculated by assuming half the present per capita use of energy in the U. S. for each of these world citizens in this model. What I ignored is that the energy requirements for food, pollution control, resource, and so forth would probably be several times higher, since all of the processes which supply resources would be pushed hard, as explained in the section on growth, population, and projections. Essentially diminishing returns in resource and food production would push up the energy (and heat and pollution) cost of doing anything enormously. Whew!!

17. Identified savings potential of eight industrial plants†

Plant Type	Total Annual Energy Bill*	Identified 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*	$ 1.05*	20.6

*In millions of dollars

†Source: E. I. Dupont 1973 Energy Management Client List.

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Readers should also consult the back issues of Scientific American, Science, Power, Energy Conversion, Oil and Gas Journal, Fortune, Business Week, Wall Street Journal, New York Times, Los Angeles Times, Environment, Environmental Action, Energy Digest, New Scientist, Technology Review, Nuclear News, Bulletin of the Atomic Scientists, and so on.

Many of the items on this list, especially government documents, can be obtained at little or no cost by contacting congressmen, committee staff members, or energy companies. Addresses for important places are listed in the back. Environmental groups also maintain large energy libraries.

Of all the references I have listed, I heartily recommend the textbook by Steinhart and Steinhart, the April 19, 1974 issue of Science, the text by Holdren, and the Energy Policy Project Report "A Time to Choose" as introductory reading. These works give many "non-traditional" views worth absorbing.

Common abbreviations include AAAS (American Association for the Advancement of Science, referring to papers given at Annual Meetings), LLL (Lawrence Livermore Laboratory), LBL (Lawrence Berkeley Laboratory), IGT (Institute of Gas Technology), ORNL (Oak Ridge National Laboratory), OST (Office of Science and Technology), GPO (Government Printing Office, with numbers given if known).

Oak Ridge National Laboratory prepares monthly a series of energy abstracts which can be obtained (at cost) by writing: M. Guthrie, Oak Ridge Environmental Program, Box X, Oak Ridge, Tennessee 37830.

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