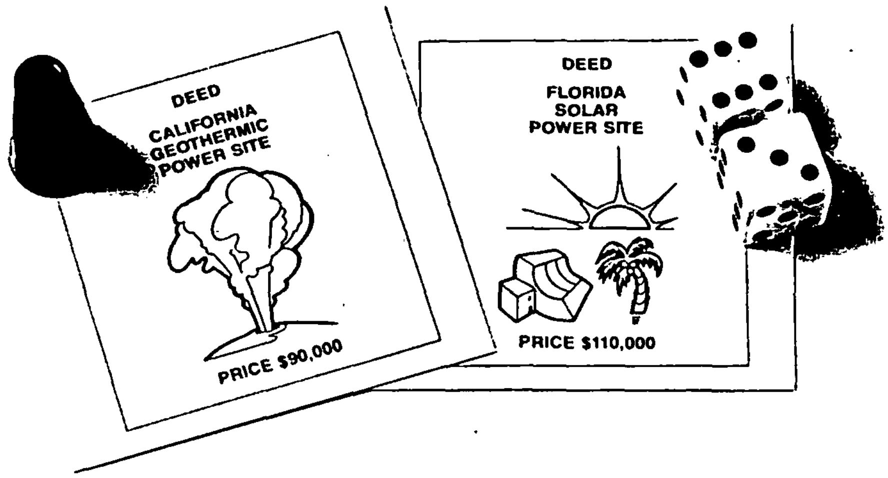
GL01337



Alternative Fuels

by Peter Gottlieb, Ph.D.

Peter Gottlieb, Dames & Moore's Director of Computer Services, has managed a wide variety of engineering and environmental studies for nuclear and alternative energy projects. He directed a cost/benefit analysis of alternative modes of energy production for the California Energy Resources Conservation and Development Commission and has presented expert testimony concerning alternative energy resources before the U.S. House of Representatives Subcommittee on Energy and the Environment.

Declining domestic supplies of oil and natural gas are forcing us to look for alternatives. The first choice for substitution is the old standby, coal. But coal is not the complete answer. To begin with, it is expensive to burn because of stringent air pollution control requirements. Also, it will become more expensive to mine and transport as high-quality local deposits are used up (although it will remain cheaper than oil or natural gas). Above all, recurrent oil supply crises should have taught us the folly of reliance on any single fuel type for a major portion of our energy budget, especially an imported fuel.

Nuclear power was once viewed as the low-cost, environmentally harmonious fuel of the future. However, questions of safety, security, and increased construction costs have considerably diminished near-term prospects for greatly expanding this energy source. We are thus left with a bewildering array of alternative fuels, most of which are highly touted by their respective proponents, and very few of which have ever been tested in a practical energy production situation. For each of these fuels the competing claims of large resource availability, low cost, and very low environmental impact must be carefully evaluated.

The purpose of this paper is to compare the total reserves and costs of some of the more popular alternative fuels to the extent that the present uncertain state of knowledge and lack of practical commercial experience will permit. We will present these alternative fuels in groups having similar origins and similar costs and/or energy potential and will conclude with a comparison of all the alternative fuels and some projections of future trends.

"UNCOMMERCIAL" HYDROCARBONS

The uncommercial hydrocarbons include syngas (synthetic natural gas from coal), synoil (synthetic oil from coal), alcohol from coal, and oil from shale. These synthetic fuels constitute a very large resource, which reflects the fact that each is derived either from coal, which is very abundant, or shale, which is nearly as abundant. (Note that three of these alternatives are derived from coal and are thus to some degree mutually exclusive—coal burned to manufacture one derivative cannot be burned again to manufacture another.)

The main obstacle to the development of these synthetic fuels has been the large initial capital investment required. Because of the current energy situation, however, the federal government may subsidize their production and make up the price differential between the synthetic fuels and the natural hydrocarbons.

The main advantage of these fuels is their relatively large supply. Expressed in quads—short for quadrillion (10^{15}) British thermal units* (Btu)—the resources of this category could total 6,000, the equivalent of 75 years of our

*A Btu is the amount of heat energy required to raise the temperature of one pound of water (about a pint) one degree Fahrenheit.

total energy consumption (from all sources) of 80 quads per year.

Our estimates for costs and total resources for these four fuel types are compared in Figure 1. The process characteristics and problems associated with each are described below.

SYNGAS

Of these four synthetic fuels, syngas has had the most commercial development. The earliest form of syngas, which was produced by simply passing steam over hot coal, was used for street lighting about a century ago (before the widespread availability of natural gas). The product was a low-energy gas (150 Btu per cubic foot) consisting mostly of hydrogen and carbon monoxide. Current gasification processes still begin with this reaction as an initial step, but the energy content of synthetic gas must be increased to approximately 1,000 Btu per cubic foot if it is to be transported economically over long distances. This can be accomplished by reacting the carbon monoxide and hydrogen catalytically to produce methane and carbon dioxide. Before this step, known as methanation, can take place, the concentration of hydrogen must be increased to provide the proper ratio for the reaction.

Commercial experience is almost entirely with the Lurgi process, which was used in Germany to produce natural gas (and gasoline) during the later stages of World War II, when their traditional oil supplies were cut off. The Republic of South Africa has developed this technology even further in an effort to lessen its dependence on politically unreliable foreign oil.

A number of other gasification technologies are also being developed in the United States, primarily to optimize the conversion of one or more of the broad range of domestic coal types. Unfortunately, the high capital investment, which appears to be required for all these processes, makes the resulting fuel too expensive—at least $4.00 per million Btu compared with $2.50 for natural gas (in 1978 dollars)—to risk development on a large commercial scale in the United States. There have however been a number of pilot plants (financed primarily by the Department of Energy), and construction on a few small commercial plants is beginning.

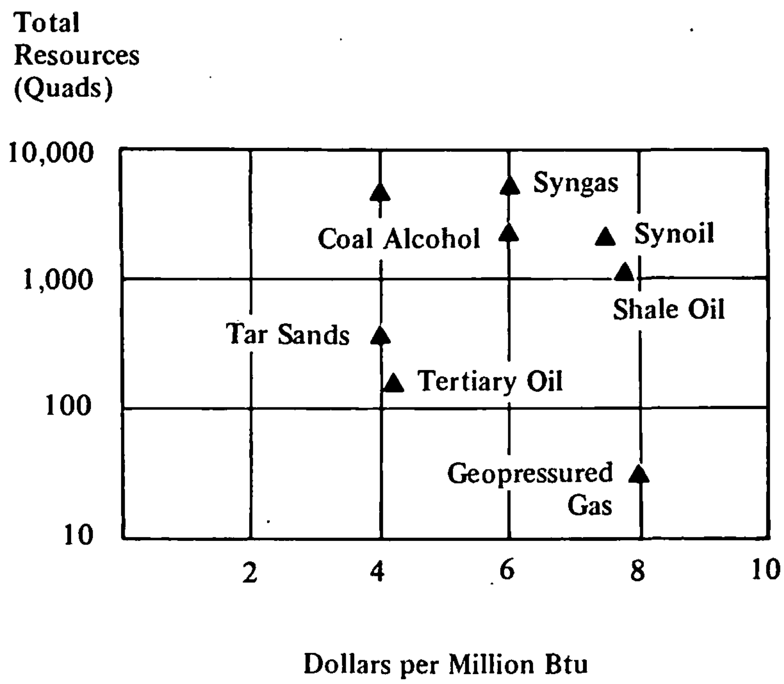


Figure 1. Uncommercial hydrocarbons: total resources versus cost per million Btu

COAL LIQUEFACTION

The methane produced in coal gasification can be easily converted to methyl alcohol (methanol). Coal can also be converted to gasoline or oil (synoil), either directly or by reactions of the methane produced in the gasification process. Unfortunately, the synoil process is less energy-efficient than the gasification process (or methanol production) because of the extra steps needed to produce the heavier, longer-chain molecules. The total resource is only half what we would expect to get from gasification (as can be seen from the comparison in Figure 1). Nevertheless, liquid hydrocarbon fuels are essential to the functioning of our current transportation system, and there is considerable political support for the production of gasoline from coal.

Despite the lower efficiency of liquid synthetic fuel production, the Republic of South Africa has embarked on an ambitious program to provide some measure of energy independence by producing oil from coal. The South Africans have developed a process (called SASOL) similar to the Lurgi gasification process, but which produces gasoline directly. South Africa's first SASOL unit is already on-line, SASOL 2 is nearing completion, and by 1983 the country hopes to be nearly 50 percent self-sufficient in oil.

OTHER HYDROCARBON ALTERNATIVES

Oil from shale and tar sands is not presently commercial in the United States, but these sources are expected to see considerable activity in the 1980s. Estimated recoverable resources in the United States and their costs are shown in Figure 1 for comparison with the other uncommercial hydrocarbons.

Enhanced recovery of oil from existing wells is already in commercial practice and should not be considered an alternative fuel source. Some of the newer techniques (e.g., application of heat by burning some of the oil in place or use of detergent) are still in the development stage; they are grouped together as "tertiary oil" in Figure 1.

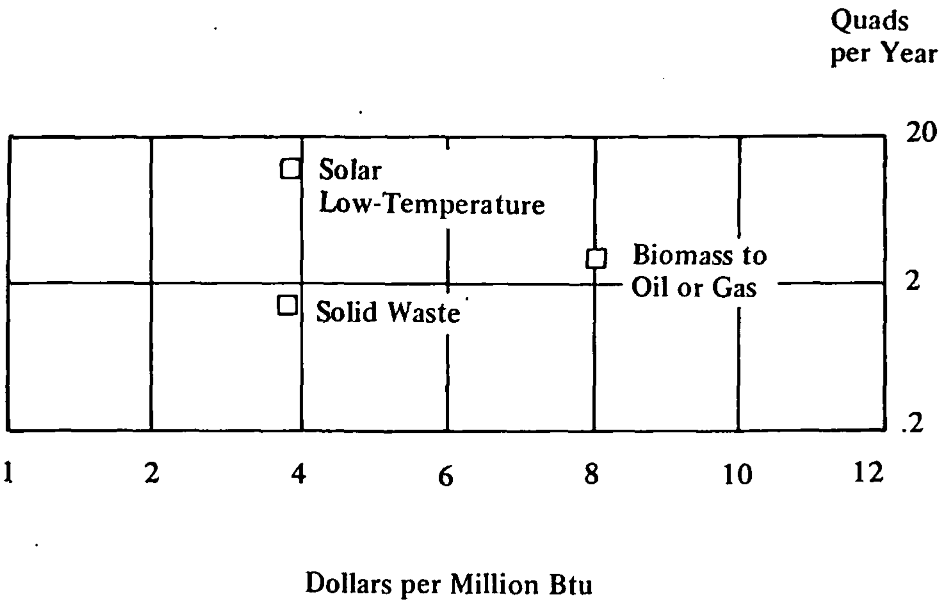


Figure 2. Marginally economic renewable resources: quads per year versus cost per million Btu

The remaining uncommercial hydrocarbon of significant potential for large supplies is geopressured brine. This is a geographically limited source, with the most promising brine reservoirs located near the Gulf Coast of Texas and Louisiana. The high reservoir pressure makes any well difficult to control, and the high concentration of brine necessitates an expensive disposal process. Improved well control technology and the use of the brine as a source of geothermal energy may make such projects commercially feasible. Unfortunately, the first test drilling in Texas resulted in a blowout, so the project is being redrilled. Another test well has begun in Louisiana. There is considerable controversy concerning the total resource that might be recoverable from this source, so the estimates shown in Figure 1 may be somewhat optimistic.

The 1980s will also see the exploitation of other unconventional sources of natural gas: Devonian shale, tight gas sands, and coal seams. The latter are already extracted extensively before mining of "gassy" coal deposits, in order to reduce the danger of explosion. However, none of these resources is large enough to show up on the scale of Figure 1.

RENEWABLE FUEL SOURCES: MARGINALLY ECONOMIC

The marginally economic, renewable fuel sources can be grouped in three main categories: solid wastes can be burned to provide energy or pyrolyzed to provide oil; biomass can be converted to alcohol or gas via fermentation or anaerobic digestion; and solar energy can be used for such low-temperature applications as water heating and industrial drying processes. The maximum annual energy potentially available and the estimated cost for each of these categories are shown in Figure 2. Under the most favorable circumstances we could get a total of 20 quads per year, or about one-fourth of our total energy consumption rate.

SOLID WASTE

The lowest-cost of these three categories is the combustion of solid waste, primarily because the fuel is free. For several years the city of Nashville, Tennessee, has been heating a major portion of the downtown area with steam produced by burning municipal solid waste. This material does not have a heating value rich enough to support efficient electric power generation, but it does burn hot enough when mixed with some other fuel.

The Union Electric Company, of St. Louis, Missouri, conducted a demonstration program using a fuel consisting of 90 percent coal and 10 percent solid municipal waste. For this particular project, the solid waste was shredded fine enough to be fed into the boilers through the same type of nozzles used for the pulverized coal. This experiment was terminated a few years ago, however, partly because of community protest over the location of trash storage facilities.

BIOMASS

The fermentation of alcohol from various agricultural products appears to have been practiced since the beginning of civilization. In response to the hardships induced by the 1979 oil shortage, some enterprising distillers have switched from the production of ethyl alcohol (ethanol) for drinking to motor fuel. The distillers can save money because the product need not be of such high purity, but the alcohol is still more expensive than the gasoline it is intended to replace, even with strong tax incentives.

This scheme is very popular as a means of disposing of surplus corn and maintaining or increasing agricultural prices, but as a long-range program it may not make much sense. If the energy used for producing the fertilizer and powering the agricultural vehicles is accounted for, the total energy input to the alcohol production process is more than the energy content of the product, even if some credit is given for the protein-rich spent grain by-product (which is used for animal feed). In other words, we might be better off by simply curtailing surplus corn production. The process can be brought into a more favorable balance by burning the non-grain parts of the corn as the heat source for the distillation process and/or by improving the efficiency of the distillation process. A breakdown of the energy consumption for current practice is given in Table 1.

There are also greater efficiencies pos-

Table 1. Energy balance for the production of ethyl alcohol from corn using traditional fermentation and/or distillation processes (units are 10^3 Btu per gallon of ethanol produced)

INPUT		OUTPUT	
Agricultural			
Fertilizer	20	Ethanol (energy value as motor fuel plus refinery energy inputs)	144
Machinery (manufacture and repair)	15	Feed by-product	16
Miscellaneous (e.g., chemicals, seeds, and transportation)	15	Agriculture waste (stalks and cobs)	64
	50		
Process			
Cooking and fermentation	26		
Distilling	42		
Purifying	15		
Evaporation	45		
Drying	20		
	148		
Total Input	198	Total Output	224

sible with higher sugar content crops. Sugar cane is the basis of the Brazilian program, by which it is hoped to replace nearly 50 percent of gasoline consumption with ethanol. Sugar cane is more appropriate than corn because it has a lower protein content (and thus consumes less fertilizer), because the stalk portion of the plant (called bagasse) is quite suitable for fueling the distillation in coal liquefaction, and because, in Brazil, sugar cane can be tended and harvested with much less mechanical energy than corn in the United States.

Another energy source in this category is wood, which can either be burned directly or converted to alcohol. Ever since the oil embargo of 1973 a great many homes have been converted to burn wood for winter space heating, especially in New England, where firewood supplies are plentiful due to natural reforestation of abandoned agricultural lands. Wood can be fermented to alcohol, but feeding bacteria on cellulose is much more complex than fermenting sugar to alcohol. Since wood is fairly uniform chemically, it can also be converted to alcohol via nonbiologic chemical processes, but these reactions are fairly complex and must usually be performed at high pressures (which complicates the problem of feeding raw material to the reactor).

In Figure 2 we estimate that biomass has the potential for producing twice as much energy annually as solid waste, as estimated from the amount of forest and other crops that could be harvested for this purpose. Some staunch advocates of biomass have spoken of devoting half our agricultural acreage to energy crops, but the resulting competition for prime agricultural land and skilled farm management would greatly increase the price of foodstuffs. Biomass can be obtained without impacting prime agricultural land if low-density crops are grown on marginal land, or if we collect agricultural and forest residues which currently are largely wasted (although they do provide some soil conditioner). However, the energy required for gathering such dispersed sources would probably be as great as the energy to be obtained from the process.

SOLAR LOW-TEMPERATURE

In the southern part of the United States, solar energy was sometimes used for domestic water heating before natural gas was readily available and, more recently, in special situations where natural gas delivery systems were either too expensive or not available. Over 1000 solar hot water heaters were in use in Southern California at the turn of the century, and, until about ten years ago, when natural gas finally became widely available, there were nearly 40,000 simple rooftop units in central Florida. Today a significant number of these simple units are still used in Israel, Australia, and Japan.

Today's ever-increasing cost of fossil fuels is bringing back solar water heating as a feasible alternative. Because the main item of expense is the large storage tank required to carry the customer through the night and the inevitable cloudy days, systems that already have large storage capacities will become economically viable first. The outstanding example is the swimming pool, which is simply one huge storage tank. (Similarly, apartment houses already maintain large hot water storage capacities by virtue of the extensive piping system necessary for distribution throughout the building.) Heating a swimming pool by solar energy will produce an economic payback within ten years—even at today's artificially low natural gas prices of about $3.00 per thousand cubic feet. With decontrol, that price will at least double within the next four years, making other domestic uses of solar water heating competitive.

A number of large, well established companies have been developing highly efficient, moderately priced solar collectors for water heating. Grumman Aircraft has been marketing (and improving) solar hot water units for the past several years, and Sears Roebuck has just begun test marketing a unit for domestic use. With tax credits of up to 55 percent of the total system cost, we can expect the use of solar energy for low-temperature applications to increase rapidly.

In addition to residential hot water heating, a number of low-temperature industrial processes would also be appropriate candidates. Examples are drying processes and low-temperature evaporation (as in certain distillation processes). Because of the large number of potential applications, solar low-temperature would appear to have the largest potential annual production rate of any marginally economic source, as indicated in Figure 2.

RENEWABLE FUEL SOURCES: GEOGRAPHICALLY LIMITED

The geographically limited renewable energy sources include wind, geothermal, tidal, and hydroelectric. All of these have applications today, and hydroelectric is quite widespread. They are only to be found, however, in limited geographical areas where the environmental conditions are particularly favorable. The geographic restriction also implies a limit to the total production rate. The source with the largest potential is wind, and it will probably have a maximum of less than 2 quads per year for the foreseeable future, as shown in Figure 3.

WIND

Wind has historically been used primarily to propel sailing vessels and power windmills for pumping water and is certainly the oldest source of mechanical energy. Today most wind development efforts are aimed at the production of electrical energy, with several small projects being funded by DOE. The first wind energy project to feed electricity into the grid will probably be the 3-megawatt (peak) wind turbine being constructed for Southern California Edison. Although the winds at the site (in Banning Pass, near Palm Springs) have the highest persistence of any in Southern California, the duty cycle of the wind turbine is expected to average only 25 percent. The cost of the electricity thus generated will be significantly higher than that generated by conventional methods, but mass production may bring the price down. The crucial factor may be the lifetime of the windmill blades, which could fail from stress or from erosion by sand or other windborne particulates.

Wind energy may again be used to propel shipping on a widespread basis, possibly sooner than the large-scale application for electricity. Some marine engineering experts have suggested that half of all oceangoing shipping could be conveniently accommodated by 800- to 10,000-ton sailing vessels equipped with auxiliary power for maneuvering in harbors and escaping stagnant wind conditions. Hundreds of thousands of small sailboats are already being used for pleasure cruises, and they are certainly economically competitive with their powered counterparts. Recent improvements in the aerodynamics of sail design, navigation, and weather forecasting should enable large sailing vessels to perform much better than they did when they were a major mode of transportation nearly 100 years ago.

GEOTHERMAL

Geothermal power is also included in this category, although it is only renewable where especially favorable geologic conditions allow the ground water to recharge the producing aquifers. Renewable or not, this resource is limited to specific geographic areas. A geothermal steam field in Sonoma County, California, produces 600 megawatts of electricity, satisfying a major part of the electrical needs of San Francisco, and will soon support an increase in power output of over 1,000 megawatts. The only other commercial geothermal facility in North America is at Cerro Prieto, Mexico; it produces 75 megawatts and will soon be expanded to 150 megawatts.

The superheated water deposits beneath California's Imperial Valley are potentially much larger energy sources. They are already supporting several research and development projects, but their commercial feasibility remains questionable. These brines are highly corrosive, which may necessitate frequent, expensive turbine replacement, and the spent brine must be disposed of with minimum environmental impact. Also,

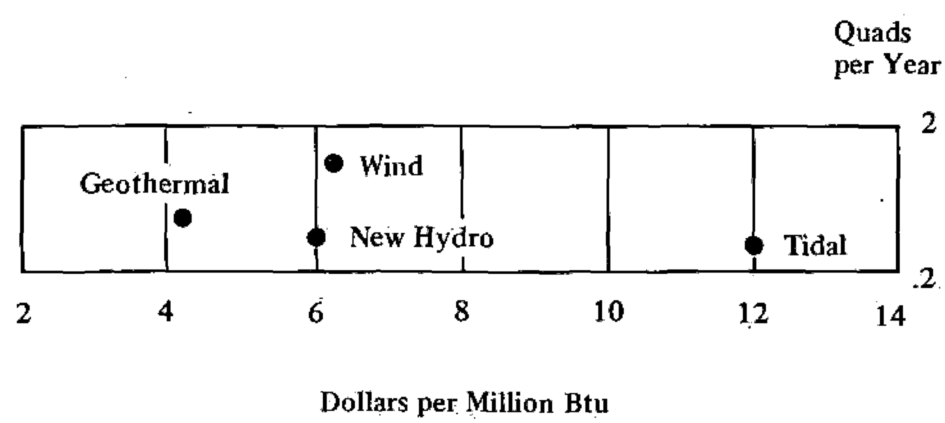


Figure 3. Geographically limited renewable resources: quads per year versus cost per million Btu

this relatively low-temperature electrical generating process will require large volumes of water for cooling.

There are two other speculative geothermal resources. The hot brines in the geopressured natural gas of south coastal Texas and Louisiana were mentioned earlier in connection with unconventional sources of natural gas. Tens of millions of dollars are also invested each year in hot dry rock geothermal. The proposal is to extract the heat from the anomalously hot rock by pumping cold water down one drill hole and extracting heated water from a nearby "gathering well." However, the extensive cracking of the hot rock (required to maintain contact for efficient heat transfer) will probably take a good deal of money and time just to show the feasibility.

Medium-temperature geothermal reservoirs, which can be exploited for space heating, are located in Idaho, Oregon, and Texas, and demonstration projects are now under way.

HYDROPOWER

Hydropower is certainly the largest renewable energy source in the United States, providing over 10 percent of our electricity, but this is down from nearly 30 percent in 1950. Hydropower has expanded very slowly, while total electricity production has increased over five-fold, because most of the good hydropower sites have long since been taken. In the future, development efforts will be concentrated on the less efficient low-head (and even run-of-the-river) sites, where water turbines will harness the power of the current. The exploitation of even these marginal resources will be restricted geographically to sites or rivers with a sufficiently steady flow.

TIDAL POWER

Tidal power is even more limited geographically than conventional hydropower—the tidal reservoir, or bay, must be of just the right configuration to produce a resonance in the shallow water waves generated by changes in the gravitational fields of the sun and the moon as the earth rotates. In addition, this properly configured, resonant bay must be situated on a coastline that, to some degree, focuses the tidal surge generated in the open ocean. This open ocean tidal surge and the changing (alternating) gravitational forces combine to pump energy into large tidal oscillations, and it is the magnitude of these oscillations that permits energy to be extracted from this low-head hydro source.

In North America the ideal geomorphic conditions are found only in the Bay of Fundy (Maine and Newfoundland) and Cook Inlet (Alaska). Exploiting even these limited resources would be quite expensive; the cost per unit of peak generating capacity is only slightly higher than for conventional coal or nuclear, but the duty cycle of these plants is less than 50 percent. That there would be a significant loss as the system shifts from high to low tide on the semidiurnal cycle is immediately apparent. There is, however, a more subtle but even greater loss on the monthly cycle, as the sun and moon move from pulling together on the same side of the earth to cancelling each other out when they are on opposite sides.

Only one moderately-sized tidal power plant exists—at La Rance, France, at the mouth of the Rhone River. This plant, which produces 240 megawatts of peak power, was originally planned to be the precursor of half a dozen similar plants, but the operating experience gained has not been especially encouraging.

RENEWABLE SOURCES: VERY EXPENSIVE

There are two sources in this category, both solar. As shown in Figure 4, both sources have a large potential, but they are also an order of magnitude more expensive than present conventional electric generating processes.

SOLAR HIGH-TEMPERATURE (THERMAL-ELECTRIC)

Low-temperature solar applications such as hot water heating and industrial drying processes are almost economically competitive, even at today's artificially low energy prices, but the high-temperature solar process for producing electricity is currently much more expensive than present technology. Large sums of money are being spent in hopes of developing a cheap technology of very lightweight reflectors. Thousands of these would focus sunlight on a central boiler elevated several hundred meters above the mirror array (hence the name "power tower"). Under contract to DOE, Southern California Edison will construct a $100 million prototype facility in the Mojave Desert. The design should generate enough steam to produce a peak power output of 10 megawatts of electricity—less than one percent of its current system capacity. The capital investment, over $10,000 per kilowatt, is more than ten times that required for more conventional coal or nuclear generation. Even if the initial capital costs can be reduced tenfold by technological innovation and mass production, the cost of maintenance and repair (removing dust from the reflectors and replacing units damaged by windstorms) may be much higher than the operating costs of a coal or nuclear plant (including fuel).

PHOTOVOLTAIC CELLS

Photovoltaic semiconductor cells for the direct conversion of solar energy into electricity have been used to power spacecraft functions for many years. For very expensive spacecraft the high cost of the photovoltaic cells is not much added burden, but here on earth it imposes a severe constraint.

Proponents of solar power are fond of saying that the raw material (silicon) for photovoltaic cells is more abundant than any fuel. Sand (silicon dioxide) will certainly always be cheap, but the amount of energy required to extract the silicon from its tight bond with oxygen and refine it to the necessary purity is greater than the resulting solar cells are expected to be able to produce with today's technology. It has been estimated that a photovoltaic cell would have to operate for seven years to pay back its energy debt, and most solar cells exposed to atmospheric environments have not lasted that long.

Research workers expect to reduce photovoltaic costs and production energy requirements by a factor of 20 to 30 within the next ten years. Achieving this would require a breakthrough in each of three areas—producing the highly purified silicon, growing the (single) crystals and cutting them into individual cells, and fabricating the arrays (including protective cover glass and mechanical support systems). The requirement that single crystals be grown could be eliminated if another breakthrough greatly improved the performance, or lowered the cost, of polycrystalline silicon. Research directed at these objectives is continuing.

It is frequently argued that increased R&D spending will lower the cost of these solar electric systems enough to make them economically feasible. The FY 1980 DOE budget already allocates $680 million to this purpose, a major portion of which is devoted to demonstration projects based on obviously uneconomic technologies. For example, $21.5 million is budgeted for a group of nine photovoltaic projects at an average cost of $23 per peak watt; at this rate a solar photovoltaic system for a minimal, 1,500-square-foot house would cost nearly $100,000. Such projects, however, may be useful for political purposes, if only to demonstrate that the technology is much too expensive at present.

SOURCES OF QUESTIONABLE FEASIBILITY

Several sources appear to offer very large, or even unlimited energy sources, but the technology requires such large-scale facilities that engineering feasibility has not yet been demonstrated, let alone economic feasibility. Sources in this category are (in order of current promise and funding) thermonuclear fusion, ocean thermal electric conversion (OTEC), photovoltaic arrays in stationary orbit (which can be exposed to sunlight nearly 24 hours a day), water turbines powered by the Gulf Stream, and wave power.

THERMONUCLEAR FUSION

Controlling thermonuclear fusion has been a research goal for nearly 30 years. The concept has considerable intuitive appeal; after all, the hydrogen bomb is much more powerful than uranium or plutonium bombs, and the basic fuel ingredient, deuterium, can be extracted from seawater in virtually unlimited quantities. The idea of a smaller reactor with unlimited fuel supply is certainly attractive, but despite the hundreds of millions now being spent on this program, a self-sustaining thermonuclear reaction is still not expected to be achieved for at least five years, at which time the real engineering problems of extracting useful energy can be tackled. First of all, the only nuclear reaction likely to be achieved for quite some time is the lowest-temperature one, and it requires lithium fuel as well as deuterium. Lithium is probably no easier to find than uranium, so the overall fuel supply picture for thermonuclear fusion should be no better than that for fission breeder reactors (for which we expect reasonable fuel supplies to be available for 700 years). Second, maintaining the walls of the thermonuclear fusion reactor chamber is expected to pose a major problem because these walls will be exposed to intense bombardment by neutrons. In fact, the ultimate practicality of fusion energy production may be determined by whether the lifetime of the inner walls of the reactor chamber is reckoned in months or weeks.

OTEC

In ocean thermal electric conversion (OTEC), the temperature differential between the cold ocean depths and the warmer surface is exploited. The massive structures required to pump huge amounts of ocean water are expensive and pose serious logistical problems, but the critical question is whether the heat transfer surfaces can be cleaned easily enough that slime buildup does not reduce efficiency to the point at which the system will no longer operate. DOE is currently spending about $30 million a year on this program, much of it on a demonstration facility in Hawaii.

SATELLITE POWER SYSTEM

The satellite power system is a completely "blue sky" concept. It consists of a large photovoltaic array (up to 5 miles square) deployed in synchronous orbit to capture sunlight nearly 24 hours a day, free of the efficiency-reducing effects of attenuation from the earth's atmosphere and damage from the weather. The power would be transmitted back to earth on a high-powered, narrow microwave beam produced by a large antenna. This system will, however, require an inordinate amount of resources to be placed in orbit. Also to be considered are the potential impact of large volumes of rocket exhaust on the ionosphere and the safety problems associated with the microwave receiving stations here on earth.

OTHER CONCEPTS

Several other concepts, such as Gulf Stream hydro, wave power, and windmills in the ocean (where the prevailing winds are steadier than over the continents) have been advanced, but they have not yet been considered seriously. In fact, defining the potential engineering problems has not even begun.

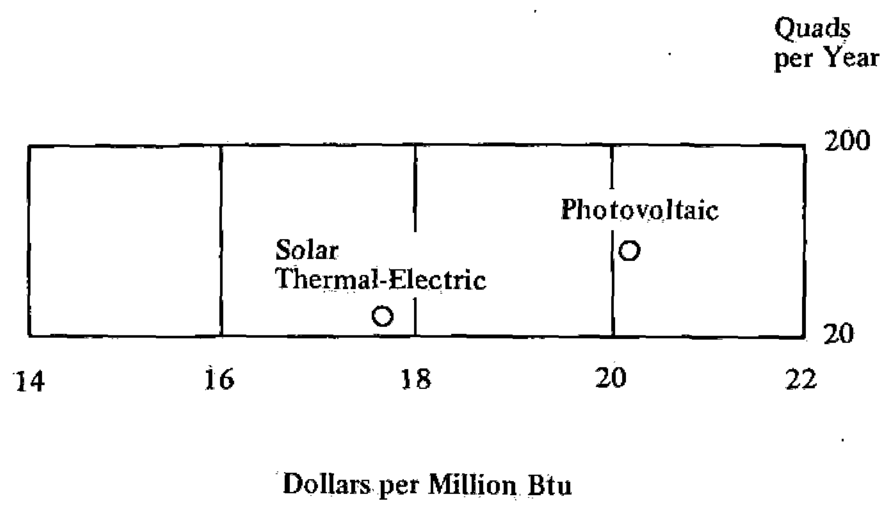


Figure 4. Very expensive renewable resources: quads per year versus cost per million Btu

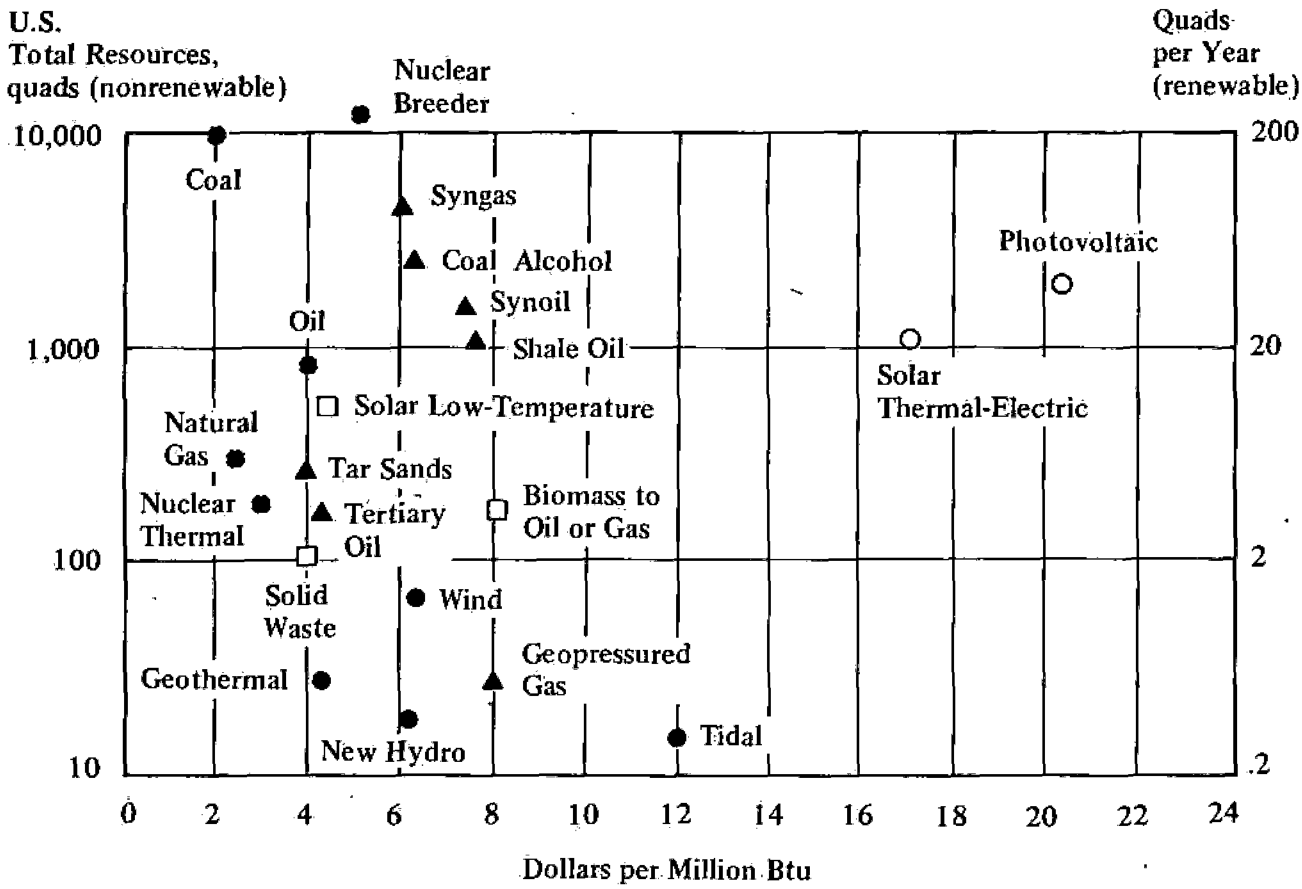


Figure 5. Composite comparison of alternative energy sources: costs and total reserves

CONCLUSION

The great number of energy alternatives in all these categories are compared in Figure 5. The left-hand scale, which shows total resource, applies to the nonrenewable sources, and the right-hand scale, which shows the annual rate of resource availability, applies to renewable resources. A correspondence has been established between renewable and nonrenewable sources through a 50-year lifetime; in other words, the energy extracted from a renewable source for 50 years should be equal to the total energy from an equivalent nonrenewable source.

Figure 5 shows that the technical alternatives that will begin to become available during the 1980s will become increasingly expensive. As we run out of the cheaper fuels, the more expensive alternatives will come into wider use. But will the cost seriously inhibit the overall economic growth of our economy?

A balanced strategy for the 1980s will require the continued development of coal and nuclear power, with conservation measures applied wherever possible without seriously restricting economic growth. We will see increasing development of alternative sources during the 1980s, but only where they can be reasonably cost effective and not too much more expensive than the conventional sources. As oil and natural gas become increasingly expensive, the alternative sources will begin to become a significant factor in our energy economy.

BIBLIOGRAPHY

Aster, R.W. (1978) "Economic Analysis of a Candidate 50 cents/wpk Flat Plate Photovoltaic Manufacturing Technology," DOE/JPL-1012-78-17, Jet Propulsion Laboratory, Pasadena, Calif.

Bergeson, Lloyd (1979) "Sail Power for the World's Cargo Ships," *Technology Review*, March/April, pp. 22-36 (Vol. 81, No. 5).

Considine, D.M., ed. (1977) *Energy Technology Handbook*, McGraw Hill Book Co., New York.

Gray, P.J., and O.K. Gashus (1972) *Tidal Power*, Plenum Press, New York-London.

U.S. Department of Energy Fiscal Year 1980 Congressional Budget Request.

Wade, Nicholas (1979) "Oil Pinch Stirs Dreams of Moonshine Travel," *Science*, June 1, pp. 928-9 (Vol. 204, No. 4,396).