Energy Crisis

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If your candle hasn't burnt out yet, you will read in this article a rational account of some of the possible causes and "cures" of the nation's current energy crisis.

The word "crisis", which, Webster reminds us, means both a crucial time and a turning point, has been used liberally during the past year to describe a shortage of petroleum energy at the consumer level of the economy. America has had a superfluity of crises in its history; these have ranged from crises in confidence and credibility to more substantial difficulties, such as the Great Depression of the 1930's. In this historical context, the energy situation clearly has not received its attention because it in itself is relatively important as crises go; rather, the current situation is important because it represents a new variety of crises. The possibility of long term shortages of a crucial resource is a problem unprecedented for American society. The effects on the United States of such a shortage are unknown and many potential solutions are untried.

During the past three months, the energy crisis has modified America in many little ways. Recently a Baltimore television station ran sixty second spots entitled "Energy Tips", pointing out to bulb loving Americans the heat and light creating potentials of candles. In Chicago, people can now make appointments with their service stations to go buy gasoline. Department stores are reporting an alarming increase in the sales of gasoline siphons and, not surprisingly, locking gasoline caps. This past Christmas, coal in one's stocking no longer meant that the stocking's owner was a bad little boy or girl.

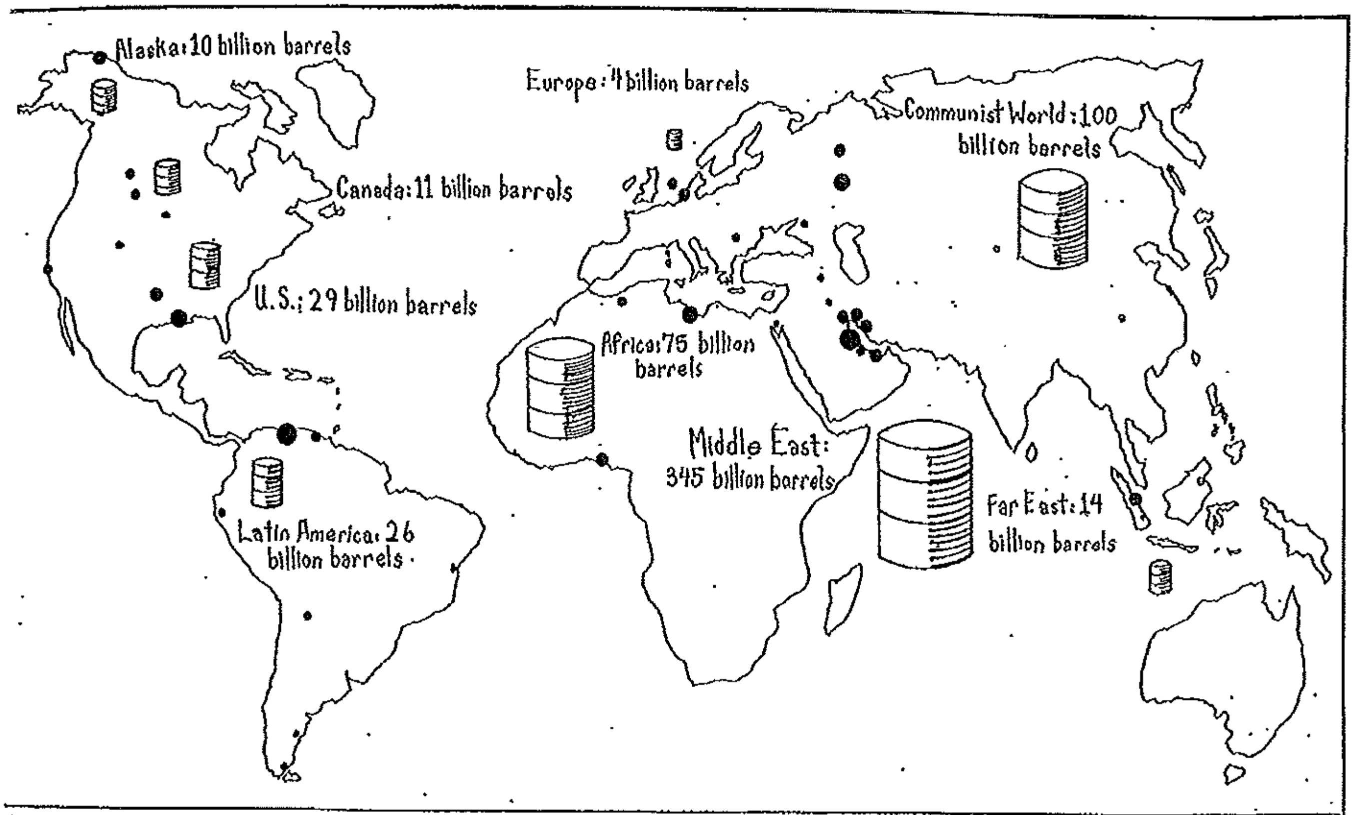
At Yale, as at other academic institutions, the energy crisis was the impetus for further belt tightening. President Kingman Brewster in a letter to the Yale community outlined in November the University's measures for energy conservation. The Administration rejected a proposal to extend Christmas vacation until the first week of February, but the Yale dormitories were shut down between December 22 and January 10 and major University facilities were closed or only partially operated. Custodial services set thermostats in the University's buildings at 68 degrees Farenheit; in many instances the thermostat setting dial was removed to prevent tampering. Finally, the President appointed a Faculty Energy Advisory Committee to explore additional means for saving energy. Of course, the most important element of the energy crisis is not its effect on American colleges and universities; the more important elements, to be dealt with in this article, deal with the national and international aspects of the crisis.

The Insatiable Demand

What is the cause of the current crisis? The question is direct; unfortunately, the facts surrounding the energy crisis indicate that its answer is complicated. Each year for the past thirty years, the world has demanded an exponentially increasing amount of energy. The world population is currently doubling every 30 to 35 years, and predicted world energy consumption is expected to triple by the year 2000. In America, increased use of energy has been advocated as the key to the cure of innumerable social and technological problems. More energy will be needed to heat and light more homes, revitalize urban centers, and clean up the air and water. By the turn of the century, Americans are expected to double their energy consumption.

In the underdeveloped countries, however, even more growth is expected. Based on the correlation between energy consumption and standard of living (Figure 1), the hope for a better life for the poor nations of the world has come to hinge upon the availability of cheap plentiful energy supplies. This, coupled again with exponentially increasing populations in the underdeveloped countries (doubling every 20-30 years), will phenomenally increase the "third world" demand for energy in the next three decades.

A majority of the energy used by both developed and underdeveloped countries is in the form of petroleum, petroleum exported from a small group of Middle Eastern nations well endowed with petroleum reserves (Figure 2). The major importers of oil are among the major industrial nations of the world and include Japan and Western Europe, both of whom have come to depend heavily on the exporting nations to meet their energy needs. France imports 80 per cent of its oil from the Middle East; the figure for West Germany is 74 per cent. Even the United States, in the past self-suffi-



igure 1. Major Petroleum Fields.
Middle East nations containing only 2 per cent of the world's population control over 65 per cent of the free world's oil reserves. Source: Am. Pet. Inst.)

ient in energy production, has gradually been joining the ranks of the 'have not" nations; in 1972, 18 per ent of America's annual petroleum ame from abroad, 6 per cent from the rab nations.

Thus, in Europe and Japan, the short erm cause of the energy crisis can be asily identified as the Arab oil embargo. In the United States, however, ince only 6 per cent of the oil supply vas affected by the embargo, this can ot be the entire story. Evidence has ccumulated indicating sizeable leakage of Arab oil through the blockade to mbargoed markets. Also, the United States experienced a shortage of gasoline in May and June of 1973 and a nodest fuel oil shortage during the 1972-1973 winter, both before the Arab il supplies were cut off.

It is clear that even without the oil mbargo, the United States would ave a domestic petroleum products hortage because of insufficient crude il refining capacity. In the 1967-1972 eriod, oil refining capacity grew lower than the demand for petroleum roducts by approximately 2.1 million barrels a day. To meet the expected demand in 1985, refining capacity still needs to be expanded by 9 million barrels a day. In 1972, however, due to economic considerations, no new refineries were being built and in many cases plans for refinery expansion had been delayed or shelved. A refinery is an expensive investment, a 150,000 barrel a day capacity plant costing over $200 million; without crude unequivocably available for its operation, the initial cost makes the investment risk unattractive.

Domestic Economic Problems

It is apparent, then, that economic effects are also involved in the cause of the energy crisis. Evidence indicates that federal interference in prices has had adverse effects on the supply and demand balance in the petroleum market. The wage-price freeze fixed American petroleum product prices at levels lower than those prices abroad, encouraging export of refined petroleum to markets overseas and increasing demand at home, in addition to making refinery construction unattractive to oil firms. Indeed, a recent *Wall Street Journal* article indicated that excessive demand for petroleum products encouraged by U.S. price controls probably has been more to blame for American fuel shortages than the Arab oil embargo.

Professor James Tobin, of the Yale Department of Economics, suggested low petroleum prices, an insufficient expansion of refining capabilities by the oil companies, and the lack of a national energy policy as among the causes of the energy crisis. In response to several questions by *Yale Scientific*, Dr. Tobin noted that some increase in petroleum prices would be necessary to bring demand more in line with supply, although he also pointed out that the currently skyrocketing oil prices were much higher than necessary to encourage development of new energy sources.

"I think that the United States could cut back on its energy consumption without a disaster to the American way of life," Tobin said. "After all, the Europeans have been driving small cars for a long time. . . You have to give

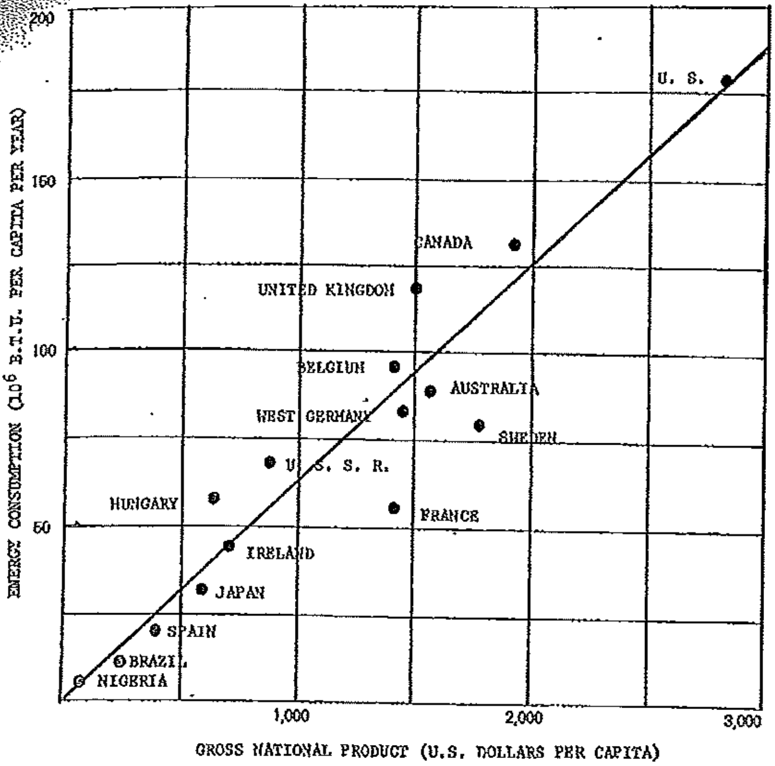


Figure 2. Gross National Product and Per Capita Energy Consumption. 16 representative nations show the correlation between energy consumption and gross national product. (Source: Office of Science and Technology)

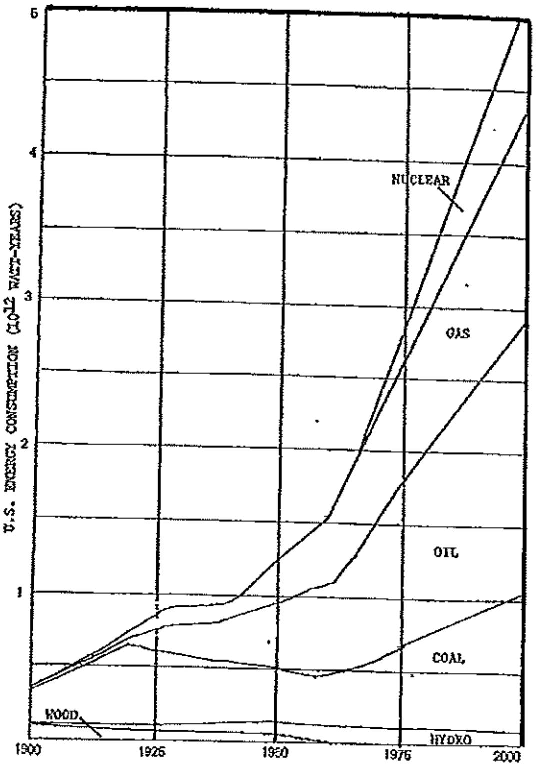


Figure 3. United States Energy Consumption Growth: America's exponentially increasing demand for energy includes an increasing share contributed by oil and nuclear power. (Source: Bureau of Mines)

Americans the price incentive to do [likewise]."

This then leads us to the next important question: what is the solution to the energy crisis? In the long run, the solution of energy shortages must deal with the ultimate cause of the shortages — the exponentially increasing demand for energy. Short run solutions exist, however, and are designed to deal with the immediate crisis. These short term solutions are based on the assumption that the shortage of oil was caused by the Arab oil embargo. Therefore, many planners argue that temporary measures, including allocation and rationing, are needed to tide the American people over until either the lifting of the embargo or the discovery of some new technology makes sufficient energy again available to meet the demand. Presumably, at that time, all allocation and rationing programs would terminate.

Government Action

This philosophy was at the heart of the current Administration's "Project Independence," a program designed to make the United States energy self sufficient by 1980. The Administration's plan eliminated rationing as a present response to the crisis situation because of the inequities, bureaucracy, and potential economic imbalances that traditional rationing systems would entail. Rather, at the heart of the proposal was an effort to create more domestic petroleum and non-petroleum energy supplies. These included making available by pipeline 10 billion barrels of oil beneath the northern Alaska coast and the development of oil shale deposits. Development of oil shale as a new source of petroleum potentially opens a currently unused large reserve of fossil fuels; current estimates indicate that there are 600 billion barrels of "high grade" oil shale beneath 11 million acres in Wyoming, Colorado, and Utah. By an *in situ* processing system the shale is heated in the ground to drive off the trapped oil — these reserves may be available for as low a cost as five dollars per barrel (in comparison with a current cost of $18.76 for a barrel of Libyan oil).

Unfortunately, mere discovery of new petroleum deposits is only a short term solution. Given an exponentially increasing demand for energy, one must find it absurd to expect that there is sufficient petroleum in the earth's crust to continue to provide the proportion of energy that it has provided up to the present time. Indeed, beyond pure energy considerations, petroleum is far more valuable in the long run for its ability to serve as a source for petrochemical feedstocks. Thus an intermediate range solution to the world energy shortage must be based on finding an alternative for petroleum on the energy market. Several of the more important alternatives, to be discussed and compared below, include "natural" energy sources, such as geothermal, tidal, wind, and solar power, and nuclear energy sources, such as fission, breeder, and hydrogen fusion reactors.

"Natural" Alternatives

The "natural" sources of energy offer in many ways an attractive alternative to the combustion of fossil fuels.

As a group, such sources have been used on a small scale for some time. They are generally non-polluting and renewable. Geothermal power is based on the fact that scattered over the earth's crust are areas termed geologic "hot spots", or regions under which magma, or molten rock, has been forced anomalously close to the surface. This dome of magma heats the surrounding rocks which in turn heat water in adjacent porous rocks. When water heated in this fashion reaches the earth's surface, geysers or, more often, hot springs are formed. Use of hot springs dates back to the days of the Romans; currently, in Iceland and New Zealand, nations well endowed with geologic heat sources, geothermally heated public baths are still popular.

The first use of geothermal power to supply electricity came in 1904 with the building in Larderello, Italy, of a generating facility drawing energy from a natural geyser and steam field; the field currently has a capacity of 370 megawatts. Similar facilities have since been developed in New Zealand, Iceland, Japan, the Soviet Union, and California. In addition to supplying power, some geothermal wells also provide a source of desalted water.

Future developments of geothermal power is a promising source of modest amounts of energy. Turkey, the Americas from Alaska to Chile, and the African rift valley are all potential areas for development. Donald White, of the U.S. Geologic Survey, has estimated that 4×10^{20} joules, or approximately 12 million megawatt years, of thermal energy are stored in the most important geothermal areas. In the extraction of this energy, efficiencies could be expected to be anywhere between 10 and 25 per cent, yielding a total energy supply of between 1.2 and 3 million megawatt years of energy available for consumption. However, this figure is small compared with expected American electricity consumption in the year 2000.

There are a reasonable number of problems associated with geothermal power in addition to its small capacity. Drilling a steam well 1000 meters deep costs between $50,000 and $150,000, and a completely developed field could be expected to have a cost comparable to that of conventional power plants. Large scale use of any one geothermal field can create several problems. Injection of large amounts of water into heated rocks will cause "channeling," or the creation of large percolation channels at the expense of smaller channels, preventing efficient heat transfer from the rock to the water. An even more serious long range problem arises from the fact that with a large amount of heat extraction from underlying rock, the rate limiting step for energy use ultimately would be the conduction of heat from rocks deeper in the earth to the developed region — a process that, because of the insulating qualities of rock, would be expected to be reasonably slow.

Wind and Water

A proposal for similar small scale utilization of a natural energy source for electric power production involves tidal power. In its simplest form, the proposal calls for the isolation of a tidal basin with dams. At high tide the basin is filled, and at low tide the collected water is allowed to run out of the basin and through an electric generator. Only one full scale tidal electric plant has been built to date; it is in France and has a capacity of approximately 320 megawatts. Several other sites have been proposed for similar generating stations; these include the Severn River in Wales and the Bay of Fundy in New Brunswick, Canada.

Tidal power, like geothermal power, is limited in scope. David Rose of the Massachusetts Institute of Technology pointed out that "if a low dike were built around the entire U.S. to harness all of the tides, the resulting electric power would only satisfy the needs of a city the size of Boston." Further limitations include problems in locating tidal electric plants. Tidal basins require considerable area and suitable land for tidal basin construction is not plentiful.

A third natural power source is the wind. Long used to generate electricity and pump water on American farms, windmills became a rarity with the inauguration of rural electrification. Because wind power is a pollution-free renewable resource, there has recently been a revival of interest in both large and small scale electric generation with windmills.

America's first large scale wind-electric station was built during World War II in Vermont. With a generating capacity of 1,250 kilowatts, the mill operated successfully for sixteen months. Although similar large scale windmills have been suggested for future large scale energy production, the most current interest in wind generation has involved small windmills supplying sufficient energy for one household. One such windmill currently on the market is capable of supplying 200 kilowatt-hours of electricity a month, the power being stored in batteries to provide electricity when the wind is not blowing. Many limitations of wind power are apparent, however. In many parts of the country, average wind speeds are inadequate and unreliable. Also, simple calculations show that a staggering number of windmills would have to be built before wind power would have any significant part in providing future energy needs.

Solar energy is the final "natural" energy source to be discussed; it is probably the most likely of the energy sources discussed so far to be utilized on a large scale basis. Until recently the only uses for solar energy have been for electric generation in spacecraft and small scale heating (e.g. in greenhouses). The earth reradiates 120,000 million megawatts back into space per year, and virtually all of this goes unutilized.

Greenhouses

Several methods have been proposed for the collection of the sun's energy. One proposal involves distributing panels of light to electricity converter cells over a desert area, converting the energy in the solar rays incident on these panels directly to electric energy. Such an operation is roughly 10 per cent efficient. Another possibility is to use the "greenhouse effect" to trap solar energy by heating air contained in a wood box covered on one side with a polyethelene sheet. The heated air is then blown by a fan into a solar heated house. Finally, to prevent loss of energy due to adverse weather and pollution conditions, one scheme advocates orbiting a solar power collection satellite in a stationary orbit around the earth; the satellite would beam the energy collected to the earth via microwaves.

Solar energy plants clearly would have to be large in size. Considering that energy consumption in 1970 was 2.2 million megawatts, to supply all of America's expected energy needs in 1980 using solar plants with 10 per cent efficiency would require a solar collection area roughly the size of Arizona. The large size and therefore large cost of solar power generating plants makes them unattractive for current use as large scale energy sources. Nevertheless, since solar power is completely renewable and non-polluting, in the long run it offers the best alternative to the next set of energy generation facilities to be discussed, nuclear power reactors.

"Unnatural" Alternatives

Nuclear power plants may be divided into three broad categories: conventional reactors, which obtain energy by fission (or splitting) of the nuclei of heavy atoms such as uranium 235; breeder reactors, which run on uranium or plutonium but, during operation, create more fissionable material than they consume by bombarding thorium or uranium 238 with neutrons; and fusion reactors, which obtain energy by the fusion of two hydrogen nuclei to form a helium nucleus.

American nuclear power plants of the conventional variety numbered 22 in 1971 and had a combined capacity of 9,132 megawatts per year. Another 99 plants with a combined capacity of 90,000 megawatts were either under construction or on order. By the year 2000, nuclear power plants may be supplying 50 per cent of America's electrical energy. This set of plants offer America's only major technologically proven alternative to fossil fuel power. Environmental problems with conventional nuclear installations have been well documented. The most serious problem relating to long term planning, however, is the fact that by the year 2000 an acute shortage of low cost uranium 235 reactor fuel will have developed. Thus, conventional reactors clearly are only an intermediate term solution to the energy shortage.

Breeder reactors have been advocated as long term replacements for conventional reactors. Because they create fuel during their operation, a set of breeders in theory would never run out of fuel necessary for their own operation. Briefly described, the operation of a breeder depends on the ability of excess neutrons from the fission process to convert bombarded "fertile" isotopes of heavy metals into fissionable isotopes. Two such fertile isotopes are uranium 238 and thorium 232, both in abundant natural supply.

Current research has led to the construction of several liquid metal fast breeder reactors ("liquid metal" refers to the heat transfer system used and "fast" refers to the use of fast neutrons in the breeding reaction); other potential breeders include the gas cooled fast breeder reactor and the thermal (slow neutron) breeders. Fast breeder reactors which create plutonium 239 as the end product have recently received the most attention because their breeding efficiencies are the highest. Glenn Seaborg of the Atomic Energy Commission has estimated that the first reactor of this type will be commercially available by 1985.

Recurring Fears

Problems with breeder reactors are numerous, however. These include technological as well as environmental and sociological difficulties. Structural difficulties are created by the instabilities of most metals under intense neutron bombardment. Furthermore, to obtain "bred" fuel, the reactor fuel pellets must be removed from the reactor and transported over long distances for chemical processing to isolate the plutonium. This involves the possible release of radioactive nucleotides to the environment in the transport and processing of the fuel elements, as well as during the long term storage of radioactive waste products. Finally, large numbers of breeder reactors would create large inventories of plutonium which is considered by many to be one of the most dangerous elements known. If obtained by the incorrect persons, plutonium could easily be fashioned into nuclear explosives suitable for political blackmail. Thus breeder reactors are not without disadvantages, disadvantages which in the minds of many make them an undesirable energy alternative no matter how much energy they can potentially provide.

In contrast, the hydrogen fusion reactor is considered to be an ideal method for creating power. The basis of fusion power is that the fusion of hydrogen nuclei to form helium releases large amounts of energy in a process similar to the process occuring in the sun. Fusion power is advocated as safe, free from radioactive waste by-products, and relatively abundantly supplied with fuel.

The single biggest difficulty with hydrogen fusion is technological. Fusion reactions take place only at temperatures in excess of 100 million

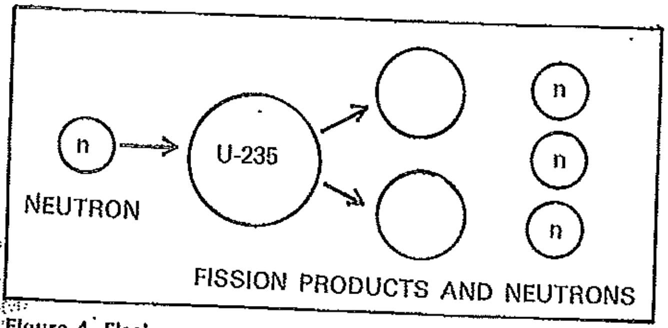


Figure 4. Fission
Nuclear fission occurs when the nucleus of a heavy metal such as uranium 235 is bombarded with neutrons; the products include more neutrons which can be used both to continue the process and to "breed" more fuel.

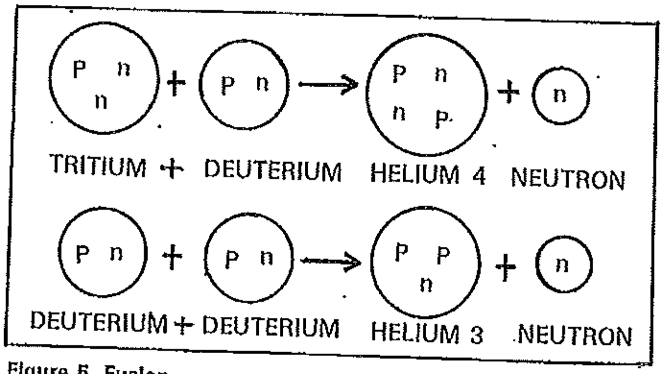


Figure 5. Fusion
Fusion occurs when tritium and deuterium (two isotopes of hydrogen) or two deuteriums combine to form helium.

degrees centigrade and at these temperatures, the hydrogen fuel exists as a plasma, or ionized mixture of electrons and atomic nuclei. Confining this plasma at sufficiently high pressures has been attempted using magnetic fields, as material containers on contact with the plasma would cool the plasma to a temperature too low for fusion to take place. These attempts have only been partially successful due to instabilities inherent in the plasma; nevertheless containment of a plasma has been achieved for periods of a few thousandths of a second.

Fusion power, despite all of its potential, will not be available before the year 2000. Research progress has been in many cases frustratingly slow; much of the basic technology still needs to be developed. A further problem arises from the fact that current fusion processes being developed use tritium, a relatively rare isotope of hydrogen, as a fuel. Tritium is manufactured from lithium 6, a not-too-abundant isotope of lithium. The measured reserves of this isotope in the United States, Canada, and Africa include only 67,000 metric tons, making the potential energy derivable using tritium fueled fusion reactors equal approximately to the energy content of the world's fossil fuels.

Outlook for the Future

This completes a brief survey of intermediate solutions to the energy crisis. These solutions are classified as intermediate in range because although they do not deal with the ultimate cause of the energy shortage, they do serve to reduce the demand pressure from the world's petroleum reserves. What is presented to the reader is a selection of small scale approaches to the crisis, many involving incomplete technologies, ecological problems, and occasionally major potentials. It should be made clear that, except possibly for breeder reactors, no new energy source definitely will be available by the year 2000 in any significant quantities to meet the expected exponentially increasing energy demand. Even this date involves a considerable gamble; it is entirely conceivable that the most promising new source of power, the fusion reactor, may not be available then.

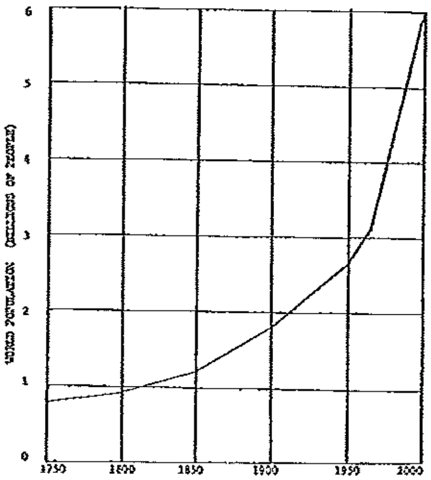


Figure 6. Exponential Growth: Growth of World population with time in an exponential fashion is one cause of increasing energy demand and the energy crisis. (Source: United Nations)

Thus, with an exponentially increasing demand resulting in large part from an increasing world population, particularly in the underdeveloped countries, the planet-wide energy situation for the next three decades looks somewhat grim. Although much of the coming demand may be met by increased reliance on traditional energy sources such as coal and petroleum, even the most rapid possible development of alternative energy supplies probably will not prevent more serious future energy shortages. This is particularly true in relation to the correlation between the standards of living and energy consumption. If the goal of bringing to the current world population of close to four billion persons a standard of living comparable to that of even the poorest nations of the western world seems difficult, it may be safely considered impossible to substantially improve the lot of a population doubling in size every 35 years. Thus, the only true long range energy policy consonant with economic and ecological standards requires long range population stability resulting from a controlled birthrate. To meet the challenge of the energy crisis, the exponential rates of industrial and population growth that have prevailed for the past two centuries must cease.

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