19 January 1979, Volume 203, Number 4377 SCIENCE

Energy Resources Available to the United States, 1985 to 2000

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Summary. Energy and the gross national product have grown hand in hand at 3 to 3½ percent a year for almost 40 years. Our energy growth is slowing down and will essentially level off in the 1990's. Our production of oil and gas passed a peak in the early 1970's, and there is no resource base to justify predictions of increased yields. Coal is the only fossil fuel capable of increased production. There are serious doubts that our uranium resources can support a large light-water reactor program. Finding rates for petroleum, natural gas, and uranium are less than half of what they were 20 years ago.

The problem of supplying energy for a growing U.S. economy is a real and a permanent one. Our natural resources have finite limits, and we have been consuming them at an ever increasing rate for many years. Like all spendthrifts living beyond their income, we have resorted to the charge account and increased our import bill for foreign oil from $3 billion to $45 billion in 6 years. This was the largest contributor to a trade deficit that reached an all-time high of $26 billion in 1977. Sooner or later the country has to reduce its imports to more manageable levels. Doing so, we must realize, will require a difficult transition from the rapid energy growth of the last 25 years to a somewhat slower one.

In the wake of the 1973 oil embargo came the first general realization that there might be supply difficulties up ahead. This realization vanished in a few months, and in 1978 we hear stories about a world oil surplus, and some deride the President for making energy a major national issue. Americans at large continue to cling to the naïve idea that we can have all the oil and gas we will ever need at 1970 prices without digging coal or building nuclear plants. This attitude slows down or stops planning for the inevitable—a less energy-intensive U.S. society.

Aside from the predictions of energy supply problems by a few individuals and a handful of government agencies, the country did not have adequate background information on energy in 1973. Since then, we have been inundated with energy demand and supply studies, ranging from responses to presidential requests to minutiae. Among the overall studies since 1972 have been those conducted under the auspices of the Department of the Interior (*1*), Project Independence (*2*), the Ford Foundation (*3*), the Energy Research and Development Administration (ERDA) (*4*), the Committee on Nuclear and Alternative Energy Sources (CONAES) (*5*), Project Interdependence (*6*), the Department of Commerce (*7*), and the Executive Office of the President (National Energy Plan) (*8*). Many other studies are summarized in (*6*) and (*7*).

There are two possible approaches in such studies. The first is that of the economist who reasons that there will always be a supply of a commodity if the price is right. The second is that of the engineer who sees declining grade, institutional constraints, and physical geography placing finite limits on availability. The difficulty with the economist's approach is that price elasticity for a wasting nonrenewable resource does not follow normal economic principles. In many cases, analyses of supply and demand do not recognize that limits to our energy growth have been imposed by the extent and availability of our natural resources and that this has affected our general growth.

In this article I am mindful of the economist's approach, but I give much more weight to the availability factor. I discuss natural resources of energy, analyze the probable domestic and import supply of each major energy sector, and arrive at the dismaying conclusion that energy growth will all but stop in another decade. In this analysis I do not address the economic, social, and political problems that will ensue and will dwarf the technical ones.

Table 1 summarizes the energy supply expected to be available to the United States in 1985 and 2000, as well as the past supply record. The following sections provide documentation for each estimate; they are presented in the sequence of Table 1, covering fossil fuels, hydropower, nuclear and solar energy, and energy from other sources. The values in Table 1 represent the energy that can probably be made available for consumption under normal development and at prices up to twice those of today.

U.S. Petroleum Liquids

It must be recognized that the United States never had and never will have the petroleum resources to sustain indefinitely the production levels of the last 25 years. In effect, we have been living off our capital all this time and cannot postpone the day of reckoning indefinitely. Talk of rising petroleum (and gas) production for long periods is both immoral and nonsensical. Whatever slight gain might be achieved for a very few years

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0036-8075/79/0119-0233$01.75/0

will be at the expense of the youth of today. Predictions of sustained increased production deny the records of 50 years of experience with the exploration, development, and extraction cycle of liquid hydrocarbons. There is a finite amount of easily recovered petroleum in this country, and no act of Congress or false optimism of government, industrial, or academic planners can add to our natural resource base.

The disparity between estimates of how much oil we can really expect to find in this country seems to have been resolved on the pessimistic side. The U.S. Geological Survey figures, which were higher than most others, were finally lowered and brought into line (*9*). Undiscovered petroleum liquid resources are now placed at 100 billion barrels, give or take 25 billion.

Notable among forecasters is Hubbert (*10*), who accurately predicted more than 20 years ago—when we were being assured of oil and gas forever—that there would be a peak in production near 1970 and an unavoidable decline in production forever after. Each passing year attests to the validity of his projections. Whether or not one subscribes completely to Hubbert's methodology (*11*), there is no longer much argument with the conclusion that U.S. resources of conventional oil will be seriously depleted by the year 2000.

Proved U.S. reserves of petroleum liquids peaked at 47 billion barrels in 1970 and then declined to the present level of 37 billion barrels. This occurred in spite of the one-shot addition of 10 billion barrels from Prudhoe Bay, Alaska, in 1970. Production and reserve figures for oil and natural gas liquids are displayed in Table 2.

It is desirable to maintain the reserve/production (*R/P*) ratio above 10 to realize maximum economic recovery. As Table 2 shows, in the past 30 years the *R/P* ratio for petroleum liquids has declined from 12 to 10. Since there is an 8- to 12-year gap between reserve additions and subsequent production, we can expect production to keep dropping. Expressed in a different manner, in the 1950's we found $1^1/_4$ barrels of oil for every barrel we extracted, but by the late 1970's this had dropped to about 1/2 barrel.

Estimates of production in 1985 and 2000 from some of the current reports are displayed in Table 3. The higher estimates of production in the CONAES (*5*) and Project Interdependence (*6*) studies are due to the assumption that government restrictions and regulations would be suspended and the price allowed to float free. They did not argue that new large fields such as that at Prudhoe Bay would be discovered, but assumed that there would be higher recovery from existing and yet to be discovered fields. In an about-face, Franssen (*12*), the leader of Project Interdependence, has pointed out that to achieve a production rate of 11 million barrels per day in 1990 it would be necessary to add 4 billion barrels a year to our reserves. However, there is no resource base to support claims of increased oil production. Aside from the one-of-a-kind Prudhoe Bay discovery, we have not found that much petroleum in any one of the last 30 years—in fact, as Table 2 shows, lately our reserves have been going down by $1^1/_4$ billion barrels a year. Just to maintain current production would require a discovery rate 50 percent higher than that of the last 10 years.

There is an estimated 2 trillion barrels of oil dispersed in shale in Colorado, Utah, and Wyoming (*13*); 80 billion barrels might be classed as a favored resource. Each ton of this shale contains 10 to 40 gallons of kerogens, which can be released by heating at a fairly low temperature (900°F). The logistics of producing 1 million barrels of oil a day are nearly overwhelming. For surface retorting it would be necessary to mine about 2 million tons of shale a day, transport it to retorts, process it, and then dispose of the spent shale in an environmentally acceptable manner in a desert-like atmosphere. In situ retorting, in which rubbilized (fragmented) shale is retorted underground, appears to be a viable alternative for overcoming these development problems. This would also reduce water requirements. Rising oil prices will lead to the conversion of some of these resources to reserves, and production could reach 1/2 to 1 million barrels a day by 2000.

Two-thirds of all the oil ever found is still in the ground waiting for an economical recovery process. Secondary or tertiary recovery methods involving water pressure, reinjection of natural gas, carbon dioxide and steam, surfactants, and so on provide limited yields. By using such methods it should be possible to

Table 1. Annual energy supplies for the United States, 1940 to 2000. Values are quadrillion (10^{15}) Btu's (quads)* per year.

Year	Petroleum liquids		Gas		Coal	Hydro	Nuclear	Other†	Gross total†	Growth (quads per year)
	Domestic	Imported	Domestic	Imported						
1940	7.5		2.7		12.5	0.9		1.4	25.0	1.02
1950	13.5		6.2		12.9	1.4		1.2	35.2	1.04
1960	16.8	3.3	12.5	0.2	10.1	1.7		1.0	45.6	2.25
1970	22.8	6.7	21.2	0.8	12.7	2.7	0.2	1.0	68.1	1.60
1977	20.0	17.4	19.1	1.0	13.0	2.7	2.7	1.8	77.7	1.13
1985	17	22	15	2	19	3.0	6.0	2.7	86.7	0.55
2000	15	17	9	1	32	3.5	11	6.5	95.0	

*Equivalents of 1 quadrillion Btu's: 1 trillion cubic feet of natural gas, 170 million barrels of oil, 40 million tons of bituminous coal, or 100 billion kilowatt-hours of electricity. †Includes biomass figures not carried in all energy summaries.

Table 2. Annual estimates of proved U.S. reserves of crude oil and natural gas liquids (*27*).

Year	Crude oil (billion barrels)		Natural gas liquids (billion barrels)		Natural gas (trillion cubic feet)	
	Proved reserves at end of year	Production	Proved reserves at end of year	Production	Proved reserves at end of year	Production
1946	20.9	1.73	3.16	0.129	159.7	4.0
1950	25.3	1.94	4.27	0.23	184.6	6.3
1955	30.0	2.42	5.44	0.32	222.5	9.4
1960	31.6	2.47	6.82	0.43	262.3	12.8
1965	31.4	2.67	8.02	0.56	286.5	16.0
1970	39.0	3.32	7.70	0.75	290.4	21.9
1971	38.1	3.26	7.30	0.75	278.8	22.5
1972	36.3	3.28	6.79	0.76	266.1	22.5
1973	35.3	3.19	6.45	0.74	250.0	22.5
1974	34.2	3.04	6.35	0.72	237.1	21.4
1975	32.7	2.89	6.27	0.70	228.2	19.7
1976	30.9	2.83	6.40	0.70	216.0	19.5
1977	29.5	2.86	5.99	0.70	208.9	19.4

add 1/2 to 1 million barrels of oil a day to our production by the year 2000.

I estimate a production of 7½ million barrels of petroleum liquids per day in 2000. This is basically a projection of the data in Table 2 and the Hubbert bell-shaped curve, augmented by shale oil and enhanced recovery.

Petroleum Imports

Foreign oil resources are much larger than those of the United States, but they too have finite limits. The Project Interdependence report (*6*) has this to say: "Half of all the oil that has ever been produced has been taken from the earth in the last 10 years. This gives a perspective on the escalating growth in world energy demand. Even in the OPEC countries, as in most producing basins of the world, most of the oil has already been found. So great is the accelerating demand for energy that the years of abundant supply of conventional liquid hydrocarbons will be relatively few."

The question of whether world production will really increase rapidly enough to satisfy all the growing demands depends on Saudi Arabia, which has 25 percent of the reserves in the Free World. That country has only 6 million citizens and could collect almost $1 trillion (1978 dollars) by the turn of the century. There is the ever present possibility that Saudi Arabia will decide to husband its great asset, which may be a better investment in the ground than money in a bank. Any future abrupt decrease in supply could cause far more havoc than did the 1973 embargo.

At the end of 1976, the recoverable world reserves of crude oil amounted to 567 billion barrels, of which 380 billion were in the countries of the OPEC (Organization of Petroleum Exporting Countries) group (*14*). Saudi Arabia and Kuwait had a total of 180 billion barrels—six times the reserves of the United States. The world is approximately halfway in its ultimate petroleum exploration (*6*).

World production of petroleum liquids has gone from 24.5 million barrels in 1960 to 45.7 million in 1970 and 55.4 million in 1975. Sixty percent of the last figure comes from four countries: the United States, Saudi Arabia, Russia, and Iran. It is estimated (*6*) that world productive capacity will peak in the next 15 years in a range from 65 million to 90 million barrels per day, depending on whether deliberate curtailment is imposed.

Table 3. Estimated production of petroleum liquids. Values are millions of barrels per day.

Source	1977	1985	1990	2000
CONAES (*5*)	10.0	9.0	8.0	6.0
Project Interdependence (*6*)		10.9	11.4	
Department of Commerce (*7*)		8.6		6.2
Hubbert (*10*)*		8.0	7.0	4.0
Exxon (*28*)		8.0	10.3	

*Estimated from graph.

There should be sufficient oil in the world to permit imports of 11 million barrels a day in 1985, if needed. This could cause a further deterioration of our trade balance and further threaten our national security.

My estimate of 8½ million barrels of imported oil a day in 2000 takes account of the expected worldwide peak followed by a decline in production in the 1990's. The United States will experience at least a 25 percent decline in availability from 1985 levels as it competes with the rest of the world for available oil.

U.S. Natural Gas

Among the fossil fuels, natural gas has the starkest outlook. A Populist-type insistence that it be sold at a fraction of its replacement cost is resulting in a squandering of the most valuable nonrenewable resource we possess. For the past 10 years we have been using 20 trillion cubic feet (TCF) a year and finding only 10 TCF.

The whole story is told in Fig. 1. The desirable *R*/*P* of 12 to 1 governs the average rate at which natural gas reservoirs can be drawn down to achieve maximum resource recovery. The United States reached a production peak of about 22 TCF in 1971 to 1973. This declined to about 19 TCF in 1977. Lowered production follows from the fact that proved reserves went through an earlier peak of 290 TCF in the late 1960's and dropped to 209 TCF in 1977 (Table 2). Projecting the proved reserve figures and holding the *R*/*P* at 12 gives production figures of 13 TCF in 1985 and less than 5 TCF in 2000.

Some of the numerous studies that have projected 1985 natural gas production at 17.5 ± 1 TCF per year have been discussed by Franssen (*12*). Such a production figure would call for finding one-third of all the undiscovered recoverable gas of the United States by 1985—a highly improbable occurrence when it is considered that the undiscovered gas figure is of the order of 500 TCF (*6*).

There are three possible sources of additional natural gas: tight sandstones, Devonian shales, and geopressured zones. The tight sandstones of the western basins, ranging from the northern tier states to the Mexican border, have marginal gas supplies at 1978 prices near $2 per thousand cubic feet and will make a modest contribution to overall supply. Three atomic blasts produced little additional gas, so there are real limits to the amount of the total resource that can be economically recovered.

Devonian shales, along with coal beds roughly covering the Appalachian area, in the aggregate contain large quantities of gas, but the dilute nature and low pressure of the gas hinder its large-scale production. In the aggregate, the Office of Technology Assessment (*15*) believes they may furnish 1 TCF per year by 2000. The Gulf Coast region supposedly has large geopressured areas at great depths containing water with dissolved gas. So far, this is mostly an interesting hypothesis and very small amounts of gas have been produced. The pumping problems for large-scale gas recovery would be formidable.

I estimate 15 TCF in 1985, assuming that decontrolling natural gas prices will add to our reserves by making it profitable to extract additional gas above the projection of Fig. 1. My estimate of 9 TCF in 2000 includes 5 TCF from conventional sources, 3 TCF from unconventional sources (currently supplying about 1 TCF), and 1 TCF from Prudhoe Bay. With complete deregulation and price levels twice that of today, it is quite possible that unconventional production could be doubled. The estimate of 9 TCF is admittedly conservative. It is based on projections of Table 2 coupled with the fact that in 10 years our finding rate for natural gas has dropped from 560,000 to 220,000 cubic feet of gas per foot of hole drilled.

Natural Gas Imports

Natural gas imports will be more limited and expensive than oil imports. The United States has imported 1 TCF a year from Canada for several years. This will probably continue until around 1985, and the amount imported will decline to zero by the early 1990's. Liquid natural gas imports from non-Canadian sources such as North Africa and the Middle East will reach 1 TCF by 1985 and rise for a few more years before declining in the 1990's. Other sources such as Indonesia and especially Mexico will add to these figures.

An estimate of 1 TCF of imported natural gas in 2000 appears generous in light of the predicted decline in reserves and production of world oil and gas starting in the middle 1980's. Use of gas near the source for energy-intensive industries such as the petrochemical and aluminum industries could imperil such imports.

Coal

The United States possesses about 31 percent of the world's known coal resources. The Bureau of Mines (*16*) estimates there are 437 billion tons of coal in deposits that can be mined under present economic conditions with current technology. About two-thirds of this is underground. Recovery of coal in place varies from 40 percent for some underground methods to more than 90 percent for strip-mining operations. This results in a fairly certain estimate of more than 250 billion recoverable tons of coal. No matter what figures are used—a present production of almost 700 million tons a year or a production of 2 billion tons a year in the future—the reassuring conclusion is that coal is available in increasing quantity to tide us over the transition to a society demanding less energy. Regardless of the present environmental and sociological constraints on its use, coal is the only abundant domestic energy resource capable of substantial expansion to keep our energy supply growing, albeit slowly.

Table 4. United States coal production estimates, 1985 to 2000. Values are millions of tons.

Source	1985	1990	2000
Project Interdependence (*6*)	940	1225	
National Energy Plan (*8*)	1050	1250	
Department of Commerce (*7*)	890		1860
CONAES (*5*)	995	1250	1700
Project Independence (*2*)	1100	1300	

Recent estimates of future U.S. coal production are shown in Table 4. By June 1978, coal production for 1985 could be estimated with confidence at 900 ± 20 million tons. Mine leases have been consummated, coal contracts signed, and mine development started for coal production in the middle 1980's. An estimate of 1700 million tons of coal production in 2000 is based on the CONAES report.

The United States exported 54 million tons of coal in 1977 and it is assumed that the amount exported will grow to 80 million tons in 1985 and 110 million tons by 2000 (*6*). This would make available to the United States 19 quads of net coal energy in 1985 and 32 quads in 2000.

These projections would require coal production to increase 50 percent in the decade 1975 to 1985 and 300 percent in the period 1975 to 2000. In itself this will require a tremendous effort in capital formation, training of a quarter-million miners, and production of mining and transportation equipment. There will be even larger expenditures in downstream facilities such as transportation and electricity-generating systems to make this coal useful.

Nuclear Energy

The story of nuclear energy is one of decreasing expectations. In 1973 the Atomic Energy Commission predicted 240 gigawatts of installed electricity-generating capacity by 1985; by 1977 their forecast had dropped to 163; in 1978 this dropped drastically to 110 GW (*17*). Part of the high figure was based on pure optimism; the decrease resulted from continued public opposition to nuclear reactors, rising capital costs, and a decreasing electrical energy growth rate.

In the second quarter of 1978 nuclear energy was furnishing 48 GW of power, and there was a reasonable expectation that plants under construction would add another 52 GW by 1985, for a total of 100 GW. This results in a forecast of 6 quads in 1985.

In addition to the constraints on the development of commercial nuclear energy that were noted above, there is a more far-reaching one of limited natural resources, and this may be the most telling constraint of all (*18*). The uranium resources of the United States may not support a light-water reactor program more than twice as large as the program for 1985.

Currently the resource picture for uranium is in serious dispute between the Department of Energy and independent studies. Domestic uranium resources in June 1977, estimated by ERDA, are shown in Table 5. Even the Department of Energy (*17*) questioned the validity of including possible and speculative resources in hard planning data. In normal ore estimating procedures,

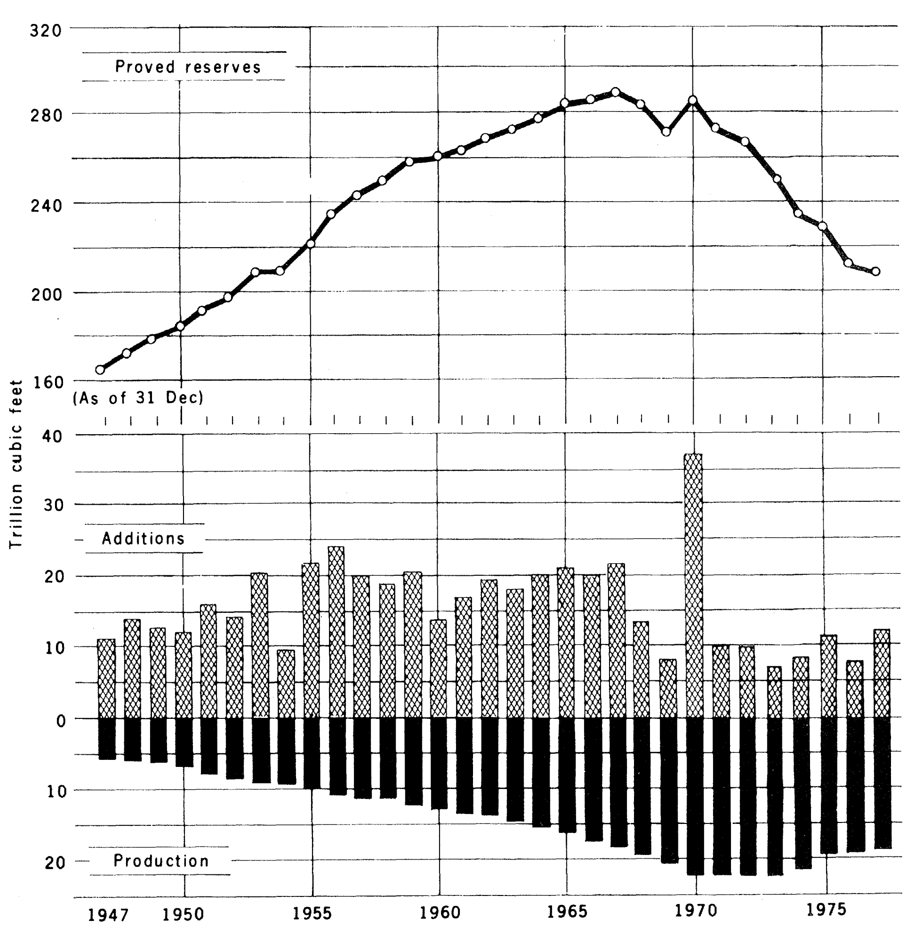

Fig. 1. Natural gas reserves, additions, and production in the United States, 1947 to 1977 (*27*).

the most optimistic analysis would include only the reserves and probable resources. Inclusion of the number of reactors in such data is highly misleading.

The CONAES Supply Panel found markedly lower values (*18*). Their consensus was that the reserve figure of 680,000 tons of U_3O_8 might diminish to 450,000 tons of recovered U_3O_8 when mining losses were taken into account. The CONAES best estimate was 1,070,000 tons of reserves and probable resources of U_3O_8. They believed that there was a 97 percent probability that the resources would be less than the ERDA estimate of 3,370,000 tons of U_3O_8 at $30 a pound.

Lieberman (*19*) analyzed the uranium exploration records from 1947 to 1976 and came up with the same serious doubts about the future U.S. uranium supply position. He arrived at a grand total of 1,090,000 tons of U_3O_8 reserves and probable recoverable resources at a price of $30 a pound. Over this period the rate of discovery declined from 18 to about 3 pounds of U_3O_8 per foot of hole drilled. All this is reflected in the real world, where the price has risen from $8 a pound in 1973 to more than $40 a pound for new contracts.

A 1-GW reactor requires 5500 to 6000 tons of U_3O_8 over its life-span of 30 years. The 100 GW of installed capacity by 1985 will require 550,000 tons of U_3O_8, which is just about the CONAES estimate of today's known reserves. A total of 200 GW by 2000 would require 1,100,000 tons of U_3O_8 or all the known and yet to be discovered economical resources, as seen by CONAES and Lieberman. The reserves plus probable categories of the Department of Energy would suffice for about 400 1000-megawatt reactors. This gives a total estimate for the ultimate U.S. capacity of 200 to 400 GW. The high figure is very optimistic when it is realized that a reactor on the drawing board today depends on uranium yet to be discovered for its fueling.

In view of all its problems—low public acceptance, capital costs, past track record, lack of fixed plans for spent fuel processing and waste disposal, cancellations, and primarily ore availability—it would appear that nuclear energy will not exceed 185 GW (11 quads) in the year 2000. Current orders are slightly over 200 GW. World competition for uranium will constrain U.S. imports. Investment enthusiasm would be diminished if a $1-billion plant were dependent on foreign ore sources.

The present political uncertainty and the development costs preclude the breeder reactor from being a factor in energy supply in this century. The cost of a reactor just to test materials going into a breeder reactor rose from an initial $87 million to almost $1 billion in a few years. Materials, engineering, and financing problems continue to plague the development of a demonstration reactor. Yet, from a resource viewpoint, we have no choice but to work on a system that, in effect, would increase our uranium reserves 70 times.

Table 5. Domestic uranium resources on 1 June 1977 (*17*, p. 202). Values are thousands of tons of U_3O_8. The numbers in parentheses represent the number of 1000-MWe reactors that can be supported for 30-year operating lifetimes by the amount of uranium in the associated resource category. It is assumed that each reactor consumes approximately 5500 tons of uranium during its lifetime.

Uranium resources	Forward cost category*	
	$30 or less	$50 or less
Reserves†	680 (125)	840 (150)
Potential resources	2690 (490)	3330 (605)
Probable	1088 (190)	1370 (250)
Possible	1188 (215)	1420 (260)
Speculative	484 (85)	540 (95)
Total	3370 (615)	4170 (755)

*Forward costs are those yet to be expended, and do not include sunk costs, taxes, profit, or amortization of existing capital equipment, and therefore do not represent prices at which U_3O_8 will be marketed. †Does not include the 140,000 tons of U_3O_8 estimated to be available as a by-product of phosphate and copper production during the period 1977 to 2000.

Solar and Other Energy Sources

The lure of free power from the sun has blinded many people to the economic facts of life. No other part of the energy spectrum generates as much optimism, emotion, and misinformation as this one. However, we are in danger of being carried away with too much spending too rapidly in a narrow area that has unlimited long-range but restricted short-range returns. A fallacy in this area is that because the sun's radiation is free, technology will convert it to a cheap source of inexhaustible energy.

The bright hopes for widespread use of solar energy will not be realized by 2000. It is a dilute form of energy and is available only part of the time, hence the processes by which it can be put to use are inefficient by our present standards or economics. The most promising immediate use is in passive collectors that heat water for use directly or in heating homes and buildings. This is near the edge of present economics and can be expected to have an impact on the design and construction of every new structure in the coming years. About 22 percent of U.S. energy consumption is for heating houses (*12*), businesses (*6*), and water (*4*). A rough estimate is that up to 10 percent of this, or 2 quads, might be supplied by solar in 2000.

This will be passed by biomass energy production. In 1976 and 1977 the contribution from this area was about 1.6 quads from wood and wood wastes and 0.2 quad from other wastes. (This is unaccountable energy in most forecasts.) The wood waste contribution is strictly one of derived demand and depends on activity in the pulp and paper industry. Tillman (*20*) has estimated that in 2000 the energy available in biomass will be 5.67 quads, consisting of 4 from wood, 0.67 from agricultural wastes, and 1.0 from municipal solid waste. This assigns very minor roles to such items as methanol and energy plantations. All of these estimates appear to be optimistic, in view of probable lower industrial growth rates. Attainment of 3 to 4 quads for 2000, about twice the current level, appears to be possible.

Wind, tide, ocean thermal, solar electric, geothermal, and other proposed energy sources do not show promise of delivering more than 1 quad of energy by 2000 (*21*). They do not fit the economics of our times since the true cost of delivered energy from these sources would be several times today's prices.

This adds up to 6 to 7 quads in 2000, which is higher than most estimates. Project Interdependence (*6*) estimated about 2 quads in 1990, and the Department of Commerce (*7*) estimate was 5 quads in 2000. The period 2000 to 2010 should see a marked gain.

Hydropower

It has taken more than 50 years of effort to reach a level of 57 GW of installed generating capacity that produces 2.7 quads of energy from hydropower. The better sites have been used, and even an accelerated effort (the current Administration has a deceleration policy) will produce only a modest addition. About 14 GW can be installed in existing structures and 8 GW in structures being built (*22*). A conservative estimate is that hydropower will produce 3 quads in 1985 and 3.5 quads in 2000.

Discussion

The summary of U.S. energy supplies shown in Table 1 is at the low end of similar compilations published in the past 4 years. The Department of Commerce

(*7*) listed ten summaries produced by ERDA, the Federal Energy Administration, the Department of the Interior, Exxon, and others. Their energy estimates for 1985 ranged from 87 to 108 quads, the average being 96 quads. Their nuclear average was 5 quads higher than the value in Table 1, so with this taken into account it can be said that there is fair agreement on about 90 quads of available energy in 1985.

There is a much greater deviation for the year 2000. The Department of the Interior forecasts 192 quads; the Department of Commerce, 116 quads; and the Department of Energy, 130 to 141 quads. The higher estimates generally include 18 to 35 quads from nuclear power, which at this point appears unlikely. When the higher estimates made 5 years ago are compared with more recent figures, it can be seen that there has been a deflation of the nuclear and solar estimates and a grudging realization that domestic petroleum and natural gas have passed their production peaks forever.

The estimate of 95 quads for 2000 in Table 1 again is at the low end of estimates. The lower nuclear estimate is the only essential difference between that value and the totals of the Department of Commerce (*7*) and the Institute for Energy Analysis (*23*). Freeman (*3*) was denounced in 1974 for suggesting a value of 100 quads based on a zero energy growth scenario.

There are other seers who indulge in wishful thinking. Their reports are laced with phrases such as "assuming all-out government funding," "pending successful demonstration," "development of necessary technology," and "a determined conservation program." The public and the scientific community must recognize that there is a long gap between speculation and delivery of energy to the consumer. In a speech at Massachusetts Institute of Technology (*24*), Frank Press stated:

> We still hear echoes of solutions to the energy problem based on back-of-the-envelope calculations that tell us: that the earth's geothermal energy at an average depth of 6000 meters is equivalent to more energy than we will ever need; that the deuterium in the world's sea water could release through fusion the energy equivalent of 500 Pacific Oceans of petroleum; that the amount of uranium in the world's granitic rock could provide the world's energy at *X* times the current rate of consumption for thousands of years, or that the sunlight falling on *X* percent of the earth's land area could give us the same amount of energy for as long as the sun shines. . . . There are even those who believe that there are still huge supplies of oil and gas available to be tapped, if only the price were right.

Such wisdom would seem to indicate there is no energy crisis, merely a few technological problems and restrictions on the free market, between us and an energy millennium. But we know differently, and not only in terms of energy but of material resources, food, water and all our other human needs. There are no ultimate or singular technological fixes, nor is everything available or possible, simply by providing enough incentive.

Table 6. Distribution of energy by fuel type. Values are percentages.

Subject	1977	2000
Fossil fuels	91	79
Petroleum	47	34
Natural gas	26	11
Coal	18	34
All other	9	21
Solar and other	2	7
Nuclear	3	11
Imports	24	18

We will still be locked in to fossil fuels in 2000, as shown in Table 6. By that year an as yet undetermined amount of coal will have been converted to supplementary industrial gas, coal liquids, or other refined forms.

Figure 2 portrays energy growth from 1940 to 2000 based on the projections in this article. It portends disaster because energy and the gross national product have gone hand in hand at a growth rate of 3 to 3½ percent for almost 40 years and there is little hope of maintaining even 1 percent energy growth in the 1990's. Although there is no proof that such an energy growth rate must be maintained, it is more than just coincidence that the nations with higher living standards are the largest energy consumers.

So far, I have discussed only gross energy. There is another figure known as net energy, which is the amount delivered to the consumer after conversion losses. For instance, in converting fossil fuels to electricity there is a two-thirds loss of energy. In petroleum refining 11 percent of the barrel is required for refinery energy. At present, the average net energy is slightly more than 80 percent of the gross, which means that the consumer received about 63 of 78 gross quads available in 1977. The trend toward greater use of electricity and coal conversion points to a lowering of the net energy factor to about 75 percent in 2000. In that case, 95 quads gross in 2000 would be more nearly comparable to 90 quads at 1978 conversion factors. This would have the practical effect of bringing energy growth almost to a halt in the 1990's, as shown in the net energy curve of Fig. 2. We will have an additional 40 million people in the United States by 2000, and just transporting and housing them will use the expected gain in energy.

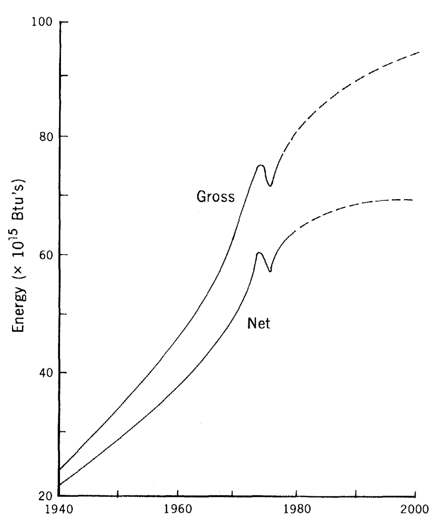

Fig. 2. Energy growth in the United States projected to the year 2000.

Mottley (*25*) showed an excellent correlation between energy and the population of the work force which, combined with conservation, will enable us to live on 95 quads. A CONAES group (*26*) claimed that with energy conservation we can live on as little as 58 net quads without much change in life-style. All signs point otherwise. At the height of the oil embargo we lost 1 quad (1 million barrels of oil a day for 6 months) and this helped start the greatest recession in 40 years. The fact remains that we are just now embarked on an economic voyage through uncharted waters to find out what happens at drastically reduced or zero energy growth rates.

Up to a point, we can substitute money in the form of energy-saving technology and subsidies for energy. However, subsidies for projects such as solar energy do not make it any cheaper. The citizen and the economy ultimately have to pay for it.

The American economy in much of the period in Fig. 2 was built on oil at $3 a barrel, coal at $4 a ton, and natural gas at $0.16 a thousand cubic feet. In 1978 dollars this translates to a fossil energy price of roughly $0.55 per million Btu's compared to a current weighted figure of $1.70. The seller's market of the 1990's, when world petroleum and gas production has passed its peak, will lead to wholesale costs more than double those of today by 2000. Some signs are already here: obtaining oil from shale will cost $20 a barrel ($3.45 per million Btu's); coal liquids, $30 to $34 a barrel ($5.17 to $5.86 per million Btu's); and Syngas from coal, $3.50 to $6.50 per million Btu's. Alaskan natural gas will cost $4 to

$6 per million Btu's at the border, depending on the final cost of the pipeline, which is now targeted as $10 billion. Iranian liquid natural gas will cost $3.50 to $4.00 per million Btu's laid down at Cove Point, Maryland. Lost from public view are the facts that (i) the United States does not control foreign oil and hence cannot dictate its price and (ii) much of today's low petroleum and natural gas pricing is based on exploration and plant development 10 to 25 years ago.

The 95-quad estimate could be low by a few quads, or the peak in world oil production could come a few years later (there could be significantly more Mexican oil than the present reserve figures indicate) but this would not change the overall picture significantly. The time for planning and husbanding our natural resources is now, and not after the inexpensive sources have been dissipated. The necessary expansion of coal utilization and the development of solar sources and the breeder reactor will not happen quickly. There is no guarantee that the latter two will ever produce energy at even what we consider high costs today, and only national planning at a high level can prevent the collapse of our economy built on cheap energy sources.

Conclusions

The facts point to the inescapable conclusion that exponential growth of energy supply is coming to an end in the United States. Energy and gross national product have risen 3 to 3½ percent a year since 1940, and a decrease in the energy growth rate to less than 1 percent a year by 2000 will occasion some fundamental national problems for which we have no precedent. The involuntary conservation brought on by higher prices and decreased supplies will be exceedingly painful for an unprepared American public.

We have sufficient energy resources to supply our basic needs for many decades, but the costs will rise continually. The country still does not understand the problem. The layman wants to believe in inexhaustible, cheap gasoline and in this has been supported by many unsubstantiated claims. The time has come to realize that no miracle is imminent and we must make do with what we have. We will never again have as much oil or gas as we have today, nor will it be as cheap. Nuclear energy has been a major disappointment. Solar energy will be slow in developing and, contrary to popular opinion, quite expensive. Coal is the only salvation for the next few decades.

In the last analysis, we have entered into a massive experiment to determine what effect energy growth has on economic growth, or how much we can slow the machine down and still maintain a democratic, capitalistic form of government.

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