Appendix

U.S. ENERGY RESOURCE BASE

The material contained in this appendix provides supplementary and background information to the overview of U.S. domestic energy resources presented in Sec. III, following the same categorization scheme as that illustrated in Fig. 21. The material on coal resources developed in this appendix was used to identify and select major representative surface- and underground-mineable coal deposits as the resource supply points for the analysis of a coal-based jet fuel supply system.

CARBONACEOUS NONRENEWABLE RESOURCES

Domestic U.S. carbonaceous nonrenewable energy resources, or fossil resources, consist primarily of crude oil, natural gas, coal, and oil shale, with significantly lesser quantities of bituminous tar sands. By virtually any estimate, the energy embodied in U.S. coal resources dwarfs that of any other fossil energy source (Fig. 46). Despite this fact, coal supplies less than 20 percent of U.S. energy needs, primarily because petroleum products and natural gas burn cleaner, are far easier to handle than coal, and have been more economical.

Coal Resource Base

The USGS groups coal resources into identified resource and hypothetical resource categories. Identified resources are those which have been determined on the basis of mapping and exploration. The hypothetical resources are determined by extrapolation of the data on identified resources into unmapped and unexplored areas. The identified resources are subdivided into measured, indicated, and inferred categories, primarily on the basis of the spacing of the points of observation, roughly 0.5, 1 to 1.5, and greater than 2 miles, respectively. Resources are further subdivided by depth of overburden and the coal seam thickness.(83,84)

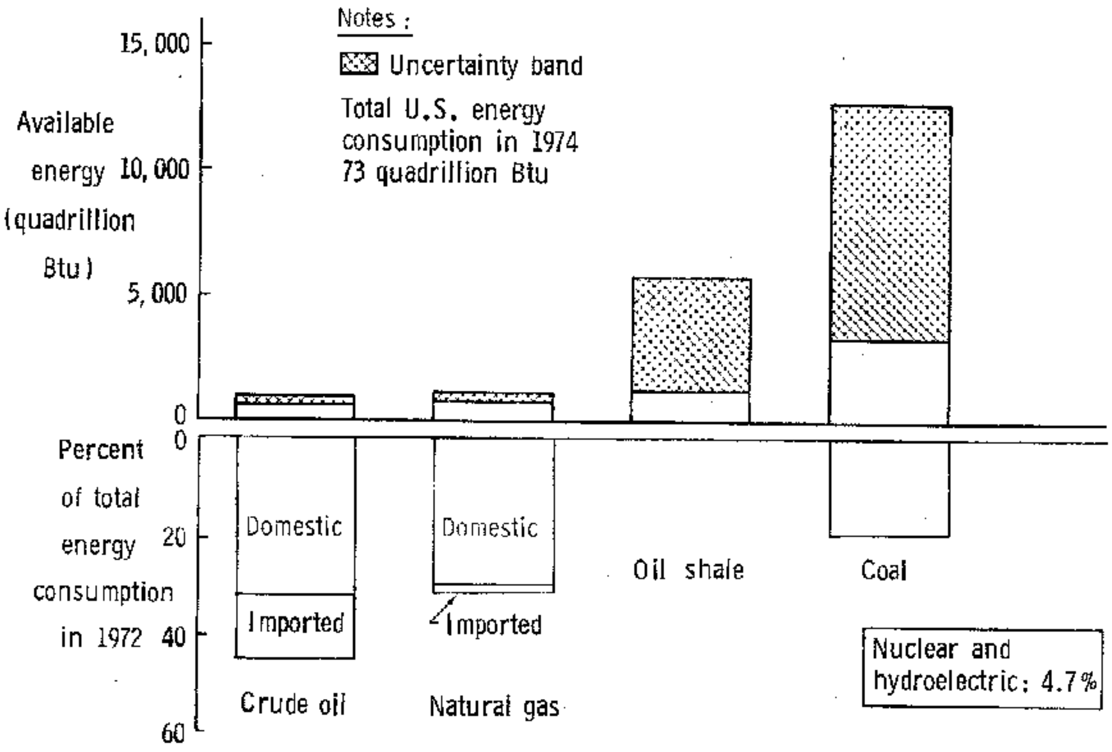

Fig. 46—Recoverable U.S. fossil resources (from Refs. 17 and 62)

Using this categorization scheme, the USGS estimates that there are about 1581 billion tons of identified coal resources remaining in the ground and about 1643 billion tons in the hypothetical category. The categorization of the identified resources according to seam thickness and reliability of the resource estimates is noted in Table 9. Measured against current U.S. coal production of about 0.6 billion tons per year, these identified resources are vast. However, far less than 100 percent of the in-place coal resources are amenable to mining given today's extraction technology and economics. For example, coal in thin beds and coal in beds more than 1000 feet below the surface are of little current economic interest. The USGS considers coal within 1000 feet of the surface in seams of intermediate thickness as a paramarginal resource which will be of increasing economic interest and importance in the future.(84)

The U.S. Bureau of Mines, Department of Interior, in developing one of the most recent estimates of the demonstrated U.S. coal reserve

Table 9

IDENTIFIED IN-PLACE U.S. COAL RESOURCES

Seam Thickness[a]	Coal Resources (billions of tons)		
	Measured	Indicated	Inferred
Less than 1000 ft overburden			
Thin	16	95	538
Intermediate	47	142	174
Thick	63	126	206
Subtotal	126	363	918
Greater than 1000 ft overburden		60	114
	126	423	1032
Total		1581	

SOURCES: Refs. 83 and 84.

[a] Thin, intermediate, and thick seam bituminous and anthracite coal, 14 to 28 inches, 28 to 42 inches, and more than 42 inches, respectively. Thin, intermediate, and thick seam subbituminous and lignite coal, 2.5 to 5 feet, 5 to 10 feet, and more than 10 feet, respectively.

base, has estimated that 433 billion tons of coal are amenable to mining, given current extraction techniques and economics (Table 10). However, only part of the 433 billion tons could be recovered because of the manner in which coal is typically extracted. Underground mining in the United States is normally accomplished using the room and pillar technique, in which pillars of coal are left in the mine to retard subsidence. As a consequence, only about 50 percent of the in-place coal is recovered. Longwall mining, not yet widely used in this country, in which controlled collapsing of the mine roof occurs, offers potential recovery rates as high as 80 to 90 percent. Surface mining is characterized by higher recovery rates, typically 80 to 90 percent of the coal in-place is recovered, except in extreme slopes. If the 50 percent recovery rate is applied to the underground-mineable reserves, and the 80 percent rate to the surface-mineable reserves noted in Table 10, the total economically recoverable reserves would amount to 257 billion tons, which is equivalent to about a 428 year reserve life

Table 10

MINEABLE IN-PLACE COAL RESERVE BASE OF THE UNITED STATES

Coal Type	In-Place Coal Reserves (billions of tons) Underground Mineable Reserves	Surface Mineable Reserves	Total	Estimated Heat Value (quadrillion Btu)
Bituminous	192	41	233	6100
Subbituminous	98	67	165	2800
Lignite	--	28	28	400
Anthracite	7	--	7	200
Totals	297	136	433	9500

SOURCE: Ref. 69.

at current rates of coal production. This 257 billion tons of recoverable coal constitutes about 15 percent of the total identified in-place resources, and about 8 percent of the total resources. As mapping and exploration better define the substantial coal resources included in the inferred category of Table 9, and the extent of the hypothetical resources, the mineable coal resource base could expand appreciably.

United States coal resources underlie about 13 percent of the land area of the United States and are present in widely varying amounts in parts of 37 states. Figure 47 shows the major coal fields of the 48 contiguous states and the types of coals found in each region. An approximate distribution of coal resources by region is shown in Table 11. The eastern region of the United States, and primarily Appalachia, which has undergone intensive mining in the past, still has significant amounts of bituminous coal amenable to underground-mining techniques. The interior region, and most predominantly Illinois, has large deposits of both surface- and underground-mineable bituminous coal. The northern Great Plains states have vast deposits of both underground- and surface-mineable lignite in North Dakota and Montana. The Wyoming Powder River Basin has large deposits of surface-mineable subbituminous coal, with some seams 90 feet thick. Surface-mineable subbituminous coal deposits in the Rocky Mountain states are

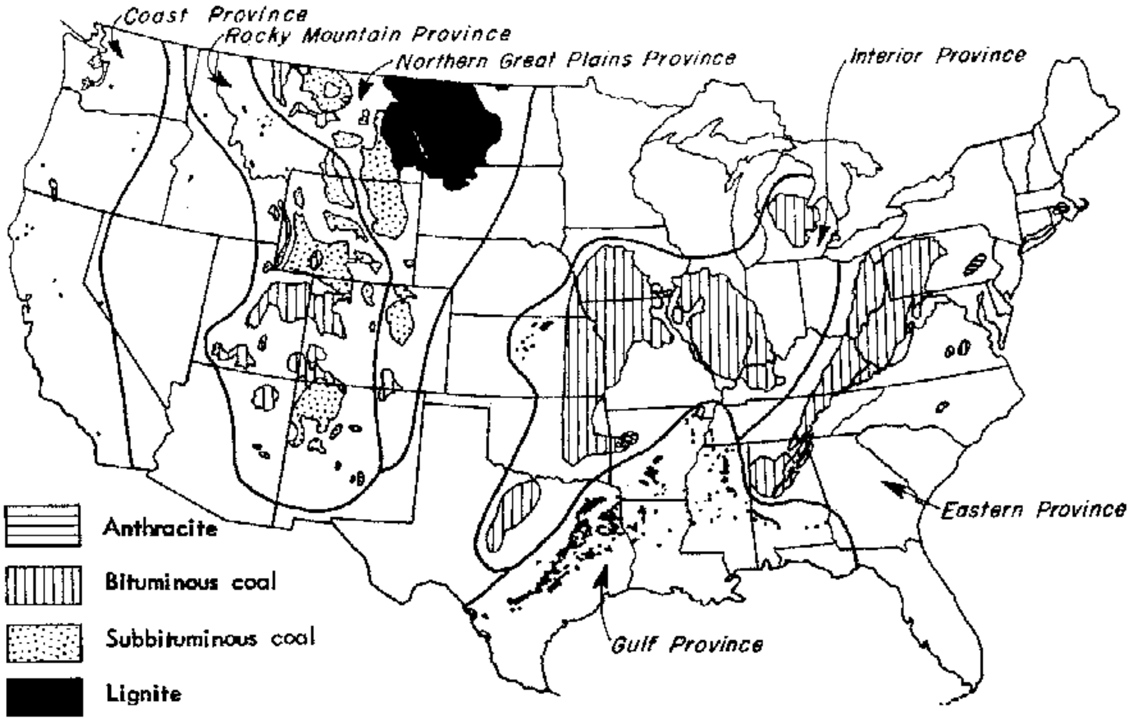

Fig. 47 — Distribution of U.S. coal resources (from Ref. 28)

Table 11

DISTRIBUTION OF U.S. COAL RESOURCES

Location	U.S. Coal Resources (billions of tons)		
	Identified	Hypothetical	Total
Eastern	276	45	321
Interior	277	259	536
Northern Great Plains	695	763	1458
Rocky Mountains	187	395	582
Other	146	181	327
Totals	1581	1643	3224

SOURCE: Ref. 28.

primarily located in northwestern New Mexico. Alaskan reserves of primarily subbituminous, and to a lesser extent bituminous coal, account for the bulk of the remaining reserves.(28)

There are significant differences in both the sulfur content and heat content of U.S. coals in the different regions. The subbituminous coal and lignite deposits in the Rocky Mountain and northern Great Plains regions have the great virtue of being low in sulfur content, with most deposits having less than a 1 percent sulfur content. Conversely, the bituminous coal deposits in the Appalachian and interior coal basins are characterized by their high sulfur content, with about one-quarter of the deposits containing from 1 to 3 percent sulfur.(84) The demands of the electric utility industry for these low sulfur western coals could directly conflict with the demands of a synthetic fuels industry for the more economic, surface-mineable western coals.

Although the western coals are generally low in sulfur, the lignite and subbituminous coal resources are also generally lower in heat content, which means that more coal must be transported and processed to deliver a given amount of energy than with the eastern and interior basin bituminous coals. Table 12 gives typical heat values for the different coals.

In summary, the domestic coal resource base is vast, and, as a consequence, has the potential for making a significant contribution to energy supplies in the future. The primary challenge, it seems, is to develop the coal resource base in an environmentally acceptable manner.

Table 12

HEAT VALUE OF U.S. COALS

Coal Type	Heat Value (Btu/lb)
Anthracite......	13540 - 14930
Bituminous......	12000 - 15630
Subbituminous...	8680 - 10760
Lignite.........	5900 - 7290

SOURCE: Ref. 83.

Oil-Shale Resource Base

Oil shale is a fine-grained sedimentary rock containing a solid organic material called kerogen. When oil-shale particles are heated, the organic matter is decomposed, forming oil vapors and gases. The oil vapors are condensed to form a syncrude product that may be refined into premium fuel products. Oil shale is usually found in layers or series of layers sandwiched between other layers of sedimentary rock.(28) The quality of the deposits is described by the average oil yield per ton of shale. Deposits yielding 30 or more gallons of oil per ton of shale are usually considered high grade; however, the characterization of the attractiveness or the economic recoverability of a particular deposit is very dependent on the technology available to extract the oil from the shale. The thickness of the shale deposit is another important factor in the determination of its recoverability. High-grade deposits are characterized by a thickness of at least 30 feet, with many high-grade deposits being over 100 feet thick.

About 90 percent of all the identified U.S. oil-shale resources are located in the Green River formation in western Colorado, Wyoming, and Utah, with most of the remaining resources located in the central and eastern United States (Fig. 48). Over three-quarters of the higher-grade deposits are in the Piceance Creek Basin northwest of Rifle, Colorado, between the Colorado and White Rivers.

A categorization of U.S. oil-shale resources according to their richness, location, and degree of uncertainty of the resource estimate is shown in Table 13. Given current technology and the uncertainties in future world oil prices, the only resources of immediate interest in Table 13 are the identified 25 to 100 gallon per ton deposits in the Green River formation. While these resources are currently classified as paramarginal because of the technological and economic uncertainties associated with oil-shale retorting processes, it is likely they would constitute the initial resource base for a synthetic fuels industry using oil shale.

Recovery rates for oil-shale deposits for underground and surface mining have been estimated to range from 40 to 65 percent.(28,86) If a 50 percent recovery factor is applied to the 418 billion barrel

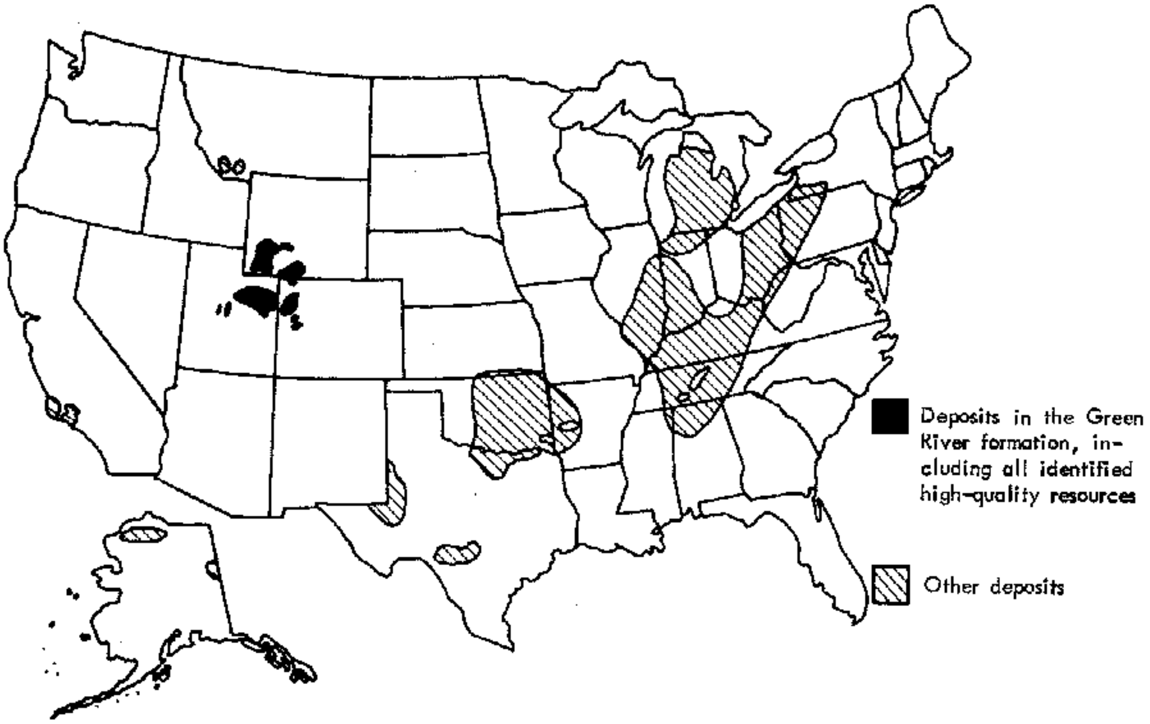

Fig. 48—Distribution of oil-shale resources (from Ref. 28)

estimate in Table 13, the recoverable oil-shale resources would amount to 209 billion barrels in the mined but unprocessed oil shale. This estimate can be compared with the 62 billion barrels of measured, indicated, and inferred recoverable U.S. crude-oil resources, and the estimated 50 to 127 billion barrels of additional remaining undiscovered crude-oil resources.(87) At a production rate equivalent to that of current domestic crude-oil production, the 209 billion barrels of oil shale might last about 69 years.

In situ recovery techniques, which might allow economical recovery of the lower-grade 10 to 25 gallons per ton shale in the Green River formation, could significantly enlarge the recoverable oil-shale resource base. In any case, the magnitude of the recoverable oil-shale resource base indicates that oil shale could potentially make a significant contribution to U.S. energy supplies, and particularly the liquid fuels supply, in the future.

Table 13

IN-PLACE U.S. OIL-SHALE RESOURCES

	Oil-Shale Resources (billions of bbl of oil)					
	Identified		Hypothetical		Speculative	
Location	25-100 Gallons per Ton	10-25 Gallons per Ton	25-100 Gallons per Ton	10-25 Gallons per Ton	25-100 Gallons per Ton	10-25 Gallons per Ton
Green River Formation (Colo., Wy., Utah)	418	1400	50	600	--	---
Chattanooga Shale equivalent formations (central and eastern United States)	--	200	--	800	--	---
Marine Shale (Alaska)	--	--	250	200	--	---
Other	--	--	--	--	600	23000
Totals	418	1600	300	1600	600	23000

SOURCE: Ref. 85.
NOTE: Blanks in columns indicate that only negligible quantities of oil-shale resources exist in these areas.

Bituminous Tar Sands Resource Base

Tar sands are a mixture of sand, water, and bitumen, a dense, usually black, hydrocarbon material, which is too viscous to be extracted by conventional petroleum recovery methods. Synthetic crude oil is currently being commercially produced from the vast Athabasca tar sand deposits in the province of Alberta, Canada.(88) It is estimated that about 895 billion barrels of proven in-place crude bitumen resources are located in Alberta.(89) In contrast, the United States is far less richly endowed with tar sand deposits. In-place tar sand deposits in Utah are estimated to contain about 28 billion barrels of bitumen, which account for over 95 percent of U.S. deposits.(19)

None of the Utah deposits are considered to be economically recoverable at present. The Department of the Interior has indicated that in 15 to 30 years it may be feasible to begin recovery of about

30 to 50 percent of U.S. tar sand resources, or about 9 to 15 billion barrels of oil. The Bureau of Mines, in a far more conservative estimate, considering shallow occurrences only, indicates that perhaps 2.5 to 5.5 billion barrels of oil from tar sands are recoverable.(20) Measured against the vast U.S. resource base of oil shale, coal, and even crude oil, and the time frame in which U.S. tar sands might be developed, it seems unlikely that U.S. tar sands will ever be a large-scale U.S. energy source.

CARBONACEOUS RENEWABLE RESOURCES

While the time span over which organic matter is converted into crude oil, natural gas, coal, etc., is measured in millions of years, energy can be retrieved from organic matter stored in green plants and other sources on essentially a continuing and renewable basis. This organic material can be obtained from the waste material that is a by-product of society's production and consumption of goods or from so-called "energy crops" grown specifically for energy production.

Organic waste material includes manure from livestock, plant residue left in the fields after normal harvest of agricultural products, industrial wastes from vegetable and meat processing and sawmills, logging wastes in the form of branches and deadwood left in the forest after saw timber has been removed, urban refuse, and municipal sewage solids. It has been estimated that in 1971 about 880 million tons of dry organic wastes were generated, perhaps 136 million tons of which might have been readily collectible.(90)

The energy content of the 136 million tons of wastes would be equivalent to roughly only 2 percent of U.S. energy consumption in 1971. As a consequence, it seems highly unlikely that organic waste products will ever be a significant energy source for a large synthetic fuels industry. However, the conversion of these wastes to energy has proved to be an attractive way to ameliorate some waste disposal problems, while at the same time supplementing energy supplies in selected regional applications.

The United States has large areas of arable land that are not cultivated, perhaps as much as 100 million acres of fallow crop land and

490 million acres of grassy pasture land.(91) If, to use a hypothetical and perhaps extremely optimistic example, a crop such as corn (maize) yielding 5 dry weight tons per acre per year with a heat content of 7200 Btu per pound were cultivated on all this land, the resulting energy would be about 42 quadrillion Btu, or about 58 percent of U.S. energy consumption in 1974. Clearly, it is extremely unrealistic to assume that all the acreage could be planted; nevertheless, the potential energy contribution from energy crops is large. Technological and economic uncertainties will have to be resolved before the potential of energy crops can be accurately assessed.

NONCARBONACEOUS, NONRENEWABLE ENERGY RESOURCES

Geothermal Energy

When the normally diffuse heat of the earth is concentrated due to local geologic conditions, these local reservoirs of thermal energy can be exploited as a source of energy. The only major commercial exploitation of geothermal steam in the United States to generate electricity thus far is of The Geysers, north of San Francisco.

Geothermal resources are usually grouped into three categories: (1) hydrothermal, (2) geopressurized, and (3) dry hot rock. Hydrothermal reservoirs consist of a heat source (magma) overlain by a permeable formation (aquifer) through which ground water circulates. The aquifer is capped by an impermeable foundation that prevents water loss. The energy can be recovered by drilling a well to transport the water and steam to the surface. Hydrothermal reservoirs are defined according to whether hot water or vapor dominates the reservoir, with vapor dominated reservoirs being the most commercially attractive but also the least common.

In geopressurized reservoirs the source of heat is not magma but rather clays in a rapid subsiding basin area, which trap heat in water-bearing formations. Dry hot rock formations are characterized, as the name implies, by the lack of a permeable aquifer. As a consequence, to recover the heat energy, the rock must be fractured and water injected.

Most of the major hydrothermal reservoirs are located in the western United States. About one-third of the known geothermal resource areas are in California. The geopressurized regions are concentrated along the Texas and Louisiana Gulf Coast.(28)

Geothermal resource estimates vary widely both in categorization and magnitude. A 1972 USGS document(92) indicates that about 10 quadrillion Btu of energy is available at the wellhead in identified recoverable reserves, and about 600 quadrillion Btu in paramarginal hot water systems. Another estimate(93) indicates about 540 quadrillion Btu at the wellhead of known reserves, with 18,000 quadrillion Btu of probable reserves, and 1.3 million quadrillion Btu of undiscovered reserves. These estimates should be tempered by the realization that characteristically only about 14 percent of the energy at the wellhead can be recovered in the form of electricity using current technology. Nevertheless, when compared with a total U.S. energy consumption of 73 quadrillion Btu in 1974, the resource base is definitely sizable. Given this resource base and the proper economic and technological climate, geothermal energy has the potential for making a meaningful contribution to the electrical generating capacity in the western United States by the turn of the century.

Nuclear Fission

When certain heavy atoms are bombarded with low-energy neutrons, they will split or fission, the products of the reaction being dissimilar atoms, neutrons, and an enormous release of heat energy. The neutron products can then react with other heavy atoms to repeat the reaction, the successive repetition of this process being termed a chain reaction. Such an uncontrolled chain reaction utilizing the heavy isotope uranium-235 was the basis for the first atomic bombs. When the chain reaction proceeds in a controlled manner, such as is the case in today's commercial nuclear reactors, the heat released in the reaction may be used in the generation of electricity, or as a source of process heat.

Of the several hundred naturally occurring atomic isotopes, uranium-235 is the only one that is spontaneously fissionable by the capture of slow or thermal neutrons. Accordingly, the initial fuel for all energy conversion systems based on the fission reaction is uranium-235. The element uranium exists as three naturally occurring isotopes in the following proportions: 99.28 percent U-238, 0.71 percent U-235, and a trace (less than 0.01 percent) of U-234. Most of the uranium mined in the United States exists as uranium oxide, commonly termed yellowcake. This stable oxide of uranium is commonly used as the yardstick by which quantitative measurements of uranium reserves are estimated. For every ton of uranium ore mined, perhaps 4 to 5 pounds of uranium oxide can be extracted, from which 0.024 to 0.03 pounds of U-235 can be obtained.(28)

Table 14 indicates U.S. uranium oxide resources by cost and exploration status as determined by the Preliminary National Uranium Resource Evaluation program. Over 84 percent of the proven reserves are located in New Mexico and Wyoming.(28) The present uncertainty in uranium resource estimates has stimulated two major government uranium resource evaluation programs, one sponsored by ERDA, the other sponsored by the USGS.(94) The outcome of these resource evaluation programs may have a major impact on the planned expansion of the nuclear industry in the United States in the future.

Of course, estimates of uranium oxide resources have little meaning in an energy assessment unless the energy potentially and practically releasable in the uranium oxide is known. The energy content realizable from uranium oxide is very dependent on the technology used to effect the energy release. Today, commercial nuclear power plants use light-water reactors that consume uranium-235 as fuel. The amount of energy that can be released using this light-water reactor technology is the subject of considerable debate, with estimates varying by factors of seven or more.(94) ERDA, in its "National Plan for Energy Research, Development, & Demonstration," estimates that each short ton of uranium oxide can be converted to about 500 billion Btu of thermal energy when light-water reactor technology is utilized, assuming recovery and recycling of fissionable plutonium and uranium from spent reactor fuel produced by the fission reaction, and an assay of 0.2 percent of the unrecovered uranium-235 isotope in the fuel enrichment process. Using this value, the identified and potential uranium

Table 14

PROJECTED U.S. URANIUM RESERVES AND RESOURCES[a]

Index Cost[b] ($/short ton uranium oxide)	Uranium Oxide Resources (thousands of short tons as of 9/74)		
	Identified[c]	Potential (Undiscovered)[d]	Total
8	280	540	820
8-15	240	1010	1250
15-30	180	1200	1380
	700	2750	3450

SOURCE: Personal communication with ERDA-Germantown personnel, summer 1975.

[a] Does not include possible concentrations in Chattanooga shales, depleted uranium tails, or by-products of copper ore leach solutions, phosphoric acid production, or coal gasification.

[b] Does not include profit, interest on capital, or other ownership costs. Does not necessarily represent open-market prices.

[c] Includes measured, indicated, and inferred resources. Eight dollars/short ton identified reserves are reported to be economical in 1974. Eight to thirty dollars/short ton resource are reportedly not yet economical.

[d] Includes probable, possible, and speculative resources.

oxide energy resources noted in Table 14 would represent about 1725 quadrillion Btu, or about 60 percent more energy than the upper bound estimate of identified and undiscovered recoverable U.S. crude-oil resources. Using the most conservative estimate results in a uranium oxide resource base containing about 334 quadrillion Btu of energy, assuming no spent reactor fuel recycling, as is the case today, and a 0.3 percent tails assay.

It is difficult to draw any firm conclusions about the potential contribution of uranium resources to the U.S. energy supply in the future, given the uncertainty that exists in uranium resource estimates, in estimates of the energy recoverable from those resources using current reactor technology, and indeed, the rate at which nuclear reactors will be built in the United States. Perhaps the only conclusion that can be made is that while the potential contribution of uranium to U.S. energy supplies is sizable, it is by no means inexhaustible when that energy is delivered using current reactor technology.

NONCARBONACEOUS, RENEWABLE ENERGY RESOURCES

Nuclear Fission (Breeder Reactors)

The potential energy content of the uranium oxide resource base changes dramatically if new breeder reactor technology is assumed to be available. Breeder reactors have the capability of converting abundant U-238 (the fertile, nonfissionable isotope) into fissile (fissionable) plutonium-239 and uranium-233, and thereby producing more fissionable fuel than they consume. This has the dramatic effect of making fertile uranium-238, the isotope which accounts for 99.28 percent of naturally occurring uranium, potentially available as an energy source, in contrast to the 0.71 percent of naturally occurring fissionable uranium-235, which can produce energy in light-water reactors.

If all the fertile natural uranium could be fissioned using breeder reactor technology, theoretically about 140 times more energy would be potentially available than with conventional light-water reactor technology, or about 70,000 billion Btu of energy per ton of uranium oxide. ERDA's current estimate is that breeder reactors might deliver about 36,000 billion Btu of thermal energy per ton of uranium oxide, or about 72 times the energy release using light-water reactors.(17) Hence, using breeder reactor technology, the identified and potential undiscovered uranium oxide resources noted in Table 14 would represent about 125,000 quadrillion Btu, or nearly 1700 times current annual U.S. energy consumption of all resources. Hence, the successful introduction of breeder reactor technology could turn uranium into a virtually inexhaustible domestic energy resource.

Nuclear Fusion

The atomic fusion of two or more of the isotopes of hydrogen, known commonly as hydrogen, deuterium, and tritium, results in the formation of helium, the next higher element on the atomic scale, and an enormous release of energy. Such reactions are responsible for the huge quantities of energy radiated from our sun and the stars. The fusion of deuterium and tritium into helium in an uncontrolled manner is the basis for the so-called hydrogen or thermonuclear bomb. Research is under way to develop the technology to harness the energy released by a controlled fusion reaction to provide a useful source of energy for the future.

While the status of this technology area at present suggests that it is unlikely that nuclear fusion will make any significant contribution to U.S. energy supplies during this century, the interest in fusion is understandable when one examines the magnitude of total energy potentially available. In the case of deuterium fusion, the potential energy content of the deuterium in the world's oceans is about 40 billion times the annual U.S. energy consumption.(4) The available energy derivable from the lithium-deuterium fusion reaction is more limited by the availability of lithium, but still dwarfs other energy resources.

Solar Energy

The solar radiation falling on the earth's surface could conceivably meet a major portion of long-term U.S. energy needs on a continuing basis. It has been estimated that the solar energy falling on the 48 contiguous states is roughly 600 times current U.S. energy consumption.(95) However, the characteristically low energy value of the solar flux and its intermittent nature pose significant collection and energy storage problems.

Some water and space heating systems utilizing solar energy have already been commercially introduced in the United States, one of the primary remaining obstacles to their widespread introduction being the high initial capital costs for collector and storage systems. R&D on electricity generation using photovoltaic cells is centering on cost reduction. Significant contributions from this energy source will probably require reductions in costs of a factor of 100 or more.(96) Solar thermal electric power systems perhaps offer more promise, although proponents expect no major market penetration any earlier than the late 1980s at best.(97,98)

It is difficult to assess the ultimate contribution of other solar energy systems, such as wind generators, tidal power, ocean thermal gradient plants, etc. Their initial contributions will probably be regional in nature at the most favorable locations.

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