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Characterization of U.S. Energy Resources and Reserves

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DISCLAIMER

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EXECUTIVE SUMMARY

This report provides a comprehensive overview of the best available estimates of the total domestic energy potential within the United States. The array of energy sources include those appropriate for power generation, liquid fuels, and direct heat applications. The energy sources examined are: geothermal energy, solar energy, biomass energy, wind energy, shale oil, coal, petroleum, natural gas, peat, uranium, and hydropower.

The traditional resource/reserve classification system used to characterize minerals according to the degree of certainty of the resource and to the economic feasibility of exploiting the resource form the basis of this report. From the broad range of terms used to characterize the potential of U.S. energy sources, three categories have been selected: *total resource base, accessible resource*, and *reserve*. The *total resource base* is the broadest term, meant to represent the total physically available energy that encompasses both identified and undiscovered resources, regardless of whether or not they can be practically or economically extracted. The *accessible resource* is that portion of the total resource base, without regard to current economics, that can be captured, mined, or extracted using current technology or technology that will soon be available. *Reserves* are a subset of the accessible resource which is identified and can be economically and legally extracted using current technology to yield useful energy. The definition for each of these categories is based on resource terminology developed by the cognizant U.S. government agencies.

The *total resource base* of energy in the U.S. is very large, with an energy content of over 657,000 billion barrels of oil equivalent (BBOE), or more than 46,800 times the annual current rate of U.S. national energy consumption.

The portion of the *total resource base* that can be captured and exploited with known or developing technology is known as the *accessible resource*. At 17% of the *total resource base*, the *accessible resource* still represents a very large energy potential of 115,000 BBOE. *Reserves*, the portions of *accessible resources* that are economically recoverable under current conditions, represent an even smaller amount of energy. Present technology is able to exploit only 1,096 BBOE economically, 0.17% of the originally identified U.S. *total resource base*. The conceptual relationship and magnitude of the three resource categories is shown in Figure 1-1.

Extraction and conversion technologies, along with changing economic conditions, have a major influence on what portions of the *total resource base* are represented in the *accessible resource* and *reserve* for each of the energy sources. In fact, the definitions established for the categories are directly based on the state of technical capabilities and concepts. Over time, advances in extraction and conversion technologies can significantly improve both the amount of energy that can be physically exploited (the *accessible resource*) and the amount that can be economically extracted and converted into useful energy (the *reserve*) and therefore, significantly change the energy supply represented by each category.

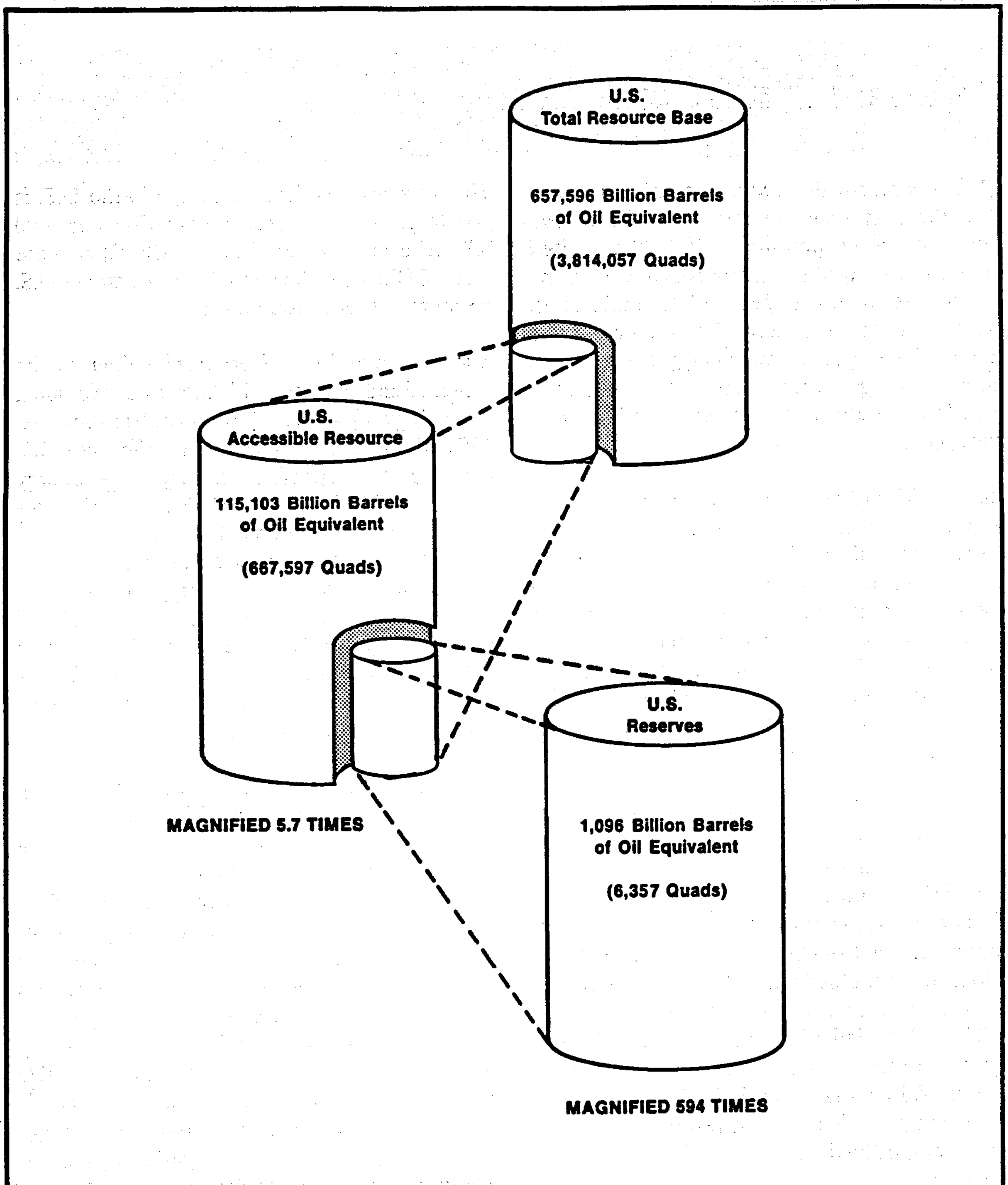


Figure 1-1: The Relationship and Magnitude of the U.S. Total Resource Base, Accessible Resource, and Reserve

INTRODUCTION

Since the founding of the U.S. Geological Survey (USGS), key U.S. governmental agencies and private industry have been collecting data and providing periodic estimates to USGS on the quantities of mineral resources that remain in the United States. This information is used for purposes ranging from planning private resource extraction ventures to estimating current and potential tax revenues. Since the fuel and mineral shortages encountered during World War I, resource estimates have also played a key role in estimating future imports and projecting their impacts on U.S. national security.

Data on estimated resources and reserves levels for major energy sources have been collected and published by private industry, the U.S. Geological Survey (USGS), the U.S Minerals Management Service (MMS), the Bureau of Mines (BoM), and more recently by the Department of Energy (DOE). These estimates are developed using a carefully delineated set of definitions and assumptions. However, U.S. resource and reserve estimates are not necessarily undertaken in a coordinated and parallel fashion across the full range of energy sources. Resource estimates for coal, for example, do not use the same measurement procedures and economic assumptions as those for uranium. Different agencies use different methodologies or classification schemes for the same fuel. Energy sources also do not have consistent reporting timeframes or equal levels of ongoing activities to update and refine previous estimates. Additionally, there has been little or no attempt to assemble and present energy resource information in a single, comprehensive data set for the United States.

This report is an effort to address these issues. It collects and assembles a set of U.S. energy resource data that is internally comparable. The report is impartial in the treatment of energy content embodied by energy resources, choosing to assess each resource based on its caloric value.

The intent is to create a reference document for the use of the energy community and government decision-makers. Existing resource and reserve data have been collected from government, academic, and private industry sources. Inconsistencies in economic and geologic assumptions among different data sources have been identified and reconciled where possible. Where definitive published data were not available, a quantification methodology consistent with other energy source methodologies has been developed and employed.

2.1 Energy Sources and Units of Measure

This report focuses on the supply of energy from various energy sources. As such, it includes any energy source that satisfies one or more of the following criteria:

- currently provide (or may in the near future provide) "significant" energy production;[1]
- are currently used (or that may in the near future be used) for commercial electrical

1. Significant is defined as an annual national production of more than 0.1 BBOE.

power generation or process heat applications; and/or

- are currently used (or that may in the near future be used) as fuels or feedstocks for fuels in the transportation sector.

Based on these selection criteria, the following energy sources were identified for inclusion: geothermal energy, solar energy, biomass energy, wind energy, shale oil, coal, petroleum, natural gas, peat, uranium, and hydropower.

A single unit of measure has been selected to present all of the data: **billion barrels of oil equivalent (BBOE).** Where required, energy resource measurements have been transformed to this unit, using standard energy conversion formulas as developed by the U.S. Department of Energy and listed in the Energy Equivalences section on pages 35-36.

This approach focuses exclusively on the energy content on the resource. To the energy end-user, other factors such as recovery rates, extraction and conversion efficiencies, energy quality, production costs, and transportation cost and availability are also of considerable importance. These factors may modify significantly the size and composition of the resource base, accessible resource, and reserves. This study is designed to serve as the basis for subsequent studies which can factor in these other considerations to determine the availability and cost of delivered energy.

ENERGY RESOURCE TERMINOLOGY

3.1 Energy Resource Classification System

The joint classification system of the United States Geological Survey (USGS) and the U.S. Bureau of Mines (BoM) has been used to establish key criteria for this analysis and to standardize definitions for the energy sources examined in the report.[2] In this system, fossil energy resource data have traditionally been minutely subdivided, creating a dozen or more categories that vary from resource to resource. These subcategories are additive.[3] However, for consistency of presentation across all energy sources, the three major definitional subdivisions of the mineral characterization scheme used to represent energy availability are: *total resource base, accessible resource* and *reserve.* In large measure the USGS/BoM methodology and definitions, originally intended for use only with hard rock minerals, have been adopted without modification. In some instances, a slight modification was required to accommodate the specific characteristics of a given energy source, but the general attributes of the definition remain.

The USGS/BoM methodology was designed to describe stocks of depletable resources, where there is uncertainty of discovery, changes in the extractive technology and market prices, and physical limits to the resource occurrence. Application of this approach to the estimation of energy flow-based sources (such as solar and wind energy) has not been successfully undertaken previously. Where there are conceptual and/or measurement difficulties or data limitations, these problems are addressed in detail in the report sections on each energy source.

The level of precision of the resource quantification will vary by energy source as a function of available resource-specific measurement/sampling technology and the past investment in gathering these data. For example, established techniques of core sampling and exploratory drilling may characterize a coal deposit quite precisely, whereas mathematical extrapolation of data from scattered indications may not definitively characterize the large "speculative" oil shale resource.

In addition, there are certain limitations to resource exploitation that are outside the realm of economics and technology. For example, a known oil resource in a wilderness area may be measured exactly yet not be counted as an accessible resource or reserve due to legal or political restrictions concerning its extraction. These same restrictions, however, may not apply to exploiting other energy resources in the same area. These restrictions, where they exist are factored into the reported total resource base, accessible resource, and reserve estimates, and noted in the appendices.

2. *Principles of the Mineral Resource Classification System of the U.S. Bureau of Mines and U. S. Geological Survey,* (Washington, DC: Geological Survey Bulletin 1450-A, 1976).

3. For example, the USGS divides coal resources by level of geological assurance into measured, indicated, inferred, hypothetical, and speculative. These categories are then further subdivided by levels of economic feasibility into economic, paramarginal, and submarginal. For a graphic demonstration of a typical resource typology, see Paul Averitt, *Coal Resources of the United States, January 1, 1974,* (Washington, DC: U.S. Geological Survey Bulletin 1412, 1975), p. 3.

One key attribute of the total resource, accessible resource, and reserve classification methodology is that it is based on elements whose quantification is directly tied to progress in science (i.e., technological and/or methodological advances), changes in economic conditions, and national political decisions on land use. Therefore, all components of the energy estimates must be continuously reassessed and updated to reflect current conditions. Wherever dated information might affect the comparability of results, such data have been either updated or clearly identified.

Additional information and documentation of resource/reserve quantification may be found in Appendix A.

3.2 Glossary of Energy Resource Terms

Energy resource classification can be depicted by a graphical representation which groups overall resource levels in terms of the two key evaluations: degree of resource assurance and relative economic feasibility. A classical representation known as the McKelvey diagram (Figure 3.1) shows the relationship between two of the energy and evaluation groups resource classifications that are quantified and compared in this report: total resource base and reserve.

3.2.1 Total Resource Base

The classical mineral definition of total resource base is:

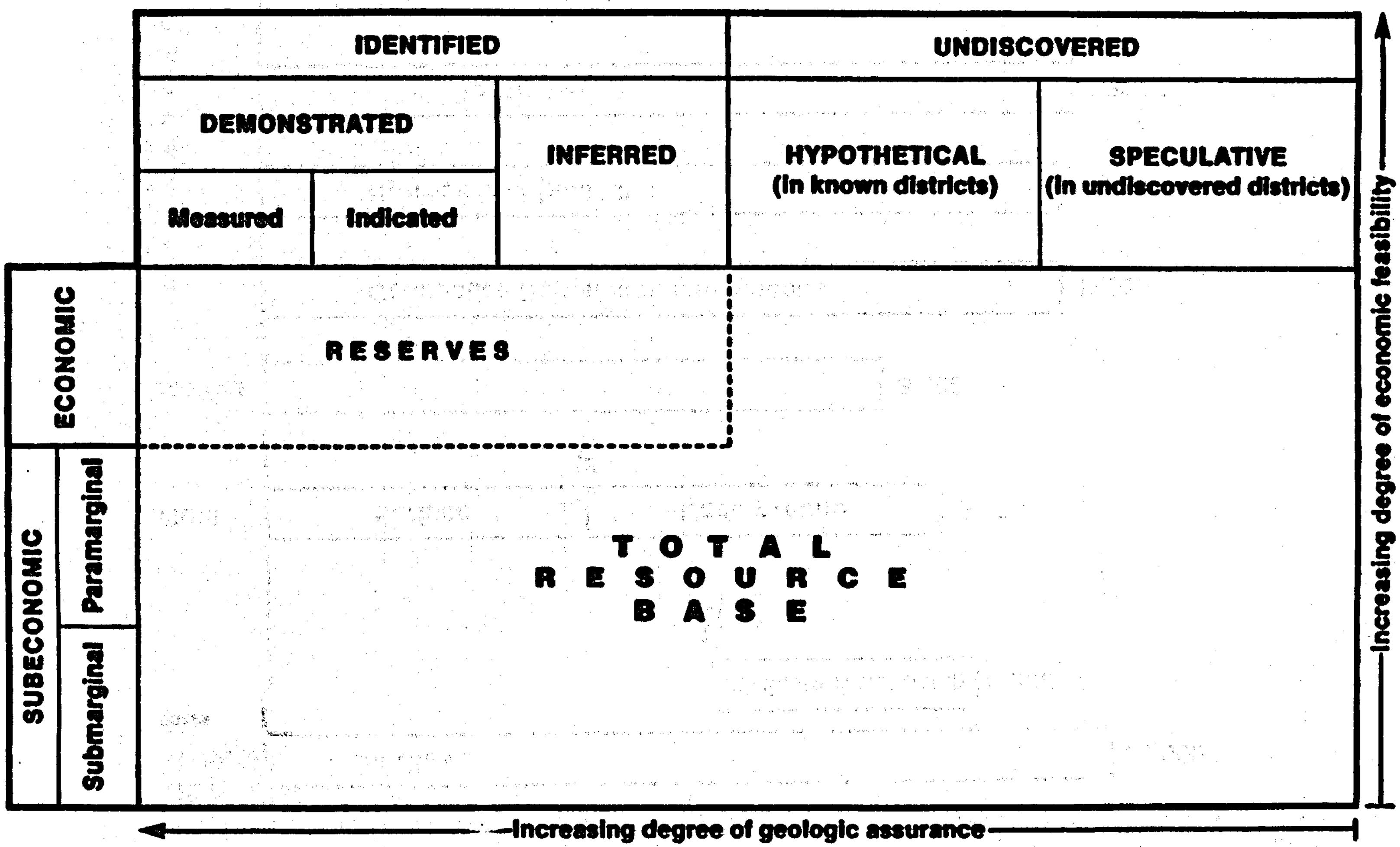
> **"A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible."[4]**

In terms of the axes of the McKelvey diagram (Figure 3.1), the total resource base is the sum of identified and undiscovered resources, whether they are subeconomic or economic. Undiscovered resources in this definition are those that are surmised to exist on the basis of "broad geologic knowledge and theory." Identified resources are those that are either "demonstrated" by comprehensive measurements, indicated by sample measurements, or "inferred" from a broad knowledge of geologic characteristics within some stated specified limits.[5]

Subeconomic resources comprise two levels: paramarginal, those that border on being economically producible or are not commercially available solely because of legal/political circumstances; and submarginal, those that would require an increase of more than 1.5 times the price at the time of determination or a major cost-reducing advance in technology.

The condition that an energy resource be in a form such that economic extraction is "currently or potentially feasible" requires a subjective judgement on the quantification of the total resource base. For oil, natural gas, peat, shale oil, and coal resources, the key judgement issue is the depth below the earth's surface to which one believes that the resource can be recovered. For these energy sources, this study has adopted the USGS and the BoM assumptions, which are depicted in Figure 3.2. For geothermal, the depth standards developed by the National Academy of Sciences have been used. In addition, for some energy sources, limits have been placed on the minimum concentration that is required to be included in the resource base. For example, oil shale has to have a minimum concentration of 10 gallons/ton to be included, while minimum coal bed thicknesses are defined for

4. *op. cit.*, Geological Survey Bulletin 1450-A, p. A2.
5. *Ibid* p. A3.



Reference: Principles of the Mineral Resource Classification System of U.S. Bureau of Mines and U.S. Geological Survey, USGS Bulletin 1450-A, 1976

Figure 3-1: McKelvey Diagram of Classification

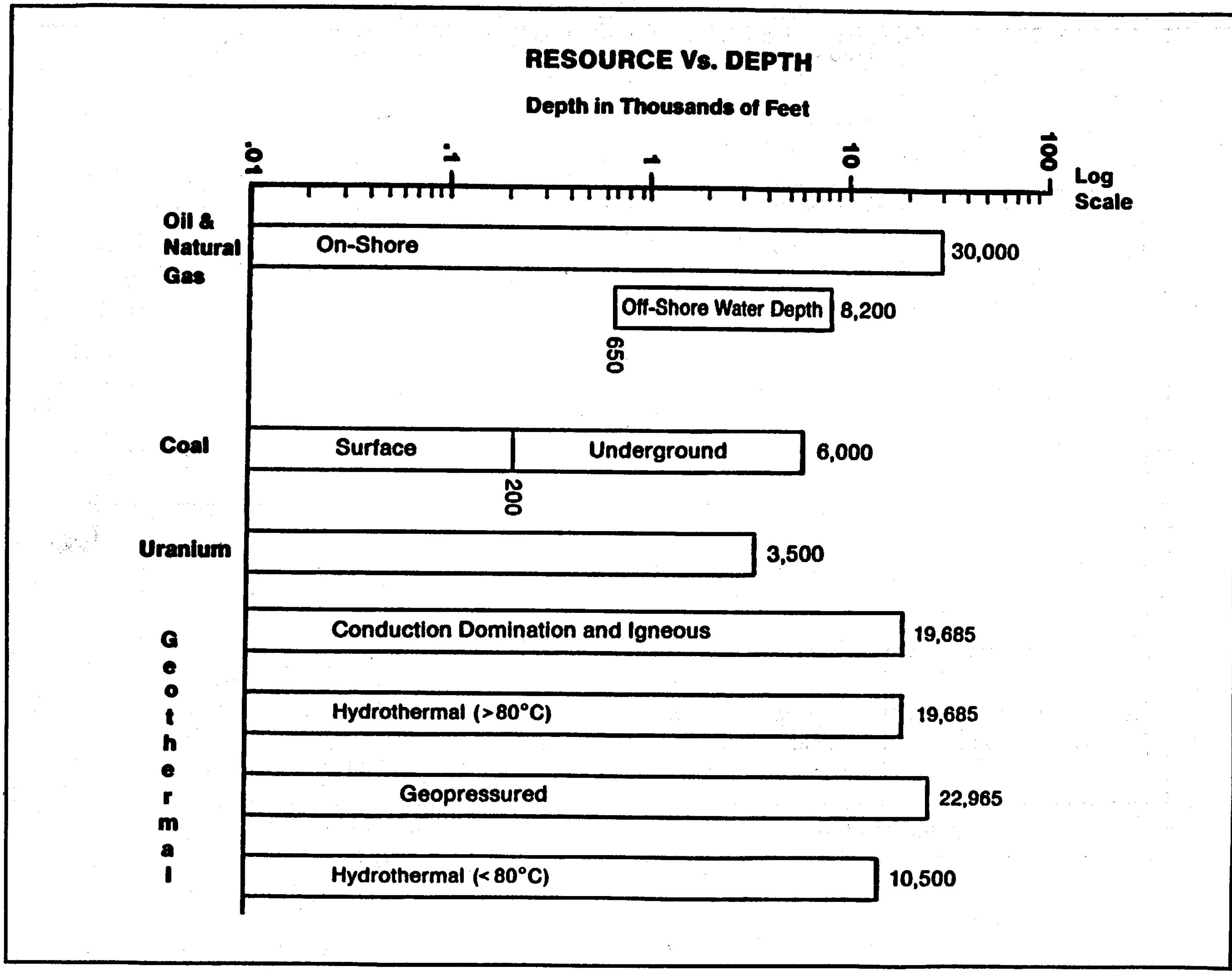


Figure 3-2: Current Limits to Resource Recovery

each rank of coal. The total energy resource potential for uranium, hydropower, wind energy, biomass, and solar energy has been developed by the U.S. Department of Energy, the Army Corps of Engineers or by analyses as explained in detail in Appendix A.

Although developed for mineral resources, the classical mineral definition of total resource base applies equally well to all energy sources except solar radiation. While sunlight cannot be classified as a "solid, liquid or gas," as in the definition, insolation on the surface of the Earth can be measured and quantified in the same way that rainfall is quantified in the determination of the hydroelectric energy resource--using standard and accepted measurement techniques.

3.2.2 Accessible Resource Base

The accessible resource is a subset of the total resource base. It is:

> **the resource that can be located, mined or extracted by technology currently available or that which will be available in the very near future (3 to 5 years).[6]**

Since accessible resource values are technology based, they will change over time. An assessment of current technology provides a generally agreed upon baseline quantity of the accessible resource. However, there is also a variable component to that quantity, based on a judgement of technology trends that will make the future exploitation of a specific energy source possible. For the purposes of this report, technology trends are based on existing prototype resource recovery technologies or those incremental improvements in available technologies that will enhance energy resource recovery.

The boundaries for the accessible resource for mineral energy sources and geothermal energy are based on current drilling, mining, and extraction depth limits, whether they be oil, natural gas, geothermal wells, or coal and uranium mines (Figure 3.2). For other energy sources, these boundaries are established by physical phenomena and by the limitations of systems to extract the energy content of the particular energy source.

For example, the accessible resource for hydroelectric energy is based on the 1980 U.S. Army Corps of Engineers estimates for the power available at all existing or potential dam sites in the U.S. Where legal restrictions preclude the use of an energy resource (i.e., oil and gas drilling is not permitted in national parks), the accessible resource has been adjusted accordingly. To calculate the accessible resource for solar energy, land use is considered (i.e., food crop area, surface area of waterways and roadways, national parks, wilderness areas, a portion of commercial and noncommercial forest land, etc., are subtracted from the surface area available for solar collectors). This is not only in keeping with physical accessibility, but also with the overall approach of this report of using a conservative methodology for estimating all renewable energy resources.

3.2.3 Reserve

The reserve is a subset of the accessible resource base. It is:

> **that resource which is identified and which can be economically and legally extracted with existing technology and under present economic conditions to yield useful energy or an energy commodity.[7]**

6. Adapted from Muffler et al., *Assessment of Geothermal Resources of the United States -- 1978* (Washington, D.C.: Geological Survey Circular 790, 1979) p.4.

7. Adapted from Donald A. Brobst and Walden P. Pratt (eds), *United States Mineral Resources* (Washington, D.C.: Geological Survey Professional paper 820, 1973), p. 2.

The size of the reserve of an energy source is directly dependent on market prices, specifically the cost of competing fuels. In addition, the economic viability of different energy sources is sensitive to regional energy price variations. For certain energy sources (oil, natural gas, geothermal and biomass), the quantity of reserves is partially dependent on the rate of extraction.

To provide uniformity of treatment across all energy sources, economic extraction of resources underlying the reserve calculations in this report are based on:

- using optimal rates of extraction and accepted physical and geophysical limits on how much resource can be extracted from a given reservoir;
- using as benchmarks for economic viability oil prices of $18-20 per barrel; and
- quantifying the energy reserve before the energy conversion device so that differences in the energy conversion processes and efficiencies do not affect the comparison of the size of the reserve for each energy source.

In cases where the estimated reserve was found to be zero or less then the current installed capacity, due to government incentives or non-economic factors, installed capacity was defined as the reserve. Thus was true for the following energy sources: oil shale, wind energy, solar energy, and peat.

DATA COLLECTION AND VALIDATION METHODOLOGY

Once a uniform set of *total resource base, accessible resource*, and *reserve* definitions was developed and their applicability to the energy sources identified, a systematic process was used to establish a set of internally consistent and comparable data. Data have been collected and analyzed from a number of sources ranging from formal, systematic, annual appraisals to derivations by individual authors as part of related energy studies.

4.1 Survey of Potential Data Sources

Initially, a search was undertaken of historical energy resource characterization publications to identify key reference material and related studies. Conversations were also held with major public and private organizations engaged in resource tracking and analysis. The objective of the search was to identify official resource and reserve publications, the limitations of reported data, assumptions underlying accessible resource reporting, and economic assumptions underlying all reserve reports. Institutions contacted were also asked to recommend other individuals or sources engaged in similar research and data collection activities. In addition, a number of U.S. national laboratories were contacted to identify any ongoing resource or reserve measurements or analyses that would contribute to the estimation effort. The information from all these sources was then collected and summarized.

Data from the U.S. Geological Survey, the Minerals Management Service, the U.S. Bureau of Mines, the U.S. Department of Energy, and the National Academy of Sciences were used to quantify resource estimates for petroleum, uranium, shale oil, natural gas, peat, and coal. The USGS and MMS appraise, analyze, and publish estimates of resources and identify measurable parameters of significance to resource evaluation, such as location, quality, quantity, and situation of the identified resources. The BoM and the DOE appraise, analyze, and publish reserve estimates from base data supplied by the mineral and energy materials industry, the USGS, and other governmental agencies. The BoM judges resource recoverability based on existing economic and legal criteria.

The BoM and the USGS confer annually on estimates of the fossil energy resource availability. These estimates are published in organizational publications and are available for the Secretary of Energy's Annual Report. For estimates of the uranium resource, 1987 Department of Energy (DOE) data were used. International Atomic Energy Agency and U.S. DOE figures were used to determine reactor input requirements.

Data from a number of sources were used to quantify the resource estimates for geothermal, hydroelectric, wind, solar, and biomass. A general summary of data sources for these energy sources is provided in Table 4-1. A detailed listing of specific documents is given in Appendix A and B.

4.2 Validation of Underlying Assumptions and Resource Categories

Developing national fossil energy resource and reserve estimations in most cases is a very detailed process. It is collected from local geophysical measurements or mapping, and then aggregated for national statistics. For example, data on coal resources are first collected on a field-by-field basis, then compiled by state, assembled by region, and finally aggregated for the nation as a whole. Such a detailed process requires the cooperation of a number of geologists and resource analysts and may take five to ten years to complete.

Table 4-1: Summary of Data Sources

Coal:	U.S. Geological Survey; U.S. Department of Energy
Shale Oil:	U.S. Geological Survey; National Academy of Sciences
Petroleum:	U.S. Department of Energy; U.S. Geological Survey; U.S. Minerals Management Service; National Petroleum Council
Natural Gas:	U.S. Department of Energy; U.S. Geological Survey; U.S. Minerals Management Service; National Petroleum Council
Uranium:	U.S. Department of Energy
Geothermal:	U.S. Geological Survey; National Academy of Sciences
Hydroelectric:	U.S. Corps of Engineers; individual authors
Wind:	U.S. Department of Energy; Pacific Northwest Laboratory
Solar:	U.S. Department of Energy; National Weather Service; and individual authors
Biomass:	U.S. Department of Agriculture; U.S. Department of Energy; annual forest industry production; and individual authors
Peat:	University of Minnesota; U.S. Bureau of Mines

At each step of the process, assumptions are made about which portions of the resource will be included in the estimates, and what limitations will be placed on the physical extent and quality of the resource. These assumptions are extremely important, since they limit the amount of the total resource in place that will be counted. To again use the example of coal, the U.S. Geological Survey includes in its resource estimates only that coal which is found in beds or seams of a certain thickness (at least 14 inches average depth in the case of anthracite, semianthracite, and bituminous coal; and 30 inches or greater in the case of subbituminous coal and lignite).[8] The coal must also be covered by an overburden of less than 2,000 feet to be considered an identified resource and by less than 1,000 feet to be considered a reserve for higher grades of coal.[9] Some of these limitations (the depth of the

8. Paul Averitt, *Coal Resources of the United States, January 1, 1974*, (Washington, DC: U.S. Geological Survey Bulletin 1412, 1974), p. 23.

9. *Ibid*, pp. 25 and 32.

resource, the size of the bed) have been used by the major data collection agencies for many years and may be currently outmoded due to technological developments. However, since that is the way that the data are collected, these limitations are included in this report.

While many major organizations use generally comparable methodologies for deriving resource and reserve estimates, all methodologies are not the same. In some cases, this reflects the nature of the energy source itself. Petroleum and natural gas, for example, are mobile underground. They can be formed in one location, migrate to another, and be dispersed or altered en route. Therefore, resource estimates are developed probabilistically, as well as on extensions or inferences from drilling data. In other cases, the data collection and reporting methodology reflects the audience for the data. Uranium resource estimates are made not on the total resource availability but on the basis of tons available at a certain extraction cost, since this is the information that government decision-makers and industry representatives have traditionally sought.

In addition, published resource data have been developed at various periods of time, ranging from 1974 to 1988. By necessity, analytic processes have been adapted to suit the particular resource being examined. Particular attention is paid to the spatial restrictions imposed on the resource and reserves (the average depth for fossil fuels and geothermal, or the rotor diameter spacing for wind turbines, for example) and on the economic assumptions underlying reserve calculations. A summary of the definitions for each energy source is presented in Table 4.2, while the detailed definitions, derivation of data, and data sources are provided in Appendix A.

4.3 Interpretation of Data to Ensure Uniformity

Certain organizations use methodologies which vary from those of the U.S. Geological Survey. In particular, the Department of Energy oil and natural gas reserve survey does not include any explicit economic assumptions for the price of the fuel being extracted.[10] Instead, producers are asked to estimate *reserves* for their field under current market conditions, which can vary greatly from location to location. Where these variations occur, they have been noted in Appendix A.

To denote resources that could be extracted or converted by available technology, the term *accessible resource* is used. This is an analytic category used directly by the USGS for geothermal energy for example, and has proven to be highly useful for technology-dependent energy sources. As noted in Appendix A, the terms for certain energy sources required modifications or limitations to be comparable to the *accessible resource* category.

4.4 Elimination of Duplication of Resource Counting

It is physically possible for more than one energy resource to be found at the same location at the same time. A natural gas or geothermal formation within a standing forest, or solar insolation striking an oil field are obvious examples. In some cases, both energy sources can be exploited simultaneously and no data adjustment is necessary. For example, biomass crops can be grown within a wind farm. In some cases, the duplication has been minimized by merging data

10. For a discussion of the effects of external economic and operating conditions on proved reserves, see "Discussion of Reserve Estimation Methodologies," in *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1986 Annual Report*, Appendix C, (Washington, DC: Energy Information Administration, 1987), pp. 66-67. For the actual survey document sent to domestic oil and gas producers and field operators, see *Ibid*, Appendix A.

Table 4-2: Summary Definitions for *Total Resource Base*, *Accessible Resource Base*, and *Reserve* By Energy Source

	Total Resource Base	Accessible Resource	Reserve
General Definition •	The combination of undiscovered and identified, subeconomic and economic concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust.	That subset of the total resource base that can be captured, mined, or extracted by current technology or technology which will be available in the near future.	That subset of the accessible resource which is identified and can be economically and legally extracted to yield useful energy or an energy commodity.
Energy Source			
Photoconversion	The energy from solar radiation that falls on the total surface area of the U.S. plus a one time cut of standing crops, forestlands, including the biomass contained in parklands and wilderness areas, as well as existing municipal solid wastes (MSW).	The energy in solar radiation that falls on the accessible surface area of the U.S., where accessible surface area is defined as total U.S. surface area minus urban and built-up areas, lands disturbed by coal mining, national parks, national wilderness areas, surface water, roadways, national defense areas, croplands and 35% of commercial and noncommercial forestlands. To this is added the annual production of all energy crops, their residues, as well as the energy value of MSW and a one-time harvest of commercial and noncommercial forests.	The reserve is a combination of the installed capacity of grid connected photovoltaic systems, solar thermal electric systems, and a fraction of passive solar gain for new construction. To this is added the energy value of biomass resources used in current energy facilities, including residential and industrial wood combustion, corn used for ethanol production, biogas and landfill gas production, and current MSW to energy consumption.
Geothermal	The total resource as specified in USGS circular 790, but modified by the National Academy of Sciences to include resources within 6 kilometers of the surface and with a heat value > 80°C (except for hydrothermal, which is 40°C). Geopressured resources are included to a depth of 7 kilometers.	The accessible resource as specified in USGS circular 790, but modified by the National Academy of Sciences to include only accessible resources within 6 kilometers of the surface and >80°C, except for hydrothermal resources which are 40°C. Geopressured resources to a depth of 7 kilometers are also included.	The reserve as specified in USGS circular 790, but modified by the NAS. In addition, low temperature (40°C) hydrothermal 30-year resources from USGS circular 892 are added to the total.

Table 4-2: Summary Definitions (Continued)

	Total Resource Base	Accessible Resource	Reserve
Wind	The energy contained in a block of moving air (wind power classes 2-7) striking the swept area of MOD 5-B wind turbines spaced one rotor diameter apart over the total surface of the U.S.	The energy contained in a block of moving air (wind power classes 3-7) striking the swept area of MOD 5-B wind turbines spaced 10 rotor diameters apart in each row with a 5 diameter spacing between rows over the accessible surface of the U.S., where available surface is defined as total U.S. surface area minus forest and crop lands, surface water, national parks, national wilderness areas, roadways, national defense areas, and urban areas.	The installed capacity for wind turbines in 1987, which is the subset of the accessible resource that can be converted to electricity at a cost competitive with current energy sources.
Shale Oil	The sum of identified, hypothetical, and speculative resources with a possible yield of between 10 and 100 gallons per ton of shale.	The identified resource with a possible yield of between 10 and 100 gallons per ton of shale.	That subset of the accessible resource from which oil can be economically extracted at $18-20/barrel.
Coal	The identified and hypothetical resources within 6000 feet of the surface and contained in beds of certain minimum thicknesses (14 inches for anthracite, semianthracite and bituminous coal; and 30 inches for subbituminous coal and lignite).	The USGS data for recoverable coal resource are used. This is the coal that can be extracted, using current mining technology, and does not include the coal that will be left in place after mining is completed.	The amount equal to one-half of the demonstrated reserve base as estimated by DOE/EIA. This assumes that one-half of the coal is left in place after mining. It includes data on bituminous coal and anthracite beds 28 inches or more in thickness and subbituminous coal beds 60 inches or more thick within 1000 feet of the surface, as well as lignite beds 60 inches or more in thickness within 200 feet of the surface.

Table 4-2: Summary Definitions (Continued)

	Total Resource Base	Accessible Resource	Reserve
Natural Gas	The sum of identified conventional resources, identified unconventional resources (including tight formations and Devonian shales) and undiscovered conventional natural gas and natural gas liquids.	The sum of identified conventional resources, recoverable identified unconventional resources, and recoverable undiscovered conventional natural gas and natural gas liquids.	The proved reserves as defined on EIA Forms 23 and 64A.
Petroleum	The sum of identified and undiscovered conventional resources; conventional resources recoverable through conventional and advanced enhanced oil recovery (EOR) methods; oil in place not recoverable by current or advanced EOR techniques; and identified unconventional resources (tar sands).	The sum of identified reserves; undiscovered conventional resources; identified resources available through current EOR techniques; and identified unconventional (tar sands) resources.	The subset of the accessible resource that is proved reserves (as specified on EIA Forms 23 and 64A).
Peat	The energy content of all existing U.S. peat beds to a depth of 7 feet.	The energy content to a depth of 7 feet of all U.S. peat beds not currently forested (25% of the total resource).	The calorific content of the current quantity of the peat, dried to 35% moisture, which is used for energy purposes.
Uranium	The sum of DOE/EIA reasonably assured resources and estimated additional resources extractable at up to $100/lb., and speculative resources.	The sum of DOE/EIA reasonably assured resources and estimated additional resources extractable at prices less than $100/lb.	DOE/EIA estimates of reasonably assured resources available at forward costs less than $30/lb.
Hydropower	The energy content of the precipitation falling on the United States as it moves toward the sea, adjusted for evaporation and consumption.	The accessible resource is the energy that produces current U.S. hydroelectric production, plus the energy in the moving water at existing dams sites and potential dam sites to expand hydroelectric production.	The reserve value is the hydraulic energy producing current U.S. hydroelectric production, combined with the energy available at existing dam sites to expand hydroelectric production at current energy prices.

categories. Thus, solar energy and biomass are reported as a single photoconversion resource.

However, these are cases where the use of one energy resource precludes the use of another. In these cases, the higher value use of the land area has been retained. Thus, the solar energy falling on land that has been or soon will be mined for coal has been eliminated from the total and accessible solar resource.

4.5 Conversion of Values to a Common Unit of Measure

The resources and reserves of different energy sources are expressed in a variety of units of measure: joules, Btus, kilowatt-hours, tons, barrels, cubic feet, etc. In order to ensure maximum comparability, all variations in measurements have been converted to a single unit: **billions of barrels of oil equivalent, or BBOE.** Standardized conversion factors have been employed as presented in the Energy Equivalences section.

4.6 Development of Total Resource, Accessible Resource, and Reserve Data for Energy Sources

The U.S. *total resource base, accessible resource,* and *reserve* figures for all of the fossil fuels are calculated on the basis of resources remaining; that is, all the resources known or estimated to be available within the boundaries and limits set forth in the definitions. In contrast, several energy sources including wind, solar, and hydropower are essentially constant or recurrent energy sources. Using energy from these flows or fluxes does not lessen the amount of resource or reserve available for the future.

In addition, there are also several renewable energy sources -- chief among them geothermal and biomass -- whose energy yield can be sustained over a very long period of time or even indefinitely if the production is limited to some optimal level that permits a regeneration of the resource. For example, the maximum sustainable yield can be calculated for an individual forest range or a geothermal field. If volumes are extracted faster than the optimal rate, the ultimate recovery from the field or forest range may be reduced. This is analogous to the situation where total yields of oil and gas fields are typically affected by the rate of extraction. The resource for biomass energy can even expand over time, through upgrading of the plant species or the planting of additional acreage.

To facilitate the comparison between renewable and depletable resources, *the total resource base, accessible resource,* and *reserve* values for the recurrent resources are the total amount of energy available from an energy resource over a typical 30-year period. The 30-year period was selected because it reflects the projected life for a number of energy conversion plants: coal, geothermal, oil, and natural gas. For constant energy sources (such as solar, wind, hydropower, etc.), total energy values equal *annual* energy values times 30. For renewable energy sources (such as biomass and geothermal) that have an optimal extraction rate, total energy values are energy yields that can be obtained over a 30-year period.[11]

4.7 Installed Capacity as a Measure of Reserve

In the cases of shale oil, wind energy, solar energy, and peat, the initial assessment of the

11. For the case of geothermal, this is taken to be the annual energy content of the optimal sustainable flow rate times 30 years. For biomass energy, the total and accessible resource treats biomass as a photosynthetic device for converting sunlight to energy. Thus the resource is the energy in the sunlight falling on land areas where biomass (by virtue of climate, soil conditions, etc.) would be the preferred photoconversion system, plus standing stocks of biomass that fit the resource description. Only the biomass reserve estimates focus exclusively on the energy already embodied in biomass.

reserve, based on current energy prices, produced a figure that was either zero or was smaller than the current installed capacity. In these cases the installed capacity is defined as the reserve. If a system is currently in operation, it is assumed to represent an actual reserve. This is parallel to the process used by DOE for calculating current reserves for oil and natural gas, which is based directly on fields that are in current production or judged to be economical at current prices.

U.S. TOTAL RESOURCE BASE OF ENERGY

5.1 Summary of U.S. Total Resource Base

The United States has a very large total resource base, as depicted in Table 5-1. If technology could be developed to completely exploit these resources, the energy embodied in the energy sources examined could provide all the energy required by the U.S. for more than 46,900 years, at current rates of consumption (14 BBOE/yr). Clearly the United States does not have a supply shortage of energy in general, but does confront limitations on the technology to exploit that energy economically. While only a portion of the total resource base can ever be economically utilized, the recovery of even a small fraction of the total resource base through advances in extraction and conversion technologies will provide for anticipated U.S. energy needs for the foreseeable future.

The bulk of the U.S. total resource base is concentrated in five major energy sources: geothermal energy, photoconversion energy (solar and biomass energy), wind energy, shale oil, and coal. (For a graphic presentation, see Figure 5-1.) Collectively, these five sources account for over 99% of the U.S. total resource base. A portrait of the estimated total resource base for each of the energy sources examined, is summarized in Table 5-1. General knowledge and geographic distribution of each of the energy sources is presented in the sections that follow.

5.1.1 Geothermal Energy

Geothermal energy is a very widely distributed energy form, consisting of heat energy contained within the earth's core that can be captured and exploited using specialized drilling technology developed over the past hundred years. Conservative estimates place the geothermal *total resource base* at nearly 258,300 BBOE, an amount nearly equal to 40% of the total resource base for all U.S. energy sources. Geothermal energy is found in five basic resource categories: conduction-dominated regimes; igneous or magmatic geothermal systems; high temperature (>150°C) vapor-dominated (steam) or hydrothermal (fluid) convection systems; low-temperature (>40°C) geothermal waters or hot springs; and geopressurized resources (which contain both thermal energy and dissolved methane gas).

Table 5-1: U.S. Total Resource Base of Energy

Energy Source	BBOE
Geothermal	258,263
Photoconversion (Solar and Biomass)	178,438
Wind	176,910
Shale Oil	27,518
Coal	15,079
Petroleum	477
Natural Gas	294
Peat	244
Uranium	203
Hydropower	170
Total	657,596

Thus far, most attention has been concentrated on the location and exploitation of high-temperature vapor-dominated and hydrothermal convection systems for power generation and for direct

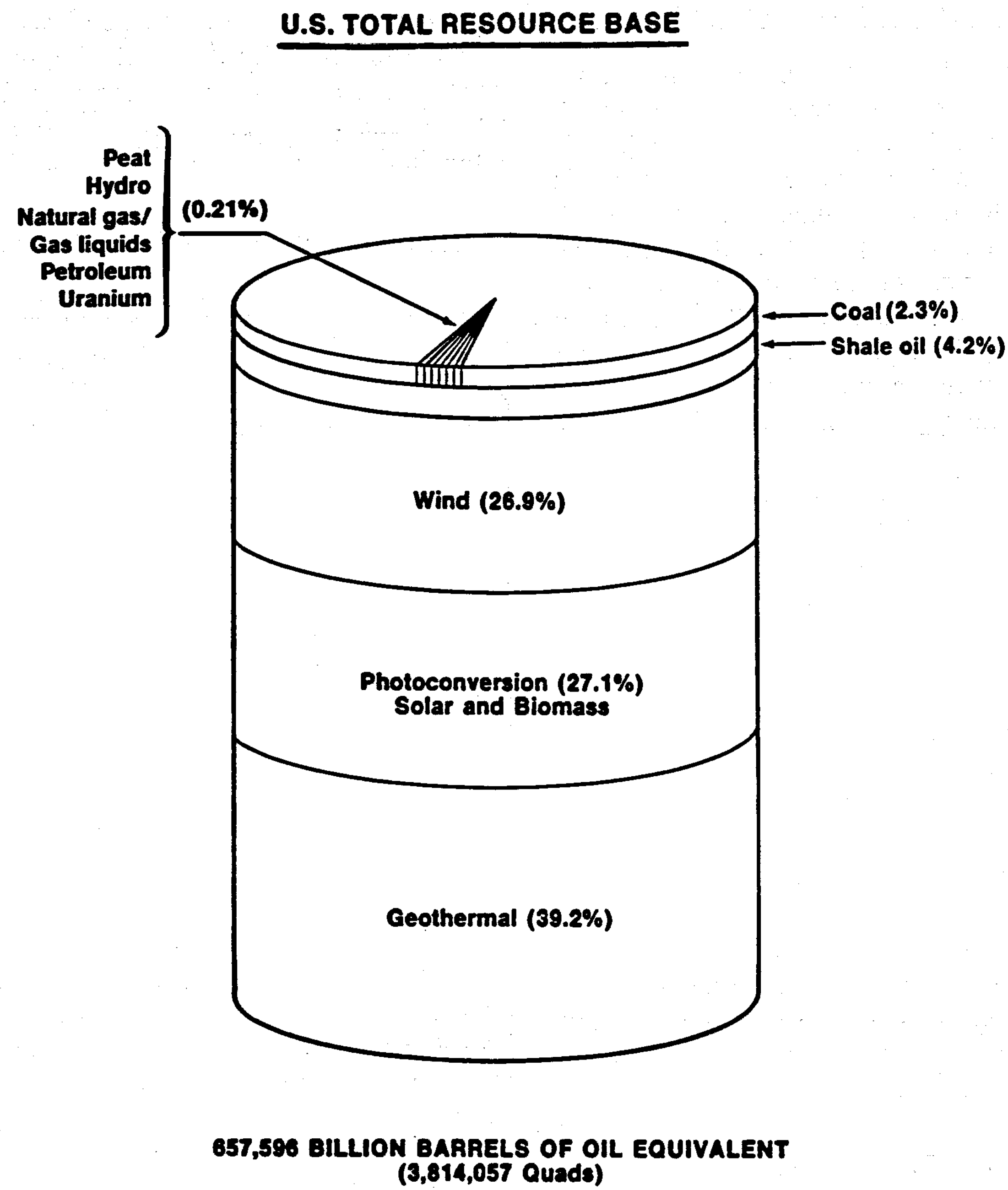


Figure 5-1: U.S. Total Resource Base of Energy

use applications. Such systems are located primarily in the western United States, with the largest concentrations occurring in California, Utah, Nevada, Hawaii, Idaho, Oregon, and Washington. Low-temperature hydrothermal resources, which are used for direct heat applications such as space heating and agricultural processing, are found throughout the United States. The overwhelming fraction of the total geothermal resource base is contained in conduction-dominated regimes and in geopressurized resources, for which resource exploitation technology is still under development. Conduction-dominated regimes are distributed relatively uniformly throughout the United States, while geopressurized resources are concentrated onshore and offshore in the Gulf of Mexico coastal region.

5.1.2 Photoconversion (Solar and Biomass Energy)

Other than geothermal, solar insolation is the basic source of most of the renewable energy resources. It is converted by solar energy conversion technologies into useful work, or by photosynthesis into biomass. Since plants function as living solar energy converters, they are included here as part of the photoconversion resource.

Photoconversion of solar energy is the most widely distributed of the major energy sources in the United States. It has a *total resource base* of over 178,000 billion barrels of oil equivalent, or nearly 27.1% of the U.S. total resource base of energy.

Solar Energy

Solar energy is distributed throughout the entire U.S. land area. There are variations in the quality and intensity of the solar radiation, with the highest levels of insolation values found in the western and southwestern parts of the U.S., where annual average daily solar radiation levels of 5.5-6.7 kWh/m^2 are common. The annual daily solar radiation level for the entire U.S. is approximately 4.3 kWh/m^2.

Biomass

Biomass accounts for a substantial portion of the photoconversion total resource, since a high proportion of the solar insolation included in the measurement is falling on land currently used for or best suited to photosynthetic conversion technology. The photosynthesis total resource base includes a one-time harvest of all the standing forest, crops and municipal solid waste resources in the United States in order to include the resource base that is already in place as a result of accumulated photosynthesis.

The approach taken here treats biomass as one of several conversion media for solar energy and includes measured solar insolation falling on the forest and crop area. This measurement of total resource establishes the conceptual outer limits to the biomass resource.

Unlike other energy sources, the total biomass resource base is capable of substantial expansion over time. Improved species capable of more efficient conversion of light into useable energy can be introduced, more land can be dedicated to biomass production, or a combination of both approaches can be used. The approach used to define the total resource was designed to accommodate this flexibility, while still establishing an outer bounds for the underlying energy resource both synthetic and biological photoconversion devices could tap. A further discussion of the biomass portion of the total photoconversion resource can be found in Appendix A.

5.1.3 Wind Energy

Wind energy is the third most abundant of the U.S. energy sources in terms of resource base. Its *total resource base* of 176,910 BBOE provides approximately 27% of the U.S. total resource base of energy. The method of calculating the wind resource base defines the current total wind resource as those sites capable of powering a wind electric turbine. By including those sites with Wind Power Class 2 or better winds (greater than 6.09 meters/second or 13.6 miles per hour at an altitude of 60.8 meters above the ground), it eliminates those locations with light or moderate wind regimes for which technology is not available.

Since the energy contained in the wind increases with the cube of the wind speed, higher wind class (Class 7) sites provide the densest and therefore most valuable wind resource. The average wind power density of a Class 7 site is nearly six times that of Class 2 sites.

5.1.4 Shale Oil

Shale oil is the most abundant fossil fuel resource within the United States. Shale oil resource deposits are geographically concentrated, with the major shale oil formations located primarily in the Green River formation in Colorado, Utah, and Wyoming. The total shale oil resource deposits (27,518 BBOE) make up approximately 4.2% of the U.S. *total resource base* of energy. The size and extent of the shale oil formations have been determined by exploratory drilling and surface exploration, while calculations of energy content are based on geophysical data collected by public and private researchers on a large range of samples.

5.1.5 Coal

Coal is the second most abundant fossil fuel resource in the United States. It has a relatively well-researched and documented resource base of 15,079 BBOE, providing approximately 2.3% of the U.S. *total resource base* of energy. The locations and size of each individual coal field or bed are well known from data collected from decades of oil and gas exploratory drilling, from surface investigations of the coal beds, and from a variety of other geophysical measurement techniques. Of the total resource base, 56% is considered hypothetical, based on geological and geophysical inference. A system of coal ranks has also been developed for describing the quality of the coal contained in each field. These rankings are based on factors such as the percentage of volatile matter and fixed carbon, and range from anthracite (with 98% fixed carbon and little volatile matter) to lignite.

5.1.6 Petroleum

The U.S. petroleum resource base is a combination of the identified resources and the estimated undiscovered resources. This total of 477 BBOE comprises only a very small portion (.07%) of the U.S. *total resource* base, but provides virtually all of the domestically produced liquid fuels and much of the nation's chemical feedstocks.[12]

5.1.7 Natural Gas/Natural Gas Liquids

The resource base for natural gas and natural gas liquids is a combination of the identified resources and the estimates of the undiscovered natural gas onshore and on the continental shelf of the United States. Despite the prominent position that natural gas plays in current U.S. residential, commercial, and industrial energy applications, it constitutes only a small fraction of the fossil fuel resource base and an even smaller portion (.04%) of the U.S. *total resource base* of energy, 294 BBOE. There is also active debate within the U.S. government and within the larger U.S. energy community as to whether these existing gas resource and reserve figures are, in fact, too large. Preliminary figures from an as-yet unpublished 1988 USGS analysis show a reduction of up to 40% in the undiscovered conventional natural gas resource figures, in part due to the

12. The main exceptions are biomass-derived ethanol, coal-derived methanol and natural gas liquids such as ethane, propane, butane, isobutane, and pentanes.

elimination of some gas-bearing formations that have now been included with unconventional resources. DOE released an alternative analysis which produced higher estimates, in part because unconventional resources were included and larger recovery from known fields were anticipated. This report uses estimates presented in ongoing USGS/MMS analysis, numbers which fall between the earlier USGS and DOE calculations. A further discussion of the issue is presented in the natural gas appendix.[13]

5.1.8 Peat

Peat is the water-saturated accumulation of plant debris that collects on poorly drained land and forms the first stage in the alteration of plants to coal. Peat accounts for 244 BBOE, or .04% of the U.S. *total resource base*. The U.S. peat resource is geographically concentrated, with over half of the resource found in Alaska and 30% located in the states of Minnesota, Michigan, and Wisconsin. Current U.S. peat production is primarily used for non-energy related applications, principally as a soil additive.

5.1.9 Uranium

The U.S. uranium resource base is the sum of the assured, estimated additional, and speculative resources of uranium oxide or U_3O_8. Uranium's resource base (203 BBOE or .03% of the U.S. *total resource base*) is one of the most difficult to calculate.

Uranium is an element that occurs in small amounts in many geologic formations. Ideally, the total resource would include even very small deposits or concentrations of the resource. But the available data only consider resources with concentrations and physical characteristics that would allow extraction with given technology and given assumed costs, up to $100/pound. This excludes resources that could be extracted at more than $100/pound. Consequently, assumptions were made in order to differentiate total resource, accessible resource, and reserve values for uranium.

The total resource includes all of the discovered and undiscovered resource, while the accessible is limited to resources that are discovered or are strongly indicated by available geologic information. Both the accessible and the total resource use values at the maximum forward cost category of $100/pound, in order to remove as far as possible the economic constraints inherent in the data. Reserves include only discovered resources available at less than $30/pound, the forward cost category.[14]

U_3O_8 is not a fuel in the sense that coal or biomass are; it cannot be burned to determine its calorific value. Rather, the uranium must be processed, first to produce uranium hexafluoride (UF_6) and then to produce concentrations of a

13. The USGS and Minerals Management Services specialists estimated that the range of accessible (recoverable) resources for petroleum were within the range of 19.6 to 51.9 billion barrels, with a mean value of 33.4. For natural gas, the range derived was 172 to 356 trillion cubic feet. See R.F. Mast, G. L. Dalton, R.A. Crovelli, R.B. Powers, R.R. Carpentier, D.H. Root, and E.D. Attanasi, "Estimates of Undiscovered Recoverable Oil and Gas Reserves for the Onshore and State Offshore Areas of the United States," *The McKelvey Forum Papers*, 1988, pp. 31-32. For a rebuttal of the figures and the methodology, see "Premature and Off the Mark, Says Hodel of Gas Reserves Flap," *The Energy Daily*, March 18, 1988, p. 3. The Department of Energy released *An Assessment of The Natural Gas Resource Base of the United States*, (Washington, DC: U.S. DOE Office of Policy, Planning and Analysis) May, 1988, which presented an alternative analysis with values of 1,188 Tcf, which includes nonconventional formations.

14. Forward costs are the operating and capital costs still to be incurred in the production of uranium from estimated reserves. that most closely matches current market prices. More information on the resource categories used in the analysis and their implications are included in the appendix.

particular uranium isotope, U_{235}, which then undergoes a controlled nuclear reaction in the fuel chamber of a nuclear power plant. The heat released by the nuclear reaction is used to heat water or a heat exchange medium, which in turn drives a turbine to produce electricity. The calculations used here assume lightwater reactor conversion, with a 33% efficient conversion of energy to electricity. In order to approximate the energy value of the uranium before it is converted to electricity and undergoes efficiency losses, the electricity equivalent of the uranium was multiplied by the reciprocal of the efficiency, 1/.33.

5.1.10 Hydropower

Hydropower, used extensively in the United States for power generation, is a relatively small resource, accounting for 170 BBOE, or .026% of the U.S. *total resource base* of energy. The total hydropower resource base is the energy contained in the precipitation falling on the surface of the United States as it drops to the sea, minus water taken off for consumption and lost to evaporation. The mass of the water times the average elevation drop yields the energy potential in the falling water.

5.2 Limitations of Total Resource Base Data

All resource data have been developed using common assumptions and similar definitions for what is to be included and excluded. However, several resource calculations are based on extrapolation and interpolation from a limited set of site measurements, rather than aggregating a large number of individual data points. This is true of the undiscovered oil and gas resource figures for example. Such data inherently have a lower confidence level than that of coal, which is based on core sampling and geophysical explorations.

In general, all aggregate resource values presented should be viewed more as an indication of overall resource availability, rather than making strict predictions of the potential for the extraction or conversion of usable energy. In fact, technology does not yet exist to exploit many of the energy resources even if the cost of energy were considered irrelevant and energy demand totally price inelastic. Moreover, even if the technology did exist to tap these resource bases, only a small fraction could be exploited as competing energy sources vied for the use of land, water, capital, etc.

Such large resource figures are useful mainly for the broad boundaries they place on the choices that will have to be made in the future on energy capture, conversion, and extraction. Technological breakthroughs and changing external conditions can dramatically increase the size of the *accessible resource* and the *reserves* for any energy source, but they will not dramatically affect the overall *total resource base*.

U.S. ACCESSIBLE RESOURCES OF ENERGY

6.1 Summary of U.S. Accessible Resources

The United States has an *accessible resource* of approximately 115,000 billion barrels of oil equivalent (BBOE). This would provide for more than 8,200 years of national energy consumption at 1987 rates of usage. While this total *accessible resource* is only a small fraction of the *total resource base* reported in Section 5.0, it is nonetheless a very large and important national asset. (See Table 6-1.)

The *accessible resource* figure is more meaningful perhaps than the *total resource base*, since it establishes the outside boundaries for the amount of energy production that is technically feasible. It encompasses only those portions of the *total resource base* that can be exploited with currently available technology or technology that will soon be available, thus eliminating many remote or speculative resources. (See Figure 6-1.)

6.1.1 Photoconversion (Solar and Biomass Energy)

The photoconversion accessible resource in the U.S. is very large, accounting for nearly 88% of the total U.S. *accessible resource*. The photoconversion accessible resource exceeds 101,100 BBOE, or an amount equal to over 7,200 years of current U.S. energy consumption. It is distributed relatively evenly across the land area of the United States, although more than 40% of the U.S. land area has been eliminated from photoconversion utilization because it is already dedicated to parklands and wilderness areas, croplands, waterways and roadways, urban areas, land disturbed by coal mining, inaccessible forests, and national defense areas.

Table 6-1: U.S. Accessible Resources of Energy

Energy Source	(BBOE)
Photoconversion (Solar and Biomass)	101,153
Coal	6,577
Geothermal	3,928
Shale Oil	2,018
Wind	870
Petroleum	190
Natural Gas	153
Uranium	126
Peat	61
Hydropower	27
Total	115,103

Biomass is a large portion of the photoconversion accessible resource, since a substantial amount of the solar insolation is falling on land that is currently used for or best suited to photosynthetic conversion technology, rather than other technologies.

The adjustment made to the photoconversion total resource figure to include only the technologically accessible share of the total resource has had only a small effect, since the great majority of the land in the U.S. is devoted to uses that at least technically could be displaced by photoconversion for energy production, including 65% of the commercial and noncommercial forestland in the U.S. Like the total resource, the accessible resource figure also includes a one-time harvest of all the standing forest in the United States in order to include the resource

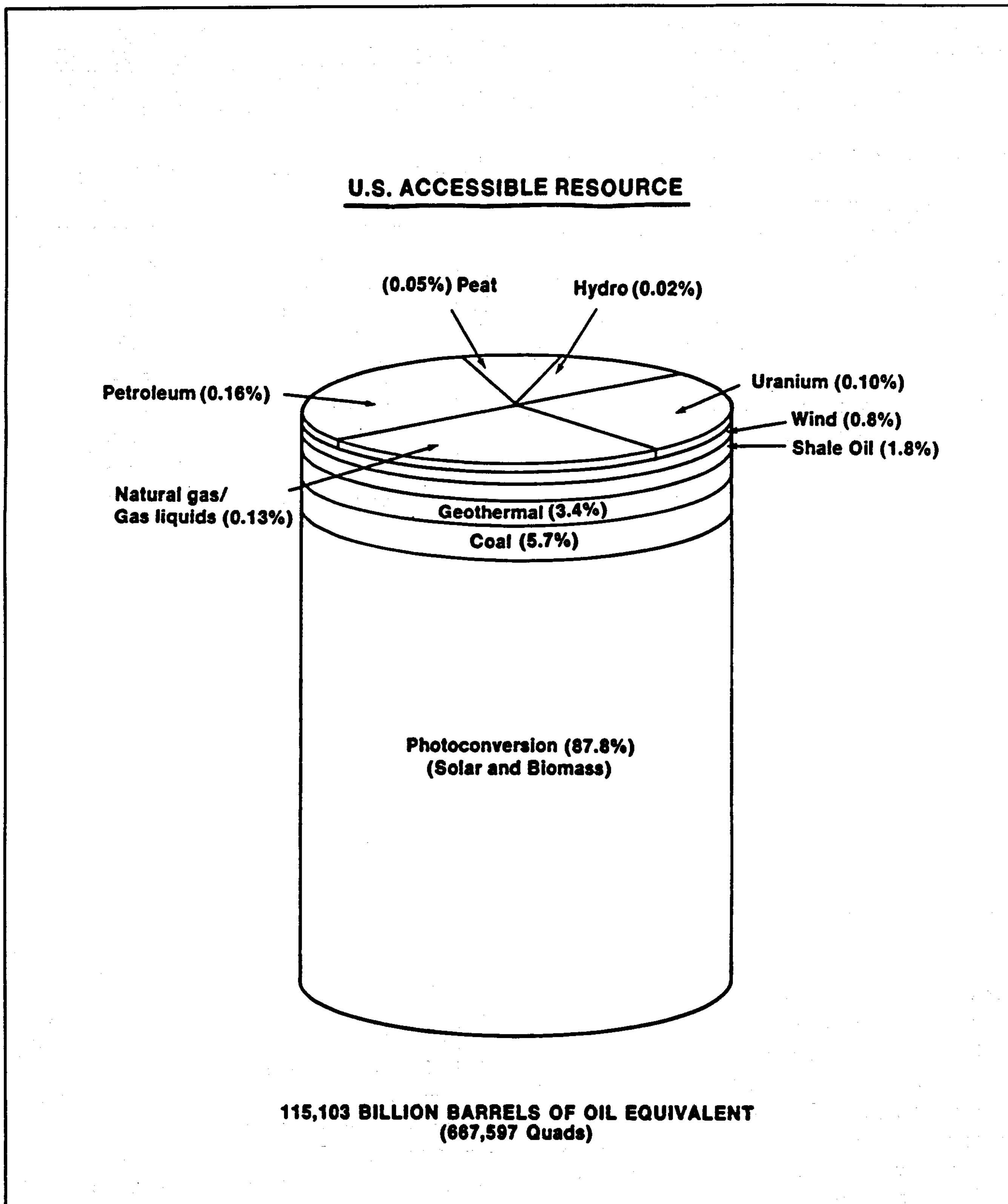


Figure 6-1: U.S. Accessible Resources of Energy

base that is already in place as a result of accumulated photosynthesis.

This view of the resource treats biomass as a conversion medium for solar energy. The approach used to define the total resource was designed to accommodate future improvements in biomass conversion, while still establishing an outer bounds for the underlying energy resource both synthetic and biological photoconversion devices could tap. A discussion of the potential impact of improvements in biomass species and of increasing land area devoted to biomass energy production is included in Appendix A.

6.1.2 Coal

The coal accessible resource is determined using the USGS terminology of total identified resource. This represents all of the known coal that can be extracted using current and near-term technology. The USGS includes only resources found in beds of a certain minimum thickness[15] and under less than a certain amount of overburden.[16] Even after these restrictions, the coal accessible resource is very large, with over 6,500 BBOE or slightly more than 5.7% of the total U.S. accessible resource of energy. The coal accessible resources are concentrated into a number of major areas; the most important located in the very large western fields in Wyoming, Colorado, Montana, Utah, and North Dakota; Alaska; the Midwestern coal fields of Illinois and western Kentucky; and the Appalachian coal found in West Virginia, eastern Kentucky, Alabama, Ohio, Pennsylvania, and Virginia. The accessible resources for all the energy sources considered is presented in Figure 6-1.

6.1.3 Geothermal

The geothermal accessible resource is that portion of the total resource base which can be exploited using current or developing drilling and resource collection technology. In general, it includes those portions of the geothermal resource base that are over a temperature of 80°C and within 6 kilometers of the earth's surface. Low temperature geothermal hydrothermal resources with a temperature of greater than 40°C and a depth of less than 3.2 kilometers are also included. The geothermal accessible resource totals 3,928 BBOE, or 3.4% of the total U.S. *accessible resource.*

6.1.4 Shale Oil

The accessible resource of shale oil is defined as the identified resources that have a potential yield of between 10 and 100 gallons of oil per ton of shale. The USGS has determined that the shale oil accessible resource contains 2,018 BBOE, or 1.8% of the total U.S. *accessible resource.*

6.1.5 Wind Energy

The wind energy accessible resource is that amount which can be captured by technology on land potentially available for turbine installation. The available land area is the total U.S. land area minus currently forested areas (since the energy output of this land has already been counted in the biomass energy section), parkland and wilderness areas, national security areas, urban and built-up areas, and the surface area of lakes, streams, and rivers. The wind energy system installation arrangement used here in a 10-diam-

15. 14 inches or thicker for anthracite and bituminous coal and 30 inches or thicker for subbituminous coal and lignite.
16. 6000 feet for anthracite and bituminous and subbituminous coal and 200 feet for lignite.

eter spacing within turbine rows and 5 diameters between rows in large windfarm configurations. This spacing is somewhat more open than that in large windfarms currently installed in the United States. However, a more open spacing has been specified to minimize array losses due to turbine wakes (which can be significant when turbines are placed close to one another), and to provide a conservative estimate of the accessible resource. The total wind energy *accessible resource* is 870 BBOE which is equal to approximately 62 years of current annual energy consumption at the 1987 level.

6.1.6 Petroleum

The accessible resource for petroleum is estimated to be 190 BBOE, an amount equivalent to 0.16% of the total U.S. *accessible resource* of energy. This value is the combination of the proved reserves, expected additions to known reservoirs, expected additions to enhanced recovery methods, and estimates of undiscovered resources. Despite the central role played by petroleum and petroleum-derived distillates in every facet of the U.S. economy, the underlying accessible resource is small, and only equal to 14 years of current total U.S. energy consumption.

6.1.7 Natural Gas/Natural Gas Liquids

The natural gas accessible resource is comprised of proved reserves, new expected discoveries in known fields, additions expected by known enhancement techniques, and undiscovered resources. Of the 153 BBOE of natural gas *accessible resources*, 13.65 BBOE or 9% is provided by natural gas liquids. As discussed in the total resources section and the natural gas appendix, there has been significant controversy over recent natural gas resource estimates. The values used for this analysis are a compromise between high and low figures available from alternative sources.

6.1.8 Uranium

The accessible resource value for uranium is the sum of U.S. DOE "reasonably assured resources" and "estimated additional resources." An upper value of $100/pound was used for both, which is the highest forward cost category used in DOE estimates. As discussed in section 5.1.9 on the uranium total resource, the uranium resource and calculations of its energy content are problematic. The resource estimates available all imply economic and technical constraints (forward cost categories). As a result, the uranium resources were categorized on the basis of their certainty rather than on the strict basis of the definitions provided in this report. The total resource contains all discovered deposits and undiscovered deposits (deposits which are inferred from geological data but have not been measured extensively enough to warrant categorization as "discovered") at the highest forward cost category available. The undiscovered portion includes resources with strong geological indications along with speculative resources based on less substantial evidence. The accessible resource estimate is more conservative in excluding the most speculative portions of the undiscovered resource, although it still includes a portion of the undiscovered uranium resource estimate. The accessible resource estimate uses the maximum forward cost category used to estimate resources, to remove economic constraints on the resource data as far as possible. The definition also includes a range of current technologies, as is explained in Appendix A. The total value for the uranium *accessible resource* is 126 BBOE, which is equivalent to approximately 9 years of national energy consumption at current levels.

6.1.9 Peat

The accessible resource for peat is that portion of the peat resource base that can be reached without removing tree and forest cover before beginning the cutting and drying of the peat.

Therefore, these estimates eliminate that portion of the total peat resource base currently dedicated to other uses, particularly the growing of forests. It is estimated that only 25% of the peat resource base is accessible without the clearing of forests. This *accessible resource* has an energy value of 61 BBOE or 0.05% of the total accessible resource.

6.1.10 Hydropower

The accessible resource for hydropower is a combination of currently installed capacity, potential for expanding power output at existing sites, and potential hydropower capacity at new high-quality sites. These data have been summed over the 30-year planning horizon to derive the *accessible resource* value of 27 BBOE which is equal to two years of current U.S. consumption.

6.2 Limitations of Accessible Resource Data

The *accessible resource* data for all energy sources accounts for some but not all potential overlaps between competing energy sources. The land area available for solar collectors has been reduced to eliminate urban areas, some portion of the biomass areas (forests and agricultural lands) and hydro sites (all waterways), as well as the land occupied by and to be disturbed in the next 25 years by surface and underground coal mines. However, other accessible resource figures do not take into account the possibility that coal operations might compete with oil and gas drilling, with wind turbines, etc.

More importantly, the accessible resource data do allow for some existing higher value uses of land which preclude energy production when that land use has specifically been forbidden by law (i.e., geothermal production is currently not allowed in Yellowstone National Park and therefore this resource is not considered accessible). Thus, the *accessible resource* figures eliminate urban and built-up suburban areas, since they are occupied and are therefore not for lease or sale, regardless of the quality of the energy resource.

U.S. RESERVES OF ENERGY

7.1 Summary of U.S. Reserves

The United States has an energy *reserve* of over 1,000 billion barrels of oil equivalent (BBOE) as indicated in Table 7-1 and Figure 7-1. This would provide for more than 78 years of national energy consumption at 1987 rates of usage. The great majority of this reserve (82.8%) is provided by coal, which is being used extensively in the U.S. The coal reserve constitutes about 14% of the accessible resource of coal.

Five other energy sources with substantial current reserves are biomass, natural gas, geothermal, petroleum, and hydropower, which comprise an additional 16.1% of the U.S. total *reserve* of energy. Uranium is the remaining energy source regularly used in the U.S., providing 0.7% of the U.S. total *reserve* of energy. Since the *reserve* is defined as the economically viable subset of the *accessible resource*, Table 7-1 provides a general indication of the energy sources that are or could be in widespread use.

Approximately 99.6% of the U.S. *reserve* is comprised of energy sources that are currently in use but that constitute only 16.6% of U.S. total *accessible resources*. This means that there is a large amount of available energy sources currently in use in the U.S. that cannot yet be economically tapped as an energy supply due to current extraction or conversion efficiencies or to technology readiness.

7.1.1 Coal

The reserve value of 908 BBOE for coal was determined from established DOE/EIA sources for 1986. The value is equal to one half of the demonstrated reserve base (DRB), which is DOE/EIA's estimate of economically recoverable coal given today's technologies. It reflects a 50% recovery rate for underground mines and an 80% rate for surface mines. It includes data for bituminous and subbituminous coal, anthracite, and lignite at various bed thicknesses and depths of overburden. The DRB is the closest representation of a reserve available.

Table 7-1: U.S. Reserves of Energy

Energy Source	(BBOE)
Coal	908.0
Photoconversion (Biomass)	57.7
Geothermal	42.5
Natural Gas	39.9
Petroleum	26.9
Hydropower	10.0
Uranium	7.3
Photoconversion (Solar)	3.0
Wind	<1.0
Shale Oil	<1.0
Peat	<1.0
TOTAL	1096.2

7.1.2 Biomass

The biomass *reserve* contributes approximately 5.3% or 57.7 BBOE of the total U.S. reserve of energy. It is dominated by wood energy use in the commercial and residential sectors, and by a large increment of annual forest growth that is currently unused but could be tapped for energy production. The value also includes corn used for

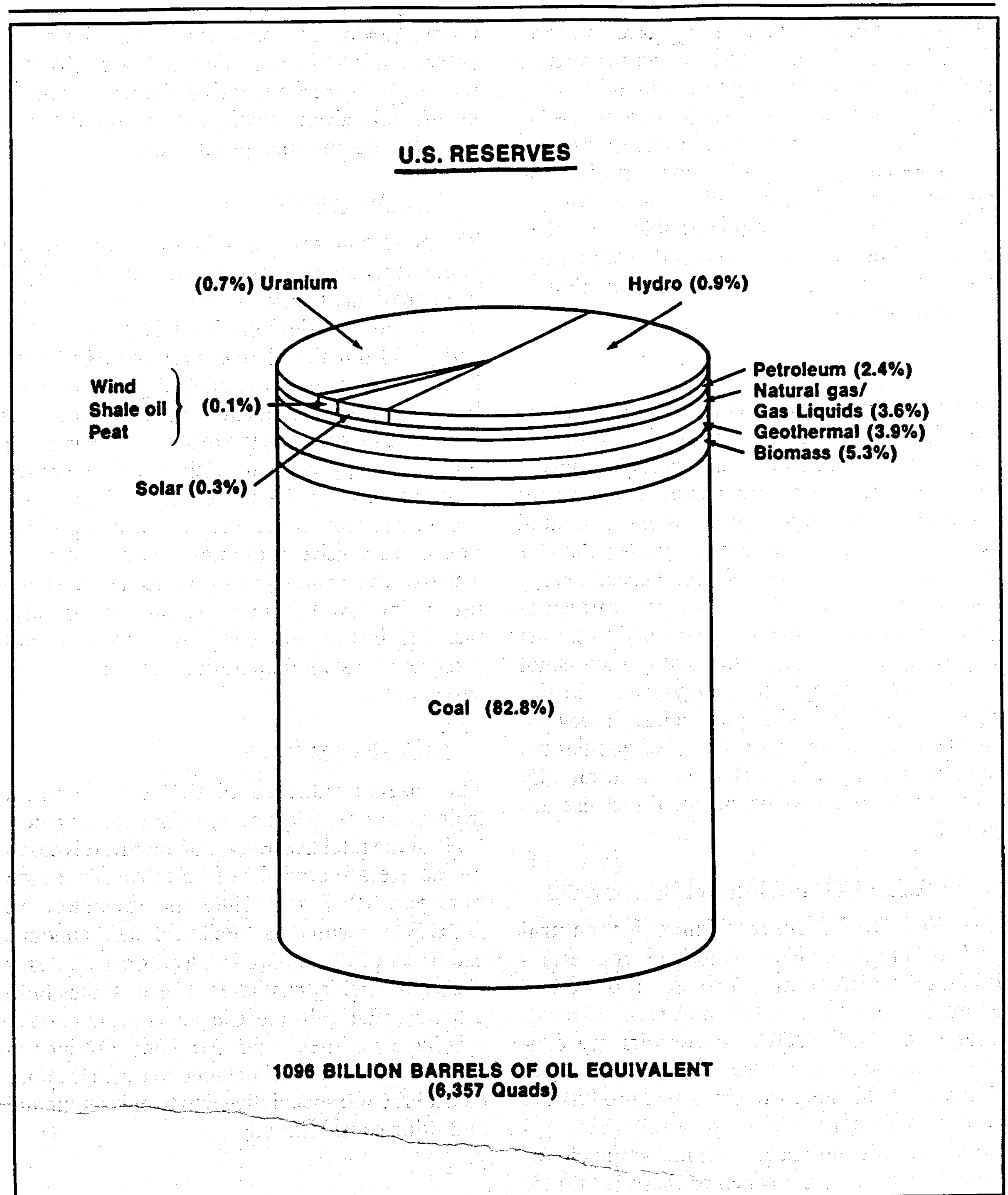


Figure 7-1: U.S. Reserves of Energy

ethanol, planned and operating waste to energy facilities, landfill gas, and biogas production facilities. This is a conservative estimate of reserves, especially in the waste-to-energy area because of the large amount of unused resource that could potentially be tapped, and the positive environmental implications of turning waste-to-energy. There is an unquantifiable amount of biomass that could be developed economically but simply has not for lack of recognition or pressing demand.

7.1.3 Geothermal

The geothermal reserve comprises 3.9% of the total U.S. energy reserve, or 42.5 BBOE. The value was derived from U.S. Geological Survey documents for hydrothermal convection systems including both vapor- and water-dominated reservoirs, with temperatures greater than or equal to 150°C. This single geothermal energy source was used for power generation measurements because the technology needed to extract electricity from other geothermal systems is not yet economic at current energy prices. To this figure were added U.S. Geological Survey estimates of low temperature (>40°C) geothermal hydrothermal energy that is economically recoverable at the wellhead for direct use applications.

7.1.4 Natural Gas/Natural Gas Liquids

The 39.9 BBOE reserve value for natural gas/natural gas liquids was derived from established DOE/EIA sources for 1986. It comprises approximately 3.6% of the total U.S. *reserve* of energy, or 39.9 BBOE. Reservoirs are considered in the reserve base if economic production potential is supported by actual production, conclusive formation tests, or core analyses. Appropriate reduction in gas volume was made for liquid gas reservoirs. Much of these data were obtained from voluntary submittal of EIA Forms 23 and 64A. Clear guidelines are not given for product estimation on these forms. Thus, the determination of economic viability is subject to the respective respondent's estimates of current profitability given specific market situations or values based on actual production.

7.1.5 Petroleum

The petroleum reserve is the fifth largest of the U.S. energy sources, accounting for 26.9 BBOE or approximately 2.4% of the U.S. total *reserve*. The value was derived from DOE/EIA data gathered from oil well operations on EIA Forms 23 and 64A, as with the natural gas/natural gas liquids data. As before, each estimate of economic feasibility is the result of the particular operator's approach to estimation of proven reserves. Reservoirs are considered proved if economic production is based on actual production or conclusive formation testing. *Reserves* which can be economically produced through the use of improved recovery techniques are also included in the "proved" classification if pilot projects of installed operations are shown to be successful.

7.1.6 Hydropower

The reserve value of 10 BBOE for current hydropower capacity accounts for approximately 0.9% of the total U.S. *reserve* of energy. It is based on the average annual hydroelectric generation between 1977 and 1987 as published in DOE/EIA documents. Technical and economic extension of these data is based on U.S. Army Corps of Engineers studies. These studies indicate potential hydroelectric power production at existing dam sites. No estimated production from new dam sites is included because they are considered too speculative due to environmental and siting considerations.

7.1.7 Uranium

The uranium reserve of 7.3 BBOE is approximately 0.7% of the total U.S. *reserve*. This value was derived from a DOE/EIA document, the *Uranium Industry Annual 1987*. The estimates are based on Reasonably Assured Resource (RAR) available at less than $30/pound. The forward cost category of $30/pound was chosen because it is nearest current average contract prices ($30.01/pound in 1986, $27.37/pound in 1987) for uranium, as reported by the Energy Information Administration in the *Uranium Industry Annual*. See the appendix for a discussion of problems in assessing the uranium resource and calculating its energy content.

7.1.8 Solar

The solar reserve of 3.0 BBOE is dependent on the energy form, i.e., thermal (the generation of industrial process heat or the heating of residues) or electric (photovoltaic systems and solar thermal electric systems).

Relative to the benchmark energy prices, the solar reserve for the generation of electricity from either photovoltaic or solar thermal electric systems (assuming grid-connected applications) is found to be negligible. There are economical applications for these technologies in the U.S., but grid-connected applications are not currently economic. There are currently over 13 megawatts of installed PV capacity in the U.S. and over 144 megawatts of solar thermal electric systems installed, which are included in the reserve figure.

The major component of the solar energy reserve is the contribution of no-cost passive solar design, particularly the reorientation of glazing in new home construction. The solar energy striking the vertical plan of the enlarged south-facing glazing of all new residential and multifamily housing, over the 30-year reserve period, totals 15.57 x 10^{15} Btus or 2.69 BBOE.

Solar thermal systems for industrial process heat are expected to supplement fossil systems rather than be a stand-alone source of heat for these applications. Current installations generate heat at a cost of approximately $30/million Btu. This is not economically competitive with current heat generation from fossil energy forms at benchmark prices.

7.1.9 Wind

Wind accounts for less than 1% of the total U.S. *reserve*. Relative to benchmark energy prices, the wind reserve is found to be negligible. However, there are over 16,000 wind turbines installed in the U.S. at a collective capacity of approximately 1500 MW.

7.1.10 Shale Oil

There are no economic reserves of shale oil in the U.S. This conclusion is based on a National Resource Council finding. High environmental, extraction, and processing costs render the technology nonviable at this time and indications are that this will be the case at least until 2010. A facility of 10,000 barrels of shale oil per day provides the only operating contribution to shale oil reserves.

7.1.11 Peat

The equivalent heat content cost for peat is currently about 30% higher than coal in the U.S. Although peat is used to produce energy in significant quantities in other countries, only 1% of the peat extracted annually in the U.S. (11,000 tons) was used for the production of energy.

7.2 Limitations of Reserve Data

Since the determination of the size of the *reserve* is dependent only on the economics of resource extraction and the cost of conversion to a useful form of energy, the same data limitations specified for the *total resource base* and the *accessible resource* apply. Factors such as competing energy sources, land use, and political or social issues have an effect on the cost-competitiveness of energy generation from a specific *reserve*.

ENERGY EQUIVALENCES

One Billion Barrels of Crude Oil equals approximately:

5.6 trillion cubic feet of dry natural gas

260 million short tons of coal production

1.7×10^9 megawatt-hours of electricity consumed

5.8 quadrillion Btus or quads

6.11×10^{17} joules

One million Btus equals approximately:

90 pounds of U.S. coal production

120 pounds of oven-dried hardwood

8 gallons of motor gasoline

10 therms of dry natural gas

11 gallons of propane

1.054×10^9 joules

One million Btus of fossil fuels burned at electric utilities can generate about 100 kilowatt-hours of electricity, while about 300 kilowatt-hours of electricity generated at electric utilities can produce about one million Btus of heat.

One quadrillion Btus of heat equals approximately:

45 million short tons of coal production

60 million short tons of oven-dried hardwood

1 trillion cubic feet of dry natural gas

170 million barrels of crude oil

470,000 barrels per day of crude oil for 1 year

1.054×10^{17} joules

One barrel of crude oil equals approximately:

5,600 cubic feet of dry natural gas

0.26 short tons (or 520 pounds) of coal production

1,700 kilowatt-hours of electricity consumed

One thousand cubic feet of natural gas equals approximately:

0.18 barrels (or 7.4 gallons) of crude oil

0.047 short tons (or 93 pounds) of coal production

300 kilowatt-hours of electricity consumed

One thousand kilowatt-hours (kWh) of electricity equals approximately:

0.59 barrels of crude oil

0.15 short tons (or 300 pounds) of coal production

3,300 cubic feet of dry natural gas

Sources: *Energy Facts, 1986* (Washington, D.C., Energy Information Administration, 1986) p. 54
E-380 Metric Practice (Philadelphia, PA: American Society For Testing and *Materials, 1980).*

GLOSSARY

Accessible Resource - That subset of the total resource base that can be captured, mined, or extracted without regard to economic feasibility by current technology or technology that will be available in the near future (3-5 years).

Anthracite Coal - A hard natural coal of high luster differing from bituminous coal in that it contains little volatile matter. A coal with a carbon content between 86-98% and a Btu/pound lower limit of 13,000.

Bagasse - The plant residue, normally of sugarcane, which remains after a product (such as juice) has been extracted.

BBOE - Billion barrels of oil equivalent.

Biomass - Living matter that can be used to generate energy in a usable form. Usually combustible and/or fermentable material of organic origin, e.g. wood, municipal solid waste, corn cobs, cotton stalks, rice husks, and animal manure.

Bituminous Coal - A coal that when burned yields a considerable amount of volatile hydrocarbon matter -- known as "soft coal." A coal with a carbon content between 31-86% and a Btu/pound lower limit of 10,500.

Central Receiver Solar Thermal System - System that uses fields of two axis tracking mirrors called heliostats to focus sunlight onto a single tower-mounted receiver.

Conventional Oil - A mixture of hydrocarbons that exists in the liquid phase in natural underground reservoirs and remains so at atmospheric pressure.

Conventional Resources - Energy resources, including fossil fuels and liquid fuels such as coal, petroleum, natural gas, uranium, and hydropower.

Demonstrated Resources - A collective term for the sum of measured and indicated reserves or resources.

Distributed Receiver Solar Thermal System - Groups of point-focusing parabolic dishes and line-focusing parabolic troughs that track the sun in two axes and focus the sunlight onto receivers located at the focal point of each separate system.

Fossil Energy - A concentrated energy source that is derived from the application of heat and/or pressure on organic matter (plants and animals) over long periods of time.

Geopressured Geothermal - Geothermal energy and methane contained in highly pressurized sedimentary formations with a temperature greater than 50°C and less than 7 kilometers below the earth's surface.

Geothermal Energy - Energy that occurs as heat within the earth's crust, especially heat in subterranean rock formations and in the fluids and gases contained in fractures and pores in the rock.

High-Temperature Geothermal - Geothermal energy at temperatures over 180°C.

Hydrothermal Convection Systems - Subterranean geothermal systems that transfer heat energy upward by the vertical circulation of fluids driven by differences in fluid density that correspond to differences in temperature.

Hypothetical Resources - Undiscovered resources that may reasonably be expected to exist in a known mining district under known geologic conditions. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as a reserve or identified-subeconomic resource.

Identified Resources - Specific bodies of fuels, forces, or fuel-bearing material whose location, quality, and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category.

Igneous-Related Geothermal - Hot dry rock and magmatic geothermal resources.

Indicated Resources - Resources for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.

Industrial Process Heat - Heat for various uses in industry such as drying, heating water, etc., generally in the broad temperature range of 200-600°C

Inferred Resources - Resources for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred reserves or resources should include a statement of the specific limits within which the inferred material may lie.

Intermediate-Temperature Systems - Geothermal heat-containing systems in the range 80-180°C.

Lignite - A brownish-black coal intermediate between peat and bituminous coal. A coal with a Btu/pound value between 6,300 and 8,300.

Low-Temperature Geothermal Systems - Heat-generating systems based on geothermal hydrothermal resources less than 6 kilometers in depth and between the temperatures 40-80°C.

McKelvey Diagram - A graphical representation which presents resource definitions in terms of key criteria such as relative economic feasibility and degree of resource assistance.

Measured Resource - A resource for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to be different from the computed tonnage or grade by more that 20 percent.

Natural Gas - A mixture of gaseous hydrocarbons.

Natural Gas Liquids - Fluid hydrocarbons produced with natural gas that are separated by absorption, condensation, adsorption, or other methods in gas processing plants.

Overburden - The volume of soil on top of a surface-mined mineral deposit.

Paramarginal Resources - The portion of subeconomic resources that (1) borders on being economically producible or (2) is not commercially available due solely to legal or political circumstances.

Peat - Partially carbonized vegetable tissue formed by decomposition of various plants in water, with a moisture content of 35% or more and a Btu/pound value of approximately 6,000.

Photovoltaics - A solar energy technology which converts sunlight directly into electricity. Electricity is generated when the sunlight strikes the photovoltaic surface, producing an electrical flow proportional to the intensity of the sunlight.

Proved Resources - Resources which geological and/or engineering data demonstrate with reasonable certainty are recoverable from known reservoirs under existing economic conditions.

Recoverable Resource - Energy sources that are both technologically accessible and economically viable to recover.

Reserves - That subset of the accessible resource which is identified and can be economically and legally extracted to yield useful energy or an energy commodity.

Shale Oil - A dark crude oil obtained from oil shale by heating.

Significant Energy Production - Energy content of at least 0.1 BBOE/year.

Speculative Resource - Undiscovered resources that may occur either in known types of deposits in a favorable geologic setting where no discoveries have been made, or in as-yet unknown types of deposits that remain to be recognized. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as reserves or identified-subeconomic resources.

Subbituminous Coal - Coal with a calorific value between 8,300 and 11,500 Btu/pound.

Subeconomic Resources - Resources that are not reserves, but may become so as a result of changes in economic and legal conditions.

Submarginal Resources - The portion of subeconomic resources which would require a substantially higher price (more than 1.5 times the price at the time of determination or a major cost-reducing advance in technology).

Total Resource Base - The total of undiscovered and identified, subeconomic and economic concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust.

Undiscovered Resources - Unspecified bodies of mineral-bearing material surmised to exist, based on broad geologic knowledge and theory.

Wind Energy - The extraction of useful work from the wind by conversion to electricity (through use of a wind turbine) or mechanical power (through use of a windmill).

Windfarm - A cluster of individual wind turbines interconnected to produce electricity to an established grid distribution system.

Wind Power Class - A specified range of mean power density or equivalent mean wind speed at a specified height above the ground. The normal range of wind power classes in the United States are 1-7, with 7 being the grouping with the highest mean wind speed.

Wind Power Density - The rate of flow of wind energy through a unit vertical cross sectional area perpendicular to the wind direction. Usually expressed in watts/m^2.

APPENDIX A

DEFINITIONS OF U.S. ENERGY SOURCES AND DERIVATION OF VALUES

DEFINITIONS AND DERIVATIONS: GEOTHERMAL

Total Resource Base

Derivation of the Total Resource Base Value

In the past 15 years, there have been three major studies of U.S. geothermal resources, the last completed six years ago. There are currently no plans to update these studies, so they serve as the latest publicly available consensus analysis.

The three publications are as follows:

U.S. Geological Survey Circular 790, L.J.P. Muffler, ed., *Assessment of Geothermal Resources of the United States -- 1978* (Arlington, Virginia: U.S. Geological Survey, 1979);

U.S. Geological Survey Circular 726, D.E. White and D.L. Williams, eds., *Assessment of Geothermal Resources of the United States -- 1975* (Arlington, Virginia: U.S. Geological Survey, 1975); and

U.S. Geological Survey Circular 892, Marshall Reed, ed., *Assessment of Low-Temperature Geothermal Resources of the United States -- 1982* (Arlington, Virginia: U.S. Geological Survey, 1983).

Our analysis concluded, however, that figures from the U.S. Geological Survey include a large fraction of geothermal resources that cannot be exploited by any known technology, and that economic extraction of those resources is not presently considered feasible based on technology that can be developed in the foreseeable future. Therefore, the more conservative approach used by the National Academy of Sciences in their landmark study *Energy in Transition, 1985 - 2010: Final Report of the Committee on Nuclear and Alternative Energy Systems* (Washington, D.C.: The National Academy of Sciences, 1979), page 401, has been adopted. The National Academy panel starts with the USGS figures but recalculates them using more conservative assumptions. In the NAS estimates, reservoirs with a minimum temperature of 80°C or more are considered; as compared to 15°C in the USGS estimates. Moreover, NAS assumes the maximum depth of a reservoir to be 6 kilometers (kms), whereas the USGS estimates consider reservoirs to a depth of 10 kms. The National Academy panel makes an exception for geopressured geothermal resources, which are measured to a depth of 7 kms.

The energy content of the methane gas contained in the sandstone strata of the Northern Gulf of Mexico Basin is also included in the total resource base. The sandstone layers have been selected because they have a pore structure that allows production flow rates required for commercial wells. The methane figure of 57×10^{14} standard cubic feet or 5,700 quads has been taken from R.H. Wallace, Jr., T.F. Kraemer, R.E. Taylor and J.B. Wesselman, *Assessment of the Geopressured-Geothermal Resources in the Northern Gulf of Mexico Basin,* USGS Circular 790, pp. 132-155.

The total resource base is the sum of all stored thermal energy (including the identified and undiscovered) in all of the different geothermal systems. More precisely, the total resource base is the geothermal energy within a specified volume of rock (up to a depth of 6 kms) and a minimum temperature of 80°C. To this is added the USGS estimates of hydrothermal resources 40°C or greater to a depth of 3.2 kms, which includes only those low-temperature resources with a temperature gradient higher than 25°C/km of depth. The considerable geothermal energy contained in the National Parks (particularly within the Yellowstone Known Geothermal Resource Area) is excluded because of current legal restrictions barring the exploitation of this energy.

The resource estimates rest on a scientific base using explicit technological and economic assumptions. In this study, the different categories of geothermal energy are assessed individually. The methods used to assess these categories and the various assumptions are discussed below.

Conduction Dominated Regimes: The calculation of the thermal energy stored in conduction-related systems is restricted to areas with temperatures above 80°C and with depths no greater than 6 kms. The exclusion by the NAS of conduction-dominated regimes in the temperature range of 15°- 80°C accounts for much of the difference between the USGS figures and those of the NAS. Since the normal temperature gradient is an increase of 30°C with every kilometer of depth, normal gradient low-temperature heat in the first 2.2 kms of crust is excluded by the NAS and the authors of this report.

Igneous-Related Geothermal Systems: The calculation of the thermal energy in igneous-related geothermal systems is restricted to systems of igneous-derived thermal anomalies to a depth of 6 kms from the surface. The major assumption in these calculations is that a fixed volume of magma is cooled from an initial temperature of 850°C to its present temperature starting from a fixed time, thus releasing a certain amount of thermal energy. The remaining thermal energy in the system is then derived using the figures from the released thermal energy.

Hydrothermal Convection Systems: The calculation of the thermal energy in hydrothermal convection systems is restricted to systems with mean reservoir temperature greater than or equal to 40°C and depths less than 6 kms for high-temperature hydrothermal systems and 3.2 kms for low-temperature systems.

Hydrothermal convection systems are categorized according to their estimated mean reservoir temperature. These systems can be classified into three main types, namely vapor-dominated and two hot-water systems:

High-Temperature Systems: These are reservoirs with temperatures above 180°C, including both vapor-dominated and hot-water systems. As defined by the NAS, high-temperature systems are restricted to reservoirs with temperatures of greater than 180°C and depths less than 6 kms.

Intermediate-Temperature Systems: These include reservoirs with temperatures greater than or equal to 80°C but less than 180°C and depths less than 6 kms. This includes hot-water dominated as well as steam- dominated systems.

Low-Temperature Waters: The calculation of the thermal energy in low-temperature water systems is restricted to reservoirs with temperature greater than 40°C but less than 80°C, a temperature gradient higher than 25°C/km of depth, and depth of less than 3.2 kms. These systems are primarily used for space heating and agriculture on a local basis.

Geopressured Geothermal: This study estimates the geopressured geothermal energy above 50°C contained in waters of sedimentary rocks to depth of 7 kms in the onshore reservoirs of the Northern Gulf of Mexico basin. This includes the energy contained in the heated water, and does not include the heat content of the reservoir rock or the energy recoverable mechanically from high-pressure fluid. The geopressured resource also includes the energy content of the methane found in the sandstone strata of the Northern Gulf of Mexico Basin.

Table A-1: Geothermal Total Resource Base Calculations

Value:	258,263 BBOE
Source Value:	1.506 x 10^6 Quads high temperature resource (> 80°C)
	314 Quads identified low-temperature hydrothermal resource (40°- 80°C)
	7180 Quads unidentified low-temperatrue resource (40°- 80° C)
	57 x 10^2 Quads geopressured methane
Conversion Formula:	1 Quad = .170 billion barrels of oil

DEFINITIONS AND DERIVATIONS: GEOTHERMAL

Accessible Resources

Derivation of the Accessible Resource Value

The accessible resource value is derived from *Energy in Transition, 1985-2010, Final Report of the Committee on Nuclear and Alternative Energy Systems* (Washington, D.C.: The National Academy of Sciences, 1979), page 402, table 8-2. These estimates are based on U.S. Geological Survey (USGS) Circular 726. However, the NAS figures are recalculated using more conservative assumptions, as described in pages A-1 and A-2. It includes hydrothermal resources, both hot-water and vapor-dominated, above 80°C to a depth of 6 kms; onshore geopressured resources over 50°C to a depth of 6-7 kms (but excluding the heat content of the dissolved natural gas); normal gradient over 80°C; as well as hot dry rock and magmatic energy to a depth of 6 kms. In addition, accessible low-temperature hydrothermal resources are calculated from U.S. Geological Survey Bulletin 892, Marshall J. Reed, ed; *Assessment of Low-Temperature Geothermal Resources of the United States -- 1982* (Arlington, VA: U.S. Geological Survey, 1983), pp. 68-69. The total value of the low-temperature accessible resource of 202.39 x 10^{18} joules is the sum of the western, central, and eastern "accessible resource" hydrothermal convection system values. The value of accessible methane gas within the sandstone strata is taken as 4 percent of the total resource, based on the extraction coefficient found in Garland Samuels *Geopressured Energy Resource Evaluation* (Oak Ridge, TN: Oak Ridge National Laboratory, 1979), pp. 14-16.

The accessible resource value represents the fraction of the total resource base that can be produced at the wellhead under reasonable assumptions of current commercial or near future technology.

Table A-2: Geothermal Accessible Resource Calculations

Value:	3,928 BBOE
Source Value:	22,675 Quads high temperature resource (>80°C)
	228 Quad accessible geopressured methane gas
	202.39 Quads low-temperature resource (40°-80°C)
Conversion Formula:	1 Quad = .17 billion barrels of oil

DEFINITIONS AND DERIVATIONS: GEOTHERMAL

Reserves

Derivation of Reserve Value

The vapor-dominated and high-temperature hydrothermal reserve values were derived from U.S. Geological Survey Circular 790: *Assessment of Geothermal Resources of the United States -- 1978.* (Update of USGS Circular 726, 1975). pp. 44-45, table 4; and pp. 45-57, table 5. These reserve numbers are calculated only for hydrothermal convection systems with temperatures greater than or equal to 150°C and within 3 kms of the surface. The technology needed to extract electricity from other geothermal systems or from deeper formations is not yet economic at current energy prices.

The low-temperature (40°C) hydrothermal reserves of 30.6 x 10^{18} joules are derived from U.S. Geological Survey Circular 892, *Assessment of Low-Temperature Geothermal Resources of the United States--1982* (Arlington, VA: U.S. Geological Survey, 1983), pp 68-69. The value is the sum of the "resource" values that can be recovered over a 30-year period taken from the western, central, and eastern regional hydrothermal convection system estimates.

The 42.5 total BBOE figure is the value of the heat energy of the steam and hot water at the wellhead before it is converted into useful work.

Economic Assumptions:

The reserves are those portions of the geothermal accessible resource that can be produced economically at $18-20/barrel oil prices or that can produce electricity for sale at prices competitive with $18-20/barrel oil.[1,2]

Table A-3: Geothermal Reserve Calculations

Value:	42.5 BBOE
Source Value:	249.9 x 10^{18} Joules
Vapor dominated systems	9.3 x 10^{18} J = 1.58 BBOE
High-temperature hydrothermal systems[2]	210 x 10^{18} J = 35.7 BBOE
Low-temperature hydrothermal systems	30.6 x 10^{18} J = 5.2 BBOE
	3.7% vapor dominated systems 84.0% hot water systems 12.3% low-temperature hydrothermal systems
Total	249.9 x 10^{18} J = 37.3 BBOE
Conversion Formula:	10^{18} Joules = .17 billion barrels of oil
Year Estimated:	1978 and 1982

1. U.S. Geological Survey Circular 790: *Assessment of Geothermal Resources of the United States 1978.* (Update of USGS Circular 726, 1975) pp. 44-45.
2. U.S. Geological Survey Circular 790: *Assessment of Geothermal Resources of the United States 1978* (Update of USGS Circular 726, 1975), pp. 46-57.

DEFINITIONS AND DERIVATIONS: PHOTOCONVERSION

Total Resource Base

Derivation of Total Resource Base Value

The total photoconversion resource is a combination of the total solar energy resource plus a fraction of the existing standing biomass that has grown in the past through the photosynthetic conversion of solar insolation.

Solar Energy

The solar resource base is quantified by calculating the energy in the sunshine that falls on the surface of the U.S. annually. To compute the total solar resource base, the solar energy falling on the surface of the U.S. (solar insolation--an energy density in watts/square meter) must be determined. The solar insolation at any one point is dependent on the site latitude and a time-based integration that considers the time of year, the time of day, and the clarity of the atmosphere at the site. All of these variations are approximated by the use of an average daily insolation for the U.S. and the number of days in one year. In addition, only a portion of the incoming solar insolation is of sufficient intensity to be considered a resource. An energy intensity coefficient is used to adjust the size of average solar insolation. The total solar resource (in kilowatt-hours) is calculated as the product of the average daily solar insolation per square meter, the surface area of the U.S. after urban areas and the land used for or disrupted by coal mining have been removed, and the energy intensity coefficient.

The conversion formulas used -- 3,412 Btu/kWh and 5.8×10^6 Btu/barrel of oil -- are from *Energy Facts - 1986* (Washington, DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0469 86). The quantification of the U.S. solar resource is derived from the following references:

- Phillip G. LeBel, *Energy, Economics, and Technology,* (Baltimore, Maryland: John Hopkins University, 1982).
- *Statistical Abstract of the United States - 1987,* (Washington, DC: U.S. Dept. of Commerce, Bureau of the Census, 1986).
- *Energy Facts-1986,* (Washington, DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-046986, June 1987).
- Utility Data Institute, Washington, D.C., 1985.
- *National Photovoltaics Program Five Year Research Plan, 1987-1991,* (Washington, DC: U.S. Department of Energy, DOE/CH10093-7).
- *National Solar Thermal Technology Program Five Year Research and Development Plan, 1986-1990* (Washington, DC: U.S. Department of Energy, DOE/CE-0160).

Biomass

The values for wood, process wastes, and crop residues are based on *Energy from Biological Processes: Technical and Environmental Analyses,* (Washington DC: Congressional Of-

Table A-4: Photoconversion Total Resource Base Calculations

Value:	178,438 BBOE (5,945 BBOE/Yr)
Photoconversion Total:	= Solar energy value + One time standing biomass harvest = Solar energy value + Wood + MSW + Agricultural
Insolation	$\frac{A \times (B - C - D) \times E \times F \times V \times G}{U} = 178{,}350 \times 10^9$
Wood	$\frac{[H + (I \times J \times K)]}{U} = 76 \times 10^9$
MSW	$\frac{L \times M \times (V)}{U} = 9.7 \times 10^9$
Agricultural	$\frac{\{[N + I + R + (O \times S)] \times T\} + O}{U} = 2 \times 10^9$
Insolation:	A = 4.32 kWh/m^2 average daily insolation
	B = 9.36×10^{12} m^2 total U.S. surface area
	C = 1.597×10^{10} m^2 disrupted coal lands[3]
	D = 18.78×10^{10} m^2 urban and built up areas[4]
	E = .7 energy intensity coefficient[5]
	F = 365 days per year
	G = 3,412 Btu/kWh
Standing Biomass:	H = 430×10^{15} Btu standing forest
	I = 24 million acres of forested recreation/wilderness area
	J = 30 tons woody biomass per clear cut acre
	K = 17×10^6 Btus per ton wood
	L = 208.4×10^6 average tons per year projected output MSW
	M = 9×10^6 Btu per ton MSW
	N = 411.24×10^6 tons annual crop residue production
	O = 91.5×10^{12} Btu agricultural process wastes annually
	P = 52×10^6 short tons average annual beet/cane production
	Q = 340.14×10^6 metric tons, average annual grain production
	R = 137.35×10^6 tons of annual hay production
	S = 1.1 metric tons per short ton
	T = 11×10^6 Btu per ton agricultural crops/residues/wastes
	U = 5.8×10^6 Btu per barrel of oil
	V = 30 years accumulation
Year Estimated:	1988

3. "Coal Mining and Preparation" in *Energy Technologies and the Environment: Environmental Information Handbook* (Germantown, MD: The Aerospace Corporation for U.S. Department of Energy, June 1981) p. 23.
4. *Statistical Abstract of the United States: 1988*, table 323, p. 187.
5. The energy intensity coefficient is a measure of the fraction of the total daily solar insolation that is of a suitable intensity or energy density to be considered a resource which can potentially be commercially exploited. It was derived by using the PV F-chart computer simulation of the solar insolation for Kansas City, MO. Solar insolation values between 5-9 A.M. and 3-7 P.M. were removed leaving a total of 1120.9 kWh/year, or 72.7% of the total, which was rounded off to 70% to establish a conservative energy intensity coefficient.

Table A-5: Average Percentage of Possible Sunshine: Selected Cities

[Average data, except as noted. For period of record through 1975]

	State and Station	Length of record (Years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
AL	Montgomery	25	47	53	58	64	66	65	63	65	63	66	57	50	59
AK	Juneau	30	33	32	37	38	38	34	30	30	25	19	23	20	31
AZ	Phoenix	80	78	80	83	89	93	94	85	85	89	88	83	77	86
AR	Little Rock	32	46	54	57	61	68	73	71	73	68	69	56	48	63
CA	Los Angeles	32	69	72	73	70	66	65	82	83	79	73	74	71	73
	Sacramento	27	45	61	70	80	86	92	97	96	94	84	64	46	79
	San Francisco	38	56	62	69	73	72	73	66	65	72	70	62	53	67
CO	Denver	26	72	71	69	66	64	70	70	72	75	73	65	68	70
CN	Hartford	21	58	57	56	57	58	58	61	63	59	58	46	48	57
DE	Wilmington*	25	50	54	57	57	59	64	63	61	60	60	54	51	53
DC	Washington	27	48	51	55	56	58	64	62	62	62	60	53	47	57
FL	Jacksonville	25	57	61	66	71	69	61	59	58	53	56	61	56	61
	Key West	17	72	76	81	84	80	71	75	76	69	68	72	74	75
GA	Atlanta	41	47	52	57	65	69	67	61	65	63	67	60	50	61
HI	Honolulu	23	63	65	69	67	70	71	74	75	75	67	60	59	68
ID	Boise	35	41	52	63	68	71	75	89	85	82	67	45	39	67
IL	Chicago	33	44	47	51	53	61	67	70	68	63	62	41	38	57
	Peoria	32	45	50	52	55	59	66	68	67	64	63	44	39	57
IN	Indianapolis	32	41	51	51	55	61	68	70	71	66	64	42	39	58
IO	Des Moines	25	51	54	54	55	60	67	71	70	64	64	49	45	59
KS	Wichita	22	59	59	60	62	64	69	74	73	65	66	59	56	65
KY	Louisville	28	41	47	50	55	62	67	66	68	65	63	47	39	57
LA	Shreveport	23	49	54	56	55	64	71	74	72	68	71	62	53	64
ME	Portland	35	55	59	56	56	56	60	64	65	61	58	47	53	58
MD	Baltimore	25	51	55	55	55	57	62	65	62	60	59	51	48	57
MA	Boston	40	54	56	57	56	58	63	66	67	63	61	51	52	59
MI	Detroit	32	32	43	49	52	59	65	70	65	61	56	35	32	54
	Sault Ste. Marie	34	34	46	55	55	56	57	63	58	46	41	23	28	48
MN	Duluth	25	49	54	56	54	55	58	67	61	52	48	34	39	54
	Minneapolis-St. Paul	37	51	57	54	55	58	63	70	67	61	57	39	40	58
MS	Jackson	11	48	55	61	60	63	67	61	62	58	65	54	45	59
MO	Kansas City	3	64	54	61	65	67	72	84	69	51	62	46	54	64
	St. Louis	16	52	51	54	56	62	69	71	66	63	62	49	41	58
MT	Great Falls	33	49	57	67	62	64	65	81	78	68	61	46	46	64
NE	Omaha	40	55	55	55	59	62	68	76	72	67	67	52	48	62
NV	Reno	33	66	68	74	80	81	85	92	93	92	83	70	63	80
NH	Concord	34	52	54	52	53	54	57	62	60	54	54	42	47	54
NJ	Atlantic City	15	49	48	51	53	54	58	60	62	59	57	50	42	54
NM	Albuquerque	36	73	73	74	77	80	83	76	76	80	79	78	72	77
NY	Albany	37	46	51	52	53	55	59	64	61	56	53	36	38	53
	Buffalo	32	34	40	46	52	58	66	69	66	60	53	29	27	53
	New York†	99	50	55	56	59	61	64	65	64	63	61	52	49	59
NC	Charlotte	25	55	59	63	70	69	71	68	70	68	69	63	58	66
	Raleigh	21	55	58	63	64	60	61	61	61	60	63	63	56	60
ND	Bismarck	36	54	56	60	58	63	64	76	73	65	59	44	47	62
OH	Cincinnati	60	41	45	51	55	61	67	68	67	66	59	44	38	57
	Cleveland	34	32	37	44	53	59	65	68	64	60	55	31	26	52
	Columbus	24	37	41	44	52	58	62	64	63	62	58	38	30	53
OK	Oklahoma City	23	59	61	63	63	65	73	75	77	69	68	60	59	67
OR	Portland	26	24	35	42	48	54	51	69	64	60	40	27	20	47
PA	Philadelphia	33	50	53	56	56	57	63	63	63	60	60	53	49	58
	Pittsburgh	23	36	38	45	48	53	60	62	60	60	56	40	30	50
RI	Providence	22	57	56	55	55	57	57	59	59	58	60	49	51	56
SC	Columbia	22	56	59	64	67	66	65	64	65	65	66	64	60	63
SD	Rapid City	33	54	59	61	59	57	60	71	73	67	65	56	54	62
TN	Memphis	25	48	54	57	63	69	73	72	75	69	71	58	49	64
	Nashville	33	40	47	52	59	62	67	64	66	63	64	50	40	57
TX	Amarillo	34	69	68	71	73	73	77	77	78	74	75	73	67	73
	El Paso	33	78	82	85	87	89	89	79	80	82	84	83	78	83
	Houston	6	41	54	48	51	57	63	68	61	57	61	58	69	56
UT	Salt Lake City	38	47	55	64	66	73	78	84	83	84	73	54	44	70
VT	Burlington	32	42	48	52	50	56	60	65	62	55	50	30	33	51
VA	Norfolk	19	57	58	63	66	67	68	65	65	64	60	60	57	63
	Richmond	25	51	54	59	62	64	67	65	64	63	59	56	51	60
WA	Seattle-Tacoma	10	21	42	49	51	58	54	67	65	61	42	27	17	49
	Spokane	27	26	41	53	60	63	65	81	78	71	51	28	20	57
WV	Parkersburg	78	32	36	43	49	56	59	62	60	59	54	37	29	48
WI	Milwaukee	35	44	47	51	54	59	63	70	67	60	57	41	38	56
WY	Cheyenne	40	61	65	64	61	59	65	68	68	69	68	60	59	64
PR	San Juan	20	65	69	74	69	61	57	64	65	59	59	57	56	63

Source: U.S. National Oceanic and Atmospheric Administration. *Comparative Climatic Data*.
* Data not available; figures are for a nearby station.
† City office data.

fice of Technology Assessment, Ballinger Press, 1983), pages 14 and 15 for wood; page 113, table 39 for process wastes; and page 68, table 26 for crop residue values. The conversion value for crop residues is from *State Biomass Statistical Directory*, (Washington, DC: National Wood Energy Association, 1988), table entitled "Summary of U.S. Capacity and Production: Biomass Fuels." MSW figures are from *Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry*, (Washington DC: Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA, PB87-206140, June 1987), page 2-2, table 2-1, using the Frost and Sullivan values with interpolations between projections and averaging to derive the value used here. Heat content of MSW is from *Waste to Energy: A Primer for Utility Decisionmakers*, (Washington DC: Meridian Corporation for the Western Area Power Administration and American Public Power Association, Dec. 1986), frontispiece "Rules of Thumb." Crop statistics for grain are from *Agricultural Statistics, 1986*, (Washington, DC: U.S. Department of Agriculture, 1986), page 1, table 1 for grain values. Beet/cane values are from *Statistical Abstract of the United States, 1987*, (Washington, DC: U.S. Department of Commerce, Bureau of Census, 1987), page 647, table 1155, values derived from average production. The energy value for residues and for crops is based on an average value for dried crop biomass developed from information in *Energy Potential of Texas Crops and Agricultural Residues*, (Texas A&M University System, The Texas Agricultural Experiment Station Center for Energy and Mineral Resources, February 1978) page 10.

The values chosen to represent the total resource are measures of the annual incident solar radiation on the surface area of the U.S. suitable for either photoconversion or photosynthesis. The biomass portion represents energy which is converted through photosynthesis into sustainable production of wood, crops, agricultural residues, and agricultural process wastes. The calculation does include the energy value of standing forest taken in a one-time inclusion of all commercial and noncommercial forest, including park and wildlife areas. Existing MSW resources and a one-time harvest of crops were also included. The MSW figure is the total tonnage of MSW produced over 30 years, times an average Btu value per ton of MSW. The total resource value does include production that is currently devoted to food and other uses. Crops such as cotton, peanuts, etc., that have a Btu value but aren't currently considered in the OTA assessment as having energy value are excluded from the one-time harvest of crops (except for their residues).

These measures were chosen because they come closest to measuring the total resource as it exists today. There is a large potential for expanding the biomass resource through species selection, energy cropping on marginal lands, new conversion techniques, etc. Therefore, defining its outer bounds simply in terms of current existing biomass is inadequate. By considering solar radiation as the ultimate source of the energy embodied in biomass and then calculating the energy value of the solar radiation incident on possible biomass production areas, this analysis defines the absolute boundary for potential biomass energy production if photosynthesis were able to completely convert sunlight into biomass.

Table A-6: Ten Major Agricultural Wastes with Potential to Produce Energy

Wastes	Btu/yr x 10^{12}
Orchard prunings[a]	.30-61
Cotton gin trash[a]	.20-31
Sugarcane bagasse[a]	4-8
Cheese whey[b]	.4-8[c]
Tobacco (burley)[a]	2.3
Rice hulls[a]	2.2
Tomato pumice[b]	1.3-1.8
Potato peel and pulp[b]	1.0-1.1
Walnut shell[a]	0.9
Citrus rag and peel[b]	0.3-1.0
Total	66-117

[a] Suitable for combustion or gasification
[b] Suitable for anaerobic digestion or fermentation
[c] Based on starch content of milk and the volume of cheese production from Agricultural Statistics (Washington, D.C., U.S. Department of Agriculture, 1978)

Source: Office of Technology Assessment, and R. Hodam, *Agricultural Wastes*, Hodam Associates, contractor report for OTA, 1979

Table A-7: Total Crop Residues in the U.S. For 10 Major Crops (1975-'77 average production)

	Acres 10^3 acres	Total residue 10^3 tons
Corn	69,530	171,084
Wheat	68,789	99,890
Soybeans	53,616	67,556
Sorghum	14,714	21,123
Oats	12,831	20,677
Barley	8,772	13,341
Rice	2,515	8,584
Cotton	10,990	3,578
Sugarcane	660	4,700
Rye	715	708
U.S. Total	243,132	411,240

Source: Barber, et al. *The Potential of Producing Energy From Agriculture*, Purdue University for OTA, May 1979

DEFINITIONS AND DERIVATIONS: PHOTOCONVERSION

Accessible Resource

Derivation of Accessible Resource Value

The photoconversion accessible resource is a combination of the accessible solar energy resource combined with a fraction of the existing biomass resources that can be legally captured using currently available technology. Wilderness and parklands have been excluded from the calculations because of legal restrictions barring the exploitation of energy or biomass resources within these protected areas. In addition, 35% of commercial and noncommercial forestland has been excluded, because they are in areas considered too steep to be physically accessible. Urban and built-up suburban areas have likewise been excluded, since this land is judged not to be accessible to widespread solar or biomass energy production. The solar insolation falling on existing croplands has been excluded, but the energy value of the current crops that can be converted to energy and their residues has been included. To prevent double-counting of energy resources, land that is projected to be strip-mined for coal or land that has or will be disturbed by underground mining in the next 30 years have also been excluded from the photoconversion resource. Details of the size of these exclusions are given below in the solar energy section.

Solar Energy

The size of the solar energy accessible resource is calculated using the same methodology as the total resource base, with the exception that land use is considered in quantifying the available surface area of the U.S. for solar collection.

The available land area of the U.S. for solar energy conversion is reduced by the following percentages:

Forest Land	10.5
Cropland	17.7
Parkland	5.1
Wildlife Areas	4.2
SurfaceWater	2.2
Roadways	1.2
Nat'l Defense	1.1
Urban Areas	2.4
Disturbed Coal Lands	0.2
Total:	44.6

Thus, the annual accessible resource for solar energy is calculated in Table A-8.

Biomass

The values for wood, process wastes, and crop residues are based on *Energy from Biological Processes: Technical and Environmental Analyses,* (Washington DC: Congressional Office of Technology Assessment, Ballinger Press, 1983), pages 15, 16, and 23, figure 5 for wood; page 113, table 39 for process wastes; and page 68, table 26 for crop residue values. Estimates of available cropland for expanded biomass production were derived from page 59, table 19. Residential and commercial wood energy capacity, and the conversion value for crop residues are from *State Biomass Statistical Directory,* (Washington, DC: National Wood Energy Association, 1988), table entitled "Summary of U.S. Capacity and Production: Biomass Fuels." MSW figures are from *Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry,* (Washington DC: Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA, PB87-206140, June 1987), page 2-2, table 2-1, Frost and Sullivan values with interpolations between projections and averaging to derive value used

Table A-8: Photoconversion Accessible Resource Calculation

Value:	101,153 BBOE
Photoconversion Total:	= Solar energy value + One time standing biomass harvest = Solar energy value + Wood + MSW + Agricultural
Insolation	$\frac{A \times (B - C) \times D \times E \times F \times R}{Q} = 101{,}010 \times 10^9$
Wood	$\frac{G}{Q} = 76 \times 10^9$
MSW	$\frac{H \times I \times R}{Q} = 11.67 \times 10^9$
Agricultural	$\frac{\{[J + L + N + (M \times O)] \times P \times R\} + (K \times R)}{Q} = 55.93 \times 10^9$
Insolation:	A = 4.32 kWh/m^2 average daily insolation
	B = 9.36×10^{12} m^2 total U.S. surface area
	C = 4.175×10^{12} m^2 (44.6% of total) inaccessible surface area
	D = 0.7 energy intensity coefficient
	E = 3,412 Btu/kWh
	F = 365 days per year
Standing Biomass:	G = 430×10^{15} Btu standing forest
	H = 250.5×10^6 average tons per year projected output MSW
	I = 9×10^6 Btu per ton MSW
	J = 411.24×10^6 tons annual crop residue production
	K = 91.5×10^{12} Btu agricultural process wastes
	L = 52×10^6 short tons average annual beet/cane production
	M = 340.14×10^6 metric tons, average annual grain production
	N = 137.35×10^6 tons of annual hay production
	O = 1.1 metric tons per short ton
	P = 11×10^6 Btu per ton agricultural crops/residues/wastes
	Q = 5.8×10^6 Btu per barrel of oil
	R = 30 years accumulation
Year Estimated:	1988

here. Information on short-rotation intensive culture of woody biomass species was developed from *Short-Rotation Intensive Culture of Woody Crops for Energy: Principles and Practices for the Great Lakes Region,* (Falls Church, VA: Meridian Corporation for the Great Lakes Regional Biomass Program, 1986) pages 38 and 49. The heat content of MSW is from *Waste to Energy: A Primer for Utility Decisionmakers,* (Washington DC: Meridian Corporation for the Western Area Power Administration and American Public Power Association, Dec. 1986) frontispiece "Rules of Thumb." Crop statistics for grain are from *Agricultural Statistics, 1986,* (Washington, DC: U.S. Department of Agriculture, 1986), page 1, table 1 for grain values. Beet/cane values from *Statistical Abstract of the United States, 1987,* (Washington, DC: U.S. Department of Commerce, Bureau of Census, 1987) page 647, table 1155. The energy value for residues and for crops is based on an average value for dried crop biomass developed from information in *Energy Potential of Texas Crops and Agricultural Residues,* (Texas A&M University System, The Texas Agricultural Experiment Station Center for Energy and Mineral Resources, February 1978) page 10.

The value for accessible resources is based on incident solar radiation on the land mass of the U.S., excluding certain areas such as cities, national parks, wilderness, etc., which are unlikely to be available for energy production through either photosynthesis or other photoconversion. Of the total 693 million acre land area of commercial and noncommercial forest, 35% has been excluded because it is too steep for current or future extraction technology. This area represents 10.5% of the total land area of the United States. The accessible resource value also includes a one-time harvest of all commercial and noncommercial forests, all possible energy crops and their associated residues, and the energy value of MSW produced over the 30-year period considered.

The solar insolation falling on existing croplands has been excluded, since it is not considered "accessible" for energy production. This is a large value, estimated to be 30,315 BBOE. Instead, the energy value of crops and crop residues produced on that cropland has been used as a more conservative approach to resource measurement. This annual harvest of crops is restricted to crops that have an identified energy application in direct combustion or ethanol production, though they are not specifically grown for these applications.

This approach to measuring accessible biomass resources was chosen because it comes nearest to defining the amount of energy, before conversion into biomass, that would be technologically accessible if economic constraints were removed. Thus, this biomass is "accessible" in the sense that it is known to exist and technologies are available to harness it. Because biomass is a resource amenable to productivity enhancing innovation and management that can actually expand the absolute amount of the resource, it is difficult to put definite bounds on the resource. However, the figures presented here provide a proxy measure of the accessible resource potential that establishes the broadest bounds which technology could possibly attain.

More than any other energy resource, biomass is capable of significant expansion through improved technology and management. As an indication of the biomass resource's potential, consider the impact of substituting improved plant and tree species specifically developed for biomass energy production for currently available portions of the conventional biomass resource.

Recent research on short-rotation intensive culture (SRIC) tree plantations has demonstrated 300% to 500% improvements in biomass production per acre over natural tree stands. Thus the 2.6 quads of wood energy now harvested annually for the residential and commercial sectors could be at least tripled to 7.8 quads annually if biomass were managed for energy production; the equivalent of 1.3 billion barrels of oil annually, or 30.9 billion barrels of oil over 30 years. Similarly, if the 3 quads of forest growth that are currently surplus to all uses were as productive as an SRIC plantation, an additional 6 quads per year might be extracted from the same land area -- 180 additional quads over 30 years.

There are also 40 quads of unmerchantable timber which could be converted to energy and possibly replaced by improved biomass species. Assuming there are roughly 17 million acres of unmerchantable timber, based on 30 tons to the acre for cleared forest land, improved tree species capable of producing 8 tons per acre would add another 2 quads of energy annually, or 50 quads over 30 years (subtracting 5 years before first harvest of an SRIC plantation).

Similarly, if part of the land now devoted to conventional food crops were used to grow species selected for biomass production, biomass production per acre could easily double, adding another 6 billion barrels of oil equivalent to the biomass resource.

In addition the biomass resource can be expanded by increasing land under cultivation for energy crops. The Office of Technology Assessment in a report on biomass energy estimates 30 million acres of potential cropland could be available for biomass energy production. If this area were planted in forage grasses chosen for biomass productivity to yield 4 tons per acre, approximately 1.3 quads of additional biomass energy could be produced annually. If planted to SRIC tree plantations with a yield of 8 tons per acre, the same area could produce nearly 3 quads annually.

DEFINITIONS AND DERIVATIONS: PHOTOCONVERSION

Reserves

Derivation of Annual Reserve

The photoconversion reserve calculation is a combination of the values derived for thermal and electric solar energy conversion, combined with that portion of the biomass accessible resource that is economical to exploit at $18-20/barrel oil.

Solar Energy

The reserve of solar energy is the subset of the accessible resource that can economically convert or capture energy. The size of this subset is dependent on energy form, i.e. thermal or electric.

Photovoltaic Systems:

Photovoltaics (PV) directly convert solar energy to electricity. At present, PV modules are commercially available for about $5-6/watt in large volume purchases. Installation and balance-of-system costs can routinely double the total system cost.

Present estimates of levelized costs for PV-generated electricity are in the range of $0.30-0.35/kWh for sites with favorable solar conditions. Relative to benchmark energy prices, the reserve of solar energy attributable to photovoltaics is zero.

However, there is approximately 13.27 MWe of installed photovoltaic capacity in the U.S. Therefore, the amount of solar resource converted by these facilities is included as reserves. The values presented here are based on average insolation falling on the surface area of the devices. The surface area of the PV systems in the U.S. was based on information on installed PV capacity as summarized in testimony submitted to the Congressional Subcommittee on Energy and Power by the Solar Energy Industries Association in October 1987. The installed PV capacity figures were converted to square meters of collector surface area by dividing the values by 100 w/m^2, which is the 1000 w/m^2 nominal solar flux used to rate PV device capacity times an assumed 10% cell efficiency. The resulting estimate of device area was multiplied by the average kWh/m^2/day of solar insolation falling on a fixed flat array (angled to maximize solar power density over the course of a year) and then by the number of days in 30 years. This was converted into Btus and then BBOEs. The rated capacity and insolation values for the major PV sites used in the calculations are provided in Table A-9. Insolation data is from Y.P. Gupta and S.K. Young, *Design Handbook for Photovoltaic Power Systems: Simplified Methods for Utility Interconnected Systems,* (Albuquerque, N.M.: Sandia National Laboratories, prepared by Science Application International and JRB Associates, McLean, VA., October, 1981)

Solar Thermal Electric Systems:

The levelized cost of electricity from solar thermal plants is $0.15-0.20/kWh (near term) which is expected to compete with newly constructed intermediate-load coal power plants in some areas in the near future. However, compared to benchmark energy prices, the solar reserve attributable to solar thermal power systems at present is zero.

There are currently, however, three major solar thermal power plants generating electricity in the U.S.: the 10 megawatt central receiver plant at Barstow, California, and two distributed receiver systems generating 134 megawatts in five system segments in Daggett and Warner Springs, California. Therefore, an estimate of the gross solar resource incident on the collectors/reflectors of these solar thermal projects is included in the solar energy reserve estimate.

The gross solar insolation incident on the collector surfaces of solar thermal installations in the U.S. was calculated by multiplying the square meter of reflector area used in major solar thermal projects times average kWh/m^2/day of solar radiation at the nearest point to the site with available insolation data. The insolation input is based on insolation falling on a fixed flat plane angled to maximize solar energy input on the plane over the course of a year given the site's location. Information on the area of reflector involved in solar thermal projects was derived from *Solar Thermal Technology Project Reference Book*, (Washington, DC: U.S. Department of Energy, Solar Thermal Technology Division, November 1987, unpublished). Insolation data are from Y.P. Gupta and S.K. Young, *Design Handbook for Photovoltaic Power Systems: Simplified Methods for Utility Interconnected Systems*, (Albuquerque, N.M.: Sandia National Laboratories, prepared by Science Application International and JRB Associates, McLean, VA, October 1981). Projects' locations, square meters of collector, insolation measurement, and average insolation are provided in Table A-10.

Solar Thermal for Industrial Process Heat:

Solar thermal systems for producing industrial process heat are intended to displace the use of premium fossil fuels such as natural gas, low-sulfur residual oil, and distillate oil.

The current capabilities for solar thermal technology are based on a preliminary design of a 1.5

Table A-9: Installed PV Capacity and Solar Insolation

INSOLATION SITE	DATA SITE	CAPACITY (MW)	Insolation kWh/M^2/DAY	30-Year BOE
Arizona	Phoenix, AZ	.44	6.40	181,449
Arkansas	Ft. Smith, AR	.25	4.29	69,107
California	Daggett, CA	10.39	6.35	4,251,201
District of Columbia	Richmond, VA	.30	4.29	82,928
Florida	Orlando, FL	.07	4.95	22,327
Maryland	Philadelphia, PA	.20	4.05	52,192
Massachusetts	Boston, MA	.98	3.88	245,008
Nebraska	Scotts Bluff, NB	.03	5.14	9,936
New Hampshire	Burlington, VT	.01	4.05	2,610
New Mexico	Albuquerque, NM	.20	6.36	81,961
Ohio	Columbus, OH	.03	3.82	7,384
Oklahoma	Tulsa, OK	.15	4.71	45,523
Oregon	Redmond, OR	.01	4.95	3,190
Texas	Dallas, TX	.05	4.95	15,948
Utah	Salt Lake City, UT	.10	5.68	36,599
Virginia	Richmond, VA	.06	4.29	16,586
TOTAL		13.27		5,123,949

Table A-10: Major Solar Thermal Power Facilities

PROJECT	INSOLATION SITE	COLLECTOR AREA (m^2)	INSOLATION $kWh/m^2/DAY$	30-YEAR BOE
1. Solar One, Barstow, CA	Daggett, CA	72,720	6.35	2,975,432
2. Solar Plant 1 Warner Springs, CA	Daggett, CA	29,688	6.35	1,214,723
3. SEGS I - V Barstow and Warner Springs	Daggett, CA	877,500	6.35	35,904,035
TOTAL		979,908		40,094,190

MW thermal trough process heat plant. The current cost for industrial process heat from such a plant is $30/MBtu.

Relative to the benchmark price of fuels, the solar reserve for the generation of heat from solar thermal industrial process heat systems is found to be zero.

Passive Solar For Space Heating:

Solar gain attributable directly to passive solar design directly displaces premium fuels such as natural gas, electricity, and home heating oil. Assigning incremental costs to passive solar heating and cooling systems is more difficult than other building sector energy systems, since passive solar system elements such as windows serve multiple functions. However, certain passive solar design concepts such as nominal direct gain heating systems require prudent design decisions but do not add to the incremental cost of a dwelling. Because no costs are added to the building, any energy gained is economically competitive with current fossil prices and is therefore an addition to the overall solar energy reserve.

In direct-gain passive designs incorporating south apertures in a ratio of 8% of total floor space, no additional costs for heat-storing materials are required beyond typical construction and finish materials. As most new, single-family detached housing units have 10-12% window-to-floor area ratio (with windows spread to all orientations), an 8% south aperture to floor area ratio can be achieved by relocating (at no cost during design) nonproductive east and west glass to the south wall. This design change will increase net solar gain in the winter months. Similarly for multifamily housing, the optimum south aperture to floor area ratio in low mass direct-gain designs is approximately 5%. Therefore, all the solar insolation striking the vertical south glazing in new residential and multifamily housing is taken in this report to be part of the solar reserve.

To calculate the size of the total contribution of passive solar design to the U.S. solar energy reserve, it has been assumed that all new single family and multifamily buildings constructed over the next 30 years will incorporate these no-cost design changes. It is further assumed that all of the housing stock built in year one will still be standing and receiving solar insolation in year 30. The south-facing glazing will have a positive energy contribution during the heating

Table A-11: Solar Photoconversion Reserve Calculations

Value:	2.989 BBOE
Source Values:	13.27 MW PV Capacity
	979,908 m^2 Solar Thermal Collector Area
	154.98 x 10^6 South Facing Glazing Added Each Year
	16.41 x 10^6 Meters Flat-Plate Collectors
Conversion Formula:	$\frac{(A \times B)}{C} \times \frac{(D \times E \times F)}{G}$ = .0051 x 10^9 Barrels of Oil Equivalent (Photovoltaics)
	$(H \times I) \times \frac{D \times E \times F}{G}$ = 0.04 x 10^9 Barrels of Oil Equivalent (Solar Thermal)
	$\frac{J \times K \times L \times M \times N}{G}$ = 2.684 x 10^9 Barrels of Oil Equivalent (Passive Solar)
	$\frac{O \times P \times A \times D \times E \times F}{G}$ = 0.26 x 10^9 Barrels of Oil Equivalent (Low-Temp. Solar Thermal)
	A = Average kWh/m^2/day at site
	B = Capacity rating of PV plant
	C = 10% efficiency x 1000 w/m^2 solar test flux or 100 w/m^2
	D = 365 days per year
	E = 30 years
	F = 3413 Btus per kWh
	G = 5.8 x 10^6 Btus per barrel oil
	H = Solar thermal collector area
	I = Average kWh/m^2/day at site
	J = South vertical glazing as % of floor area of housing
	K = Average house size
	L = Insolation/ft^2 on vertical plane for October to April
	M = Number of units constructed per year
	N = 291 or 435
	O = Total installed capacity for low/medium temp. solar
	P = 12 hours per day

Table A-12: Biomass Photoconversion Reserve Calculations

Value:		57.7 BBOE
Conversion Formula:		
	Wood	$\frac{(A + B + C) \times D}{E} = 50.7 \times 10^9$
	Crop residues /agr. wastes	$\frac{[(G \times H) + F] \times D}{E} = 5.4 \times 10^9$
	Corn for Ethanol	$\frac{I \times J \times K \times D}{E} = .6 \times 10^9$
	Biogas/ MSW	$\frac{[L + (M \times N \times O)] \times D}{E} = 1.02 \times 10^9$
	Total	$(50.7 \times 10^9) + (5.4 \times 10^9) + (.6 \times 10^9) + (1.02 \times 10^9) = 57.7$ BBOE
		A = 2.6×10^{15} Btu residential and commercial wood energy annually[6]
		B = 4.2×10^{15} Btu logging residue, stand improvement, unused harvest[7]
		C = 3×10^{15} Btu unused forest growth
		D = 30 year resource
		E = 5.8×10^6 Btu per barrel oil
		F = $.19 \times 10^{15}$ Btu current agricultural waste use[7]
		G = 78.2×10^6 tons available crop residue production[7]
		H = 11×10^6 Btu per ton crop residues[6]
		I = 340×10^6 bushels of corn for ethanol[8]
		J = 56 pounds per bushel corn
		K = 6000 Btus per pound of corn
		L = $.009 \times 10^{15}$ Btu biogas and landfill gas production[9]
		M = 57,461 tons per day waste to energy capacity[9]
		N = 365 days per year
		O = 9×10^6 Btu per ton of MSW[6]
Year of Estimate:		Varies with publication date of sources, see footnotes

6. *State Biomass Statistical Directory*, (Washington, DC: National Wood Energy Association, 1988), Table, "Summary of U.S. Capacity and Production: Biomass Fuels" Values corrected by Meridian Corporation to remove typographical and information errors.
7. *Energy from Biological Processes: Technical and Environmental Analyses*, (Washington, DC: Congressional Office of Technology Assessment), pages 23, 24 for wood data, page 68 for crop residue data.
8. *Fuel Ethanol Cost-Effectiveness Study*, (Washington, DC: National Advisory Panel on Cost-Effectiveness of Fuel Ethanol Production, November 1987) page 1-4, Figure 1-2.
9. Donald Klass, *The U.S. Biofuels Industry*, (Chicago, Illinois: Institute of Gas Technology, presentation to the International Renewable Energy Conference, Honolulu, Hawaii, September 18-24, 1988) pages 13, 18, and 21.

season, which is taken to be, on a national average, October to April. Therefore, the passive solar addition to the solar energy reserve is taken to be the sum of the solar energy, during the months of October to April, striking the south glazing of all the detached and multifamily housing stock built for the next 30 years.

To allow for regional variations in insolation levels striking a vertical plane, in new housing starts, and in south-facing glazing levels, the U.S. has been divided into four regions, as shown in Table A-13 below. In the Northeast and North-Central regions, which are primarily heating-dominated areas, the south-facing glazing is taken to be 8% of floor area in detached residential housing and 5% in multifamily dwellings. In the South and Western regions, which have more moderate heating requirements, the south-facing glazing is taken to be 6% of floor area in detached residential housing and 4% in multifamily units.

Calculating the solar energy reserve due to the passive solar gain is unique, in that the building stock with passive solar characteristics will be increasing during the whole 30 years, whereas the reserves of other energy sources will be gradually depleted. To sum the insolation striking the south-facing glazing over a 30-year period, it is

Table A-13: Passive Solar Reserve Determination

	%South Glazing Ratio	Average Floor Space (ft²) [10]	BTUs of Insolation/ft² Vertical Glazing (Oct-April) [11]	Annual Additions to Housing Stock [12] (millions)	10^{12} Btus/ Year
Detached Residential					
Northeast	8%	1650	199020	.315	8.275
North Central	8%	1650	250380	.287	9.485
South	6%	1650	213270	.391	8.255
West	6%	1650	285210	.230	6.494
Annual Total					32.509
Multifamily					
Northeast	5%	900	199020	.07	0.627
North Central	5%	900	250380	.09	1.014
South	4%	900	213270	.12	0.921
West	4%	900	285210	.07	0.719
Annual Total					3.281
GRAND TOTAL					35.790

10. From *Housing Characteristics* (Washington, D.C.: U.S. DOE/EIA, 1984).
11. *Passive Solar Design Handbook* (Los Alamos National Laboratory, 1980).
12. "Housing Economics," *National Association of Home Builders Newsletter*, July-August 1988. Modified to assign units to four regions, based on current census of households.

important to remember that the housing built by the end of year one will receive solar flux for 29 years, those built in year two for 28 years, etc.

Solar Thermal for Domestic and Pool Water Heating:

Based on current costs for flat-plate low-temperature and medium-temperature collectors of $111.50/m^2 and insolation levels of 1000 w/m^2, the cost for delivered energy is more than $8/million Btus. Compared to the reference values for fossil fuels, the reserve value for solar energy for domestic and pool water heating is negligible.

There is a substantial installed low- and medium-temperature solar thermal capacity in the United States. It is assumed that all of the collectors shipped in the United States since 1974 (except for exports) have been installed and are operating successfully. It is further assumed that 1987 shipments are equal to 1986, and that 1985 shipments are equal to 1984. The total U.S. installed area is 152.46 million square feet. The total installed capacity (in square meters) is multiplied by an average annual value of insolation per square meter for the three major solar flat-plate markets (Florida, California, and Puerto Rico) and then multiplied by 30 years. This totals 4.413 x 10^4 Btus, or 0.076 BBOE over a 30-year period.

<u>Biomass:</u>

The values for wood, rice hulls and bagasse are based on *Energy from Biological Processes: Technical and Environmental Analyses,* (Washington DC: Congressional Office of Technology Assessment, Ballinger Press, 1983), page 17, figure 3 for wood growth in excess of use; page 23, figure 5 for wood use for energy; page 68, table 27 for crop residues; and page 113, table 39 for agricultural wastes. Estimates of available cropland for expanded biomass production were derived from page 59, table 19. Forage grass potential production per acre was based on values provided on page 64 and page 67. Residential and commercial wood energy capacity, current agricultural waste use, and the conversion value for crop residues and municipal waste are from *State Biomass Statistical Directory,* (Washington, DC: National Wood Energy Association, 1988), table entitled "Summary of U.S. Capacity and Production: Biomass Fuels." The MSW, landfill gas and biogas values are from Donald Klass, *The U.S. Biofuels Industry,* (Chicago, IL: Institute of Gas Technology, presentation to the International Renewable Energy Conference, Honolulu, Hawaii, September 18-24, 1988) pages 13, 18, and 21. Corn for ethanol is from *Fuel Ethanol Cost-Effectiveness Study,* (Washington, DC: National Advisory Panel on Cost-Effectiveness of Fuel Ethanol Production, November 1987) page 1-4, figure 1-2. The energy content of corn is based on an average value for dried crop biomass developed from information in *Energy Potential of Texas Crops and Agricultural Residues,* (Texas A&M University System, The Texas Agricultural Experiment Station Center for Energy and Mineral Resources, February 1978) page 10. Information on short-rotation intensive culture of woody biomass species was developed from *Short-Rotation Intensive Culture of Woody Crops for Energy: Principles and Practices for the Great Lakes Region,* (Falls Church, VA: Meridian Corporation for the Great Lakes Regional Biomass Program, 1986) pages 38 and 49.

The biomass estimate of reserves includes current capacity and resources that are economically available given current technology and competing uses. The measurement is analogous to coal reserves, which are defined mainly through physical measurements compared to a techno-economic standard. Like lignite, the reserve calculations for biomass do not factor in transportation costs and implicitly assume on-site or near-site utilization. However, large portions of biomass reserves are also committed, either formally or informally, to non-energy uses of biomass such as food, building materials, paper, etc. This is true because the energy value of biomass is not the predominant factor in determining supply or consumption of biomass. Instead, alternative uses and ownership patterns predominate. This is not an argument that other uses of biomass necessarily have a higher value than energy production. It is simply the case that other uses of biomass have established, substantial demands and infrastructure that dominate the market. This is similar to the way the use of petroleum as a chemical feedstock (a higher value use than fuel) is overshadowed by the magnitude and influence of the fuel market. Thus biomass dedicated to other uses is not considered in the reserves, unlike petroleum and natural gas estimates.

For agricultural wastes, biogas and MSW reserve figures, only the energy value of resources used in current facilities is included. Current usage was chosen to represent ready reserves because it is the best available indicator of economically useful supplies. The corn figure represents the quantity of corn converted to ethanol in 1987, with the Btu figure based on the heating value of the corn before conversion. Crop residue production is a value derived by OTA which measures only residues unnecessary to soil conditioning, and which could be gathered using existing technology. Logging residues, stand improvement, and harvested but unused wood represent wood resources that probably could be used economically. Forest growth in excess of demand is also included in reserves in order to include a portion of the forest resource that is really in ready reserve for energy production if an expansion of demand occurred.

Although the biomass reserve is significant even when calculated on the basis of the existing biomass infrastructure and resource inventory, it only captures a very limited portion of the full biomass potential. More than any other energy resource, biomass is capable of significant expansion by improved efficiency in converting sunlight into biomass fuel, by increasing the land area available to cultivate biomass energy, or through a combination of both approaches.

As an indication of the biomass resource's potential, consider the impact of substituting improved plant and tree species specifically developed for biomass energy production for the small portion of the conventional biomass resource that is now available as reserves. Even without any change in the land area devoted to crops or forest, and no displacement of wood or crops that are not currently surplus to the non-energy segments of the agriculture and forest products industries, the biomass energy contribution could be more than doubled.

Recent research on short-rotation intensive culture (SRIC) tree plantations has demonstrated 300% to 500% improvements in biomass production per acre over natural tree stands. Thus the 2.6 quads of wood energy now harvested annually for the residential and commercial sectors could be at least tripled to 7.8 quads annually if biomass were managed for energy production; the equivalent of 1.3 billion barrels of oil annually, or 39 billion barrels of oil over 30 years. There are already 50,000 acres of short-rotation trees being maintained for pulp, paper and energy use. The value of the short-rotation wood used for energy is included in the commercial wood energy estimate.

Similarly, if the 3 quads of forest growth that are currently surplus to all uses were harvested and replaced with SRIC plantations, an additional 6 quads per year might be extracted from the same land area, or 180 additional quads over 30 years.

Using the same approach, if part of the land now devoted to conventional food crops diverted to energy production, such as corn for ethanol, were used to grow species selected for biomass production, biomass production per acre could easily double, adding another 6 billion barrels of oil equivalent to the biomass resource.

In addition the biomass resource can be expanded by increasing land under cultivation for energy crops. The Office of Technology Assessment in a report on biomass energy estimates a potential 30 million acres of potential cropland could be available for biomass energy production. If this area were planted in forage grasses chosen for biomass productivity to yield 4 tons per acre, biomass equivalent to approximately 7 billion barrels of oil could be produced over 30 years. If planted to SRIC tree plantations with a yield of 8 tons per acre, the same area could produce nearly 14 billion barrels of oil equivalent annually. There is also the potential for converting crop or forest land to biomass energy production when and if the economics of biomass energy production improve.

Economic Assumptions

It is assumed that the current biomass use identified is economic given the users' alternatives and financial situations. The exact economic conditions in which they are using biomass are not documented.

DEFINITIONS AND DERIVATIONS: WIND ENERGY

Total Resource Base

Derivation of Total Resource Base Value

The total annual wind energy resource base is quantified by calculating the energy contained in a block of moving air equal to the swept area of wind turbines spaced one rotor diameter apart over the entire surface area of the United States. The methodology is derived from Neil Cherry, *An Estimate of the Known Wind Resource of the United States* (Richland, WA: Pacific Northwest Laboratory, 1981). The wind speed data is taken from *Wind Energy Resource Atlas* (Pacific Northwest Laboratory, Volumes 1-12, PNL-3195-WERA-1/12, 1980-1981) and *Wind Energy Resource Atlas* (Pacific Northwest Laboratory, DOE/CH10093-4, October 1986).

Two factors affect the magnitude of this resource base: (1) the size of the wind turbine rotor, and (2) the speed of the moving air (the wind speed). Rotor diameters of commercially available turbines used for the generation of electricity were used to compute the area of the block of moving air. These turbines range in size from a few hundred kilowatts peak power (rotor diameters of approximately 20 meters) to megawatt-scale turbines (rotor diameters of approximately 100 meters). At a uniform one rotor diameter spacing, machines of a few hundred kilowatts peak power with smaller turbine rotors can be installed closer together than larger turbines with larger rotors. The swept area of the total number of turbines remains relatively the same in either case.

The energy in a mass of moving air is expressed in terms of watts per square meter of surface area. This concept of "wind power density" incorporates in a single number the combined effect of the frequency distribution of wind speed and the dependence of the wind power on air density and the cube of the wind speed. The concept is expressed in terms of "Wind Power Classes" which represent a range of wind power density or equivalent mean wind speed at a specified height above the ground. The specified height used is the hub height of the respective wind turbine that is used. The Wind Power Classes used for calculating the total resource base are Class 2 through Class 7. This range of wind power density is designated as suitable for the generation of electricity by Pacific Northwest Laboratory. At the turbine hub height used for this analysis (60.8 meters), a Wind Power Class 2 or greater includes all regions of the United States where the mean wind speed is greater than 6.09 meters/second (13.6 miles/hour).

To determine the energy content of the total wind resource over the United States, the swept area of the turbines that can be installed in one square kilometer of land area (at one rotor diameter spacing) is multiplied by the total land area of the United States (9,363,100 km^2). This total swept area for the United States is multiplied by the average wind power density of Wind Power Class 2 through Wind Power Class 7 to compute the total power available in the wind. This will provide the *outside limit* of the wind energy potential. It is certain that any attempt to actually place wind turbines closer than 5-7 rotor diameters leads to alteration of the wind resource. The downwind machines do not

Table A-14: Wind Power Density and Energy (By Wind Class)

Wind Power Class	Average Wind Power Density (W/m^2)	Land Area $10^3 km^2$	BBOE/ Year
2	272	1441.9	1832
3	381	1017.3	1,811
4	489	699.1	1,597
5	598	105.4	294
6	761	45.3	161
7	1522	28.4	202
			TOTAL: 5897

Table A-15: Wind Total Resource Base Calculations

Value: 176,910 BBOE (5897 BBOE/Yr)

Conversion Value: Average wind power density for Wind Power Classes 2-7, (W/m^2) x 8760 hours/year x 3412 Btu/kWh ÷ 5.8×10^6 Btu/BOE x number of turbines x swept area of turbine

Conversion Formula:

$$\text{Wind Resource (kilowatts)} = \underbrace{\frac{A}{0.866L^2}}_{\text{Number of Turbines}} \times \underbrace{\frac{\pi D^2}{4}}_{\text{Swept Area}} \times \underbrace{\text{Wind Power Density } (W/m^2)}_{\text{Power Classes 2-7}}$$

Where: D = Turbine Diameter in Meters

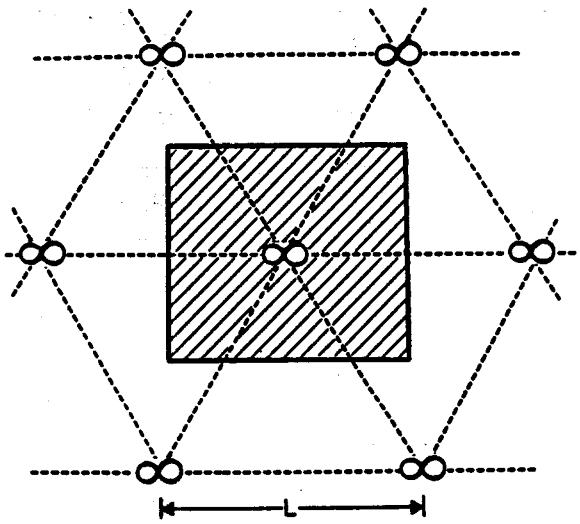
L = D

A = Total U.S. Land Area (Wind Classes 2-7)

Year Estimated: 1988

COMPUTATION OF TOTAL AND ACCESSIBLE WIND RESOURCE

For the Total Resource (Accessible Resource) estimate, it was assumed that all land in the U.S. with Wind Power Class (2 or greater for Total Resource and 3 or greater for Accessible Resource) has MOD 5 turbines installed in a triangular array* with a one (ten by five) diameter spacing.



*The land area associated with each turbine is $L^2 \sin 60° = 0.866L^2$

SWEPT AREA AND TURBINE SPACING FRONT VIEW

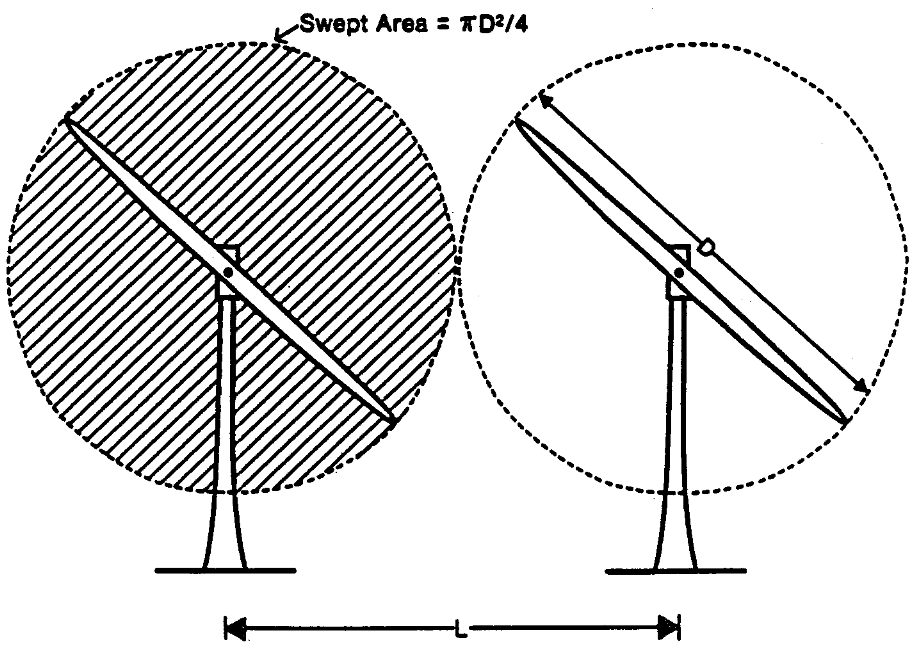


Figure A-1: Computation of Total and Accessible Wind Resources

Table A-16: Average Wind Speed: Selected Cities

(In miles per hour. Airport data, except as noted. For period of record through 1975.)

	State and Station	Length of Record (Years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
AL	Mobile	27	10.8	11.0	11.3	10.7	9.1	7.9	7.1	6.9	8.2	8.4	9.6	10.3	9.3
AK	Juneau	32	8.5	8.8	8.8	8.9	8.4	7.9	7.6	7.6	8.0	9.7	8.7	9.4	8.5
AZ	Phoenix	30	5.1	5.7	6.4	6.8	6.8	6.8	7.1	6.5	6.2	5.7	5.2	5.0	6.1
AR	Little Rock	33	8.9	9.4	10.1	9.6	8.1	7.6	7.0	6.6	7.0	7.0	8.2	8.5	8.2
CA	Los Angeles	27	6.7	7.3	8.0	8.4	8.2	7.8	7.6	7.5	7.1	6.8	6.6	6.6	7.4
	Sacramento	27	8.0	8.0	9.0	9.1	9.4	10.0	9.2	8.7	7.9	6.9	6.5	7.2	8.3
	San Francisco	48	7.1	8.5	10.3	12.1	13.1	13.9	13.6	12.8	11.0	9.2	7.2	6.8	10.5
CO	Denver	27	9.3	9.3	10.0	10.4	9.5	9.1	8.6	8.2	8.2	8.2	8.7	9.0	9.0
CN	Hartford	21	9.6	9.9	10.5	10.7	9.5	8.5	7.9	7.7	7.8	8.2	8.8	9.0	9.0
DE	Wilmington	27	9.7	10.5	11.2	10.5	9.0	8.4	7.7	7.4	7.8	8.1	9.1	9.3	9.1
DC	Washington	27	9.9	10.4	10.9	10.5	9.2	8.7	8.1	8.0	8.2	8.5	9.2	9.4	9.2
FL	Jacksonville	26	8.4	9.6	9.6	9.3	8.8	8.5	7.6	7.4	8.4	8.8	8.3	8.2	8.6
	Miami	26	9.3	10.0	10.3	10.6	9.4	8.2	7.8	7.7	8.2	9.3	9.4	9.0	9.1
GA	Atlanta	37	10.5	11.0	11.0	10.1	8.6	7.9	7.4	7.1	8.0	8.3	9.1	9.8	9.1
HI	Honolulu	26	10.0	10.8	11.4	12.1	12.2	12.9	13.6	13.6	11.7	10.9	11.2	11.1	11.8
ID	Boise	36	8.6	9.4	10.4	10.3	9.6	9.2	8.5	8.3	8.3	8.6	8.7	8.5	9.0
IL	Chicago	33	11.4	11.6	11.9	11.8	10.4	9.4	8.3	8.1	9.0	9.8	11.3	11.1	10.3
	Peoria	32	11.2	11.6	12.3	12.3	10.4	9.1	8.0	7.8	8.8	9.5	11.2	10.9	10.3
IN	Indianapolis	27	11.1	11.2	11.9	11.5	9.7	8.5	7.4	7.2	8.1	8.9	10.7	10.5	8.7
IO	Des Moines	26	11.7	11.8	13.1	13.4	11.6	10.5	9.0	8.8	9.6	10.6	11.7	11.5	11.1
KS	Wichita	22	12.5	13.1	14.5	14.7	13.1	12.6	11.3	11.3	11.7	12.3	12.4	12.2	12.6
KY	Louisville	28	9.6	9.8	10.4	10.1	8.1	7.4	6.7	6.4	6.8	7.1	9.0	9.3	8.4
LA	New Orleans	27	9.5	10.1	10.3	9.8	8.3	7.0	6.3	6.1	7.5	7.6	8.9	9.2	8.4
ME	Portland	35	9.2	9.6	10.1	10.0	9.2	8.2	7.7	7.6	7.8	8.5	8.8	9.0	8.8
MD	Baltimore	25	9.9	10.7	11.2	11.0	9.6	8.7	8.2	8.2	8.4	8.9	9.5	9.4	9.5
MA	Boston	18	14.2	14.2	14.0	13.4	12.2	11.3	10.8	10.8	11.4	12.2	13.1	13.8	12.6
MI	Detroit	41	11.6	11.5	11.5	11.1	9.9	9.1	8.3	8.1	8.9	9.5	11.3	11.3	10.2
	Sault Ste. Marie	34	10.1	10.0	10.5	10.8	10.2	8.9	8.3	8.1	9.0	9.6	10.2	10.0	9.6
MN	Duluth	26	12.1	11.9	12.1	13.3	12.3	10.8	9.9	9.8	10.7	11.5	12.2	11.4	11.5
	Minneapolis-St. Paul	37	10.4	10.6	11.3	12.4	11.4	10.5	9.3	9.1	9.9	10.5	11.0	10.3	10.6
MS	Jackson	12	9.1	9.0	9.6	9.1	7.3	6.4	6.1	5.8	6.7	6.5	7.9	8.7	7.7
MO	Kansas City	3	10.7	11.7	11.7	11.8	9.6	9.4	7.9	8.6	8.3	10.0	11.6	10.9	10.2
	St. Louis	26	10.3	10.8	11.8	11.4	9.4	8.6	7.6	7.4	7.9	8.5	9.9	10.2	9.5
MT	Great Falls	34	15.9	14.8	13.5	13.2	11.5	11.4	10.3	10.5	11.6	13.8	15.0	16.1	13.1
NE	Omaha	40	11.1	11.5	12.7	13.2	11.4	10.5	9.1	9.2	9.7	10.1	11.2	10.8	10.9
NV	Reno	33	6.0	6.1	7.6	8.0	7.6	7.2	6.6	6.2	5.4	5.3	5.3	5.1	6.4
NH	Concord	34	7.3	7.9	8.2	7.9	7.0	6.3	5.6	5.3	5.4	5.9	6.5	7.0	6.7
NJ	Atlantic City	17	11.8	12.2	12.5	12.3	10.8	9.7	9.1	8.7	9.3	9.7	11.1	11.3	10.7
NM	Albuquerque	36	8.0	8.8	10.0	10.9	10.5	10.0	9.1	8.1	8.5	8.3	7.8	7.7	9.0
NY	Albany	37	9.8	10.3	10.6	10.5	9.1	8.1	7.3	6.9	7.3	7.9	8.9	9.1	8.8
	Buffalo	36	14.5	14.1	13.8	13.0	11.8	11.3	10.6	10.1	10.6	11.4	13.0	13.4	12.3
	New York*	56	10.7	10.9	11.1	10.5	8.8	8.1	7.7	7.7	8.1	9.0	9.9	10.4	9.4
NC	Charlotte	26	8.0	8.5	9.0	9.1	7.6	6.9	6.6	6.5	6.8	7.1	7.3	7.4	7.6
	Raleigh	26	8.7	9.2	9.6	9.4	7.9	7.1	6.8	6.5	7.0	7.3	7.9	8.2	8.0
ND	Bismarck	36	10.1	10.1	11.3	12.6	12.2	11.0	9.6	9.9	10.4	10.2	10.4	9.6	10.6
OH	Cincinnati	43	8.3	8.4	9.0	8.4	6.7	6.4	5.2	5.1	5.4	6.1	7.7	7.9	7.1
	Cleveland	34	12.5	12.3	12.5	11.9	10.4	9.5	8.7	8.4	9.1	10.0	12.1	12.3	10.8
	Columbus	26	10.3	10.5	10.8	10.2	8.6	7.5	6.7	6.4	6.8	7.6	9.5	9.8	8.7
OK	Oklahoma City	27	13.3	13.7	15.1	15.1	13.3	12.7	11.3	10.8	11.5	12.2	12.7	12.8	12.9
OR	Portland	27	10.1	8.8	8.3	7.2	6.9	6.9	7.4	7.0	6.4	6.4	8.4	9.6	7.8
PA	Philadelphia	35	10.3	11.1	11.5	11.1	9.7	8.8	8.1	7.9	8.3	8.9	9.7	10.1	9.6
	Pittsburgh	23	10.7	11.0	11.1	10.8	9.3	8.2	7.5	7.3	7.7	8.4	10.1	10.5	9.4
RI	Providence	22	11.5	11.9	12.4	12.5	11.1	10.1	9.5	9.5	9.6	9.7	10.6	11.0	10.8
SC	Columbia	27	7.1	7.7	8.4	8.5	7.0	6.7	6.5	6.0	6.2	6.1	6.5	6.6	6.9
SD	Sioux Falls	27	11.0	11.2	12.6	13.6	12.1	10.7	9.7	9.8	10.3	10.8	11.6	10.7	11.2
TN	Memphis	27	10.6	10.6	11.3	10.8	9.0	8.1	7.6	7.1	7.6	7.8	9.4	10.1	9.2
	Nashville	34	9.2	9.4	10.0	9.6	7.6	7.0	6.4	6.1	6.4	6.5	8.4	8.8	7.9
TX	Dallas	22	11.5	12.3	13.3	13.1	11.4	11.0	9.7	9.3	9.7	9.9	10.9	11.2	11.1
	El Paso	33	9.2	10.0	11.9	12.0	11.0	10.1	8.9	8.4	8.4	8.2	8.6	8.6	9.6
	Houston	6	8.1	8.6	9.4	9.5	7.8	7.3	6.3	5.1	6.7	6.3	7.9	7.7	7.6
UT	Salt Lake City	46	7.7	8.2	9.2	9.5	9.3	9.3	9.4	9.5	9.0	8.5	7.8	7.5	8.7
VT	Burlington	32	9.7	9.4	9.3	9.3	8.8	8.2	7.8	7.4	8.0	8.6	9.5	9.7	8.8
VA	Norfolk	27	11.7	12.1	12.5	11.9	10.3	9.6	8.8	8.7	9.6	10.4	10.7	11.1	10.6
	Richmond	27	7.9	8.6	9.0	8.9	7.8	7.2	6.7	6.3	6.6	6.8	7.4	7.5	7.6
WA	Seattle-Tacoma	27	10.4	9.9	10.2	9.8	9.2	9.0	8.4	8.1	8.3	8.9	9.4	10.0	9.3
	Spokane	28	9.0	9.1	9.5	9.7	8.8	8.8	8.2	8.0	8.1	8.2	8.3	8.8	8.7
WV	Charleston	28	7.6	7.9	8.6	7.9	6.3	5.6	5.0	4.5	4.8	5.3	6.9	7.2	6.5
WI	Milwaukee	35	12.9	12.8	13.2	13.2	12.0	10.5	9.7	9.6	10.7	11.5	12.8	12.5	11.8
WY	Cheyenne	18	15.8	15.3	14.9	15.0	13.1	11.8	10.5	10.8	11.5	12.5	13.8	15.0	13.3
PR	San Juan	20	9.3	9.3	9.7	9.4	8.7	9.0	9.9	9.2	7.6	6.9	7.7	8.9	8.8

Source: U.S. National Oceanic and Atmospheric Administration. *Comparative Climatic Data.*
* City office data.

receive the full force of the wind energy, since that is not sufficient space for the wind to be replenished from above the rotor's swept area.

The total annual energy available is obtained by multiplying the total power by 8,760 hours in one year. The total available energy is converted to billions of barrels of oil equivalent (BBOE) by multiplying the available energy by 3,412 Btu/kWh and dividing by 5.8×10^6 Btu/barrel of oil.

DEFINITIONS AND DERIVATIONS: WIND ENERGY

Accessible Resources

Derivation of Accessible Resource

The accessible wind resource base is quantified using the same methodology as the total wind resource base (see Table A-15). There are four computational differences: (1) the turbine spacing in a row is 10 rotor diameters; (2) the spacing between turbine rows is 5 rotor diameters; (3) only Wind Power Classes 3-7 are included; and (4) land use is taken into consideration.

A turbine spacing of 10 rotor diameters in a row and 5 diameters between rows, installed in a triangular array as shown in Figure A-1, is the spacing used to minimize blockage of the wind and turbulence from turbines upwind. This spacing is more open than that used in many large windfarms currently installed in the United States, but recent research has shown considerable downwind wakes from existing windfarm installations. The result is a reduction by a factor of 50 of the total wind resource due to the wider spacing of turbines. Wind Power Classes 3-7 (wind speeds of 6.94 meters/second or greater at a hub height of 60.8 meters) are used, since these can be exploited by current commercial wind turbines or turbines soon to become commercial.

The computation of wind power density from the above references takes into account the complicated and difficult process of quantifying the relationship between land-surface area and land-surface form. For example, land features such as steep mountain cliffs are considered in the computation of available land area for a given wind power class. However, the land use is not accounted for in these calculations. To compute the accessible wind resource, the land area of the U.S. is reduced by that already occupied by competing renewable resources (forests and croplands), areas proscribed to energy development (parklands and wilderness areas), national defense areas, roadways, urban areas, and areas covered by surface water. This process tends to underestimate slightly the wind accessible

Table A-17: Wind Energy Accessible Resource Calculations

Value:	870 BBOE (29 BBOE/YR)
Conversion Value:	Same as total resource base except for a reduced number of turbines
Conversion Formula:	

$$\text{Wind Resource (kilowatts)} = \underbrace{\frac{A}{0.866L^2}}_{\text{Number of Turbines}} \times \underbrace{\frac{\pi D^2}{4}}_{\text{Swept Area}} \times \underbrace{\text{WIND POWER DENSITY (W/m}^2\text{)}}_{\text{Wind Power Classes}}$$

WHERE:	D = Turbine Diameter in Meters
	L = 10D in a row and 5D between rows
	A = 0.361 x Total U.S. Land Area (Wind Classes 3-7)
Year Estimated:	1988

resource, since exploiting the wind resource for the stronger wind classes (particularly Classes 6 and 7) may be a more productive use of land than forestry and crop production. It is also likely that some wind development can take place without displacing the production of these other renewable resources. The result is an additional average reduction of the available wind resource by approximately 64% across all wind power classes because of the smaller available land area.

The available land area of the U.S. for wind energy conversion is reduced by the following percentages:

Forestland	30.0
Crop Land	17.7
Parkland	5.1
Wildlife Areas	4.2
Surface Water	2.2
Roadways	1.2
Nat'l Defense	1.1
Urban Areas	2.4
Total:	63.9

DEFINITIONS AND DERIVATIONS: WIND ENERGY

Reserves

Derivation of Reserve Values

The wind energy reserve is a small subset of the accessible wind resource. It includes only that portion of the resource that is economical at current energy prices. Specifically, it is that fraction of the accessible resource that can produce electric power for a price equal to or less than coal at a price of $26/ton of $1.16/MBtus. This is equivalent to the price of electricity of $0.023/kWh. Present cost estimates for wind-generated electricity is $0.08/kWh for favorable sites. Relative to the benchmark coal energy price, the wind reserve is negligible.

However, 16,438 wind turbines in the United States produced 1.7×10^9 kWhs of electrical energy in 1987. The wind resource that produced this electrical energy, using an average 35% efficiency of current wind turbines, is 4.86×10^9 kWhs/year.

- Cherry, Neil, *An Estimate of the Known Wind Resource of the United States,* (Pacific Northwest Laboratory, 1981).
- *Wind Energy Resource Atlas* (Pacific Northwest Laboratory, Volumes 1-12, PNL-3195-WERA-1/12, 1980-1981).
- *Wind Energy Resource Atlas of the United States* (Pacific Northwest Laboratory, DOE/CH 10093-4, October 1986).
- *Wind Energy Weekly*

Table A-18: Wind Energy Reserve Calculations

Value:	0.85 BBOE
Conversion Value:	1.7×10^{11} kWh = 1 BBOE
Conversion Formula:	
Wind Reserve (kWh)	$= A \times \frac{1}{B} \times C$
Where:	A = annual wind turbine electrical energy output
	B = efficiency of wind turbine energy conversion
	C = 30 years
	$1.7 \times 10^9 \text{ kWh} \times \frac{1}{0.35} \times 30 = 1.45 \times 10^{11}$ kWh

DEFINITIONS AND DERIVATIONS: SHALE OIL

Total Resource Base

Derivation of Total Resource Base Value

The total resource value was derived from *U.S. Mineral Resources, Geological Survey Professional Paper 820,* U.S. Department of the Interior, U.S. Geological Survey, 1973, table 95, page 500. This data have not been updated by the USGS since that time, although additional investigations of some deposits have been initiated. More recent examinations (John Ward Smith, 1980) have focused only on the major formations, thereby producing a total resource calculation that is much smaller (2,000-10,000 BBOE).

The sum of identified, hypothetical and speculative resources was chosen to represent the total resource base of shale oil. This is a measure only of the oil that can be extracted. Energy can also be extracted from the combustible gas in the retorting process or from char left in retorted shale. Eastern shales yield more gas and less oil, but this difference is not expected to change the overall size of the total resource.

Identified resources are explained in the following discussion of accessible resources of shale oil. They account for 2,000 BBOE and are located primarily in the Green River and Phosphoria formations and in the eastern oil shales.

Hypothetical resources add undiscovered mineral deposits, whether of subeconomic or recoverable grade that are geologically predictable as existing in known districts. Hypothetical resources are resources in possible extensions of identified deposits or in nearby deposits, in which the approximate magnitude of the oil shale deposit is known, but whose oil yield is inferred from scant evidence.

Speculative resources add undiscovered mineral deposits, whether of recoverable or subeconomic grade, that may exist in unknown districts or in unrecognized or unconventional forms. Speculative resources account for 23,600 BBOE or over 85% of the total resource base.

There are an estimated 2.4 million cubic miles of sedimentary rock in the U.S. to a depth of 20,000 feet, 0.5% of which is estimated to be shale containing 10-100 gallons of oil per ton, which results in an estimated 28 trillion barrels of oil.

Table A-19: Shale Oil Total Resource Base Calculations

Value:	27,518 BBOE
Source Value:	27,518 x 10^9 barrels oil
Conversion Formula:	NA
Year Estimated:	1973

DEFINITIONS AND DERIVATIONS: SHALE OIL

Accessible Resource

Derivation of Accessible Resource Value

The source value was derived from *U.S. Mineral Resources, Geological Survey Professional Paper 820,* U.S. Department of the Interior, U.S. Geological Survey, 1973, table 95, page 500.

The USGS category of identified resources was chosen to represent accessible resources. Identified resources are defined as specific, identified mineral deposits that may or may not be evaluated as to extent and grade, and whose contained minerals may or may not be profitably recoverable with existing technology and economic conditions. There are sufficient data available to establish the magnitude and oil yield within reasonable limits. All resources with a possible yield between 10-100 gallons per ton were included.

Table A-20: Shale Oil Accessible Resource Base Calculation

Value:	2018 BBOE
Source Value:	2018 x 10^9 barrels of oil equivalent
Conversion Formula:	NA
Year Estimated:	1973

Table A-21: Shale Oil Resources of the U.S.

Billions of Barrels, By Grade (Oil Yield) of Oil Shale

Deposit	Identified[1] 25-100 gal/ton4	Identified[1] 10-25 gal/ton	Hypothetical[2] 25-100 gal/ton	Hypothetical[2] 10-25 gal/ton	Speculative[3] 25-100 gal/ton	Speculative[3] 10-25 gal/ton
Green River Formation, Colorado, Utah and Wyoming	418	1,400	50	600	---	---
Chattanooga Shale and equivalent formations, Central and Eastern United States	---	200	---	800	---	---
Marine shale, Alaska	Small	Small	250	200	---	---
Other shale deposits	---	Small	NE	NE	600	23,000
Total	418	1,600	300	1,600	600	23,000

N/E - not estimated

(All resource figures except those for the Green River Formation are adapted from Duncan and Swanson, 1965, table 2)

1 Identified resources: Specific, identified mineral deposits that may or may not be evaluated as to extent and grade, and whose contained minerals may or may not be profitably recoverable with existing technology and economic conditions.

2 Hypothetical resources: Undiscovered mineral deposits, whether of recoverable or sub-economic grade, that are geologically predictable as existing in known districts.

3 Speculative resources: Undiscovered mineral deposits, whether of recoverable or sub-economic grade, that may exist in unknown districts or in unrecognized or unconventional form.

4 The 25-100 gal/ton category is considered virtually equivalent to the category "average of 30 or more gallons per ton."

DEFINITIONS AND DERIVATIONS: SHALE OIL

Reserves

Derivation of Reserve Value

The conclusion that there are no economic reserves of shale oil is based on the National Resource Council in *Energy in Transition, 1985-2010, Final Report of the Committee on Nuclear and Alternative Energy Systems* (Washington, DC: National Academy of Sciences, 1979), pages 138-139.

There are currently high environmental costs, especially in terms of water demand, and high extraction and processing costs which render shale oil extraction and use non-viable under current conditions. One significant shale oil extraction operation is being conducted by the Unocal Corporation in Colorado; this 10,000 barrel-per-day facility is run on an experimental basis, and thus output is a function of the operators' experimentation with equipment and feedstocks.

These figures are based on data on shale oil extraction in *Technology Characterizations: Environmental Information Handbook*, (Washington, DC: U.S. Department of Energy Office of Environmental Programs, 1981), pages 31-37.

Table A-22: Shale Oil Reserve Calculations

Value	0.11 BBOE
Source Value:	10,000 barrels per day, shale oil production capacity
Conversion Formula:	A x B = 0.11 x 10^9 barrels of oil
	A = 10,000 barrels per day shale oil capacity x 365 days/year
	B = 30 years
Year Estimated:	See above

DEFINITIONS AND DERIVATIONS: COAL

Total Resource Base

Derivation of the Total Resource Base Value

The total resource base value is derived from *Coal Resources of the United States, January 1, 1974* (Washington, DC: U.S. Department of the Interior, U.S. Geological Survey, Geological Survey Bulletin 1412, 1975) page 15, table 3. This is the most current USGS systematic coal resource survey, although data on local fields and production are being continuously updated.

The estimated total identified and hypothetical resources remaining in the ground was chosen to represent the total resource base because it removes technical restraints on the identification and accessibility of the resource, and thus comes closest to capturing the total resource as currently estimated. It includes beds of bituminous coal and anthracite 14 inches thick or more, and subbituminous coal and lignite 30 inches thick or more, to a depth of 6,000 feet. The estimates are based on measurements, mapping, and inferences and extrapolations of existing data. Thus there is a theoretical basis for assuming the existence of the total reported resource, but it is much more tenuous than for accessible resources.

Table A-23: Coal Total Resource Base Calculations

Value:	15,079 BBOE
Source Value:	3,968,264 x 10^6 short tons, total remaining coal resources
Conversion Formula:	A x B = 15,079 x 10^9 barrels of oil
	A = 3,968,264 x 10^6 short tons, total remaining coal resources
	B = 3.8 barrels of oil per ton of coal
Year Estimated:	1974

DEFINITIONS AND DERIVATIONS: COAL

Accessible Resource

Derivation of Accessible Resource Value

The accessible resource value is derived from *Coal Resources of the United States, January 1, 1974* (Washington, DC: U.S. Department of the Interior, U.S. Geological Survey, Geological Survey Bulletin 1412, 1975) page 15, table 3.

Total identified resources were selected to represent accessible resources because they are based mostly on factual information. The data used to identify the resources included state geological surveys, company map and drill records, and drill records of petroleum exploration companies. It includes anthracite and bituminous coal in beds 14 inches or more thick, and all subbituminous coal and lignite in beds 30 or more inches thick, down to 3,000 feet. Location, rank, quality and quantity are also estimated before resources are included in the identified category. Thus the identified resource fits the definition of technically accessible, whether or not it is economically viable.

The USGS normally uses a more restrictive definition, that of the demonstrated resource, when developing an availability assessment. This would include only coal in beds 28 inches or greater in thickness and within 1,000 feet of the surface. USGS also normally includes other factors that limit physical accessibility: required pillars around oil and gas wells, pillars between mines, proximity of coal beds to one another, etc. There are also local environmental and legal restrictions which further reduce the physically accessible fraction of the total resource base. The total identified resource is used here because it is more consistent with the definitions used for other energy sources.

Table A-24: Coal Accessible Resource Base Calculations

Value:	6,577 BBOE
Source Value:	1,730,919 x 10^6 short tons, remaining identified coal
Conversion Formula:	A x B = 6577 x 10^9 barrels of oil
	A = 1,730,919 x 10^6 short tons, remaining identified coal
	B = 3.8 barrels of oil per ton of coal
Year Estimated:	1974

Table A-25: Total Estimated Remaining Coal Resources of the U.S., January 1, 1974

[In millions (10⁶) of short tons. Estimates include beds of bituminous coal and anthracite generally 14 in. or more thick, and beds of subbituminous coal and lignite generally 2½ ft or more thick, to overburden depths of 3,000 and 6,000 ft. Figures are for resources in the ground]

State	Overburden 0–3,000 feet							Overburden 3,000–6,000 feet	Overburden 0–6,000 feet
	Remaining identified resources, Jan. 1, 1974 (from table 2)								
	Bituminous coal	Subbituminous coal	Lignite	Anthracite and semianthracite	Total	Estimated hypothetical resources in unmapped and unexplored areas[1]	Estimated total identified and hypothetical resources remaining in the ground	Estimated additional hypothetical resources in deeper structural basins[1]	Estimated total identified and hypothetical resources remaining in the ground
Alabama	13,262	0	2,000	0	15,262	20,000	35,262	6,000	41,262
Alaska	19,413	110,666	([2])	([3])	130,079	130,000	260,079	5,000	265,079
Arizona	[4]21,234	([4])	0	0	21,234	0	21,234	0	21,234
Arkansas	1,638	0	350	428	2,416	[8]4,000	6,416	0	6,416
Colorado	109,117	19,733	20	78	128,948	161,272	290,220	143,991	434,211
Georgia	24	0	0	0	24	60	84	0	84
Illinois	146,001	0	0	0	146,001	100,000	246,001	0	246,001
Indiana	32,868	0	0	0	32,868	22,000	54,868	0	54,868
Iowa	6,505	0	0	0	6,505	14,000	20,505	0	20,505
Kansas	18,668	0	([6])	0	18,668	4,000	22,668	0	22,668
Kentucky:									
Eastern	28,226	0	0	0	28,226	24,000	52,226	0	52,226
Western	36,120	0	0	0	36,120	28,000	64,120	0	64,120
Maryland	1,152	0	0	0	1,152	400	1,552	0	1,552
Michigan	205	0	0	0	205	500	705	0	705
Missouri	31,184	0	0	0	31,184	17,489	48,673	0	48,673
Montana	2,299	176,819	112,521	0	291,639	180,000	471,639	0	471,639
New Mexico	10,748	50,639	0	4	61,391	[7]65,556	126,947	74,000	200,947
North Carolina	110	0	0	0	110	20	130	5	135
North Dakota	0	0	350,602	0	350,602	180,000	530,602	0	530,602
Ohio	41,166	0	0	0	41,166	6,152	47,318	0	47,318
Oklahoma	7,117	0	([6])	0	7,117	15,000	22,117	[9]5,000	27,117
Oregon	50	284	0	0	334	100	434	0	434
Pennsylvania	63,940	0	0	18,812	82,752	[9]4,000	86,752	[10]3,600	90,352
South Dakota	0	0	2,185	0	2,185	1,000	3,185	0	3,185
Tennessee	2,530	0	0	0	2,530	2,000	4,530	0	4,530
Texas	6,048	0	10,293	0	16,341	[11]112,100	128,441	([11])	128,441
Utah	[12]23,186	173	0	0	23,359	[13]22,000	45,359	35,000	80,359
Virginia	9,216	0	0	335	9,551	5,000	14,551	100	14,651
Washington	1,867	4,180	117	5	6,169	30,000	36,169	15,000	51,169
West Virginia	100,150	0	0	0	100,150	0	100,150	0	100,150
Wyoming	12,703	123,240	([5])	0	135,943	700,000	835,943	100,000	935,943
Other States[14]	610	[15]32	[16]46	0	688	1,000	1,688	0	1,688
Total	747,357	486,706	478,134	19,662	1,730,919	1,849,649	3,580,568	387,696	3,968,264

[1] Source of estimates: Alabama, W. C. Culbertson; Arkansas, B. R. Haley; Colorado, Holt (1975); Illinois, M. E. Hopkins and J. A. Simon; Indiana, C. E. Wier; Iowa, E. R. Landis; Kentucky, K. J. Englund; Missouri, Robertson (1971, 1973); Montana, R. E. Matson; New Mexico, Fassett and Hinds (1971); North Dakota, E. A. Brant; Ohio, H. R. Collins and D. O. Johnson from data in Struble and others (1971); Oklahoma, S. A. Friedman; Oregon, R. S. Mason; Pennsylvania anthracite, Arndt and others (1968); Pennsylvania bituminous coal, W. E. Edmunds; Tennessee, E. T. Luther; Texas lignite, Kaiser (1974); Virginia, K. J. Englund; Utah, H. H. Doelling; Washington, H. M. Beikman; Wyoming, N. M. Denson, G. B. Glass, W. R. Keefer, and E. M. Schell; remaining States, by the author.

[2] Small resources of lignite included under subbituminous coal.

[3] Small resources of anthracite in the Bering River field believed to be too badly crushed and faulted to be economically recoverable (Barnes, 1951).

[4] All tonnage is in the Black Mesa field. Some coal in the Dakota Formation is near the rank boundary between bituminous and subbituminous coal. Does not include small resources of thin and impure coal in the Deer Creek and Pinedale fields.

[5] Lignite.

[6] Small resources of lignite in western Kansas and western Oklahoma in beds generally less than 30 in. thick.

[7] After Fassett and Hinds (1971), who reported 85,222 million tons "inferred by zone" to an overburden depth of 3,000 ft in the Fruitland Formation of the San Juan basin. Their figure has been reduced by 19,666 million tons as reported by Read and others (1950) for coal in all categories also to an overburden depth of 3,000 ft in the Fruitland Formation of the San Juan basin. The figure of Read and others was based on measured surface sections and is included in the identified tonnage recorded in table 2.

[8] Includes 100 million tons inferred below 3,000 ft.

[9] Bituminous coal.

[10] Anthracite.

[11] Lignite, overburden 200–5,000 ft; identified and hypothetical resources undifferentiated. All beds assumed to be 2 ft thick, although many are thicker.

[12] Excludes coal in beds less than 4 ft thick.

[13] Includes coal in beds 14 in. or more thick, of which 15,000 million tons is in beds 4 ft or more thick.

[14] California, Idaho, Nebraska, and Nevada.

[15] California and Idaho.

[16] California, Idaho, Louisiana, and Mississippi.

Source: *Coal Resources of the United States*, January 1, 1974, Geological Survey Bulletin 1412, 1975

Table A-26: Demonstrated Reserve Base of Coal in the U.S. (Million Short Tons)

Area and Potential Method of Mining	Anthracite		Bituminous		Subbituminous		Lignite		Total	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
States East of the Mississippi River	7,196.6	7,193.2	208,303.4	207,354.7	-	-	1,083.0	1,083.0	216,583.0	215,631.0
Underground Minable	7,083.6	7,082.8	169,765.6	169,090.0	-	-	-	-	176,849 2	176,172 8
Surface Minable	112.9	110.4	38,537.8	38,264.7	-	-	1,083.0	1,083.0	39,733.8	39,458.2
States West of the Mississippi River	131.9	131.9	35,538.4	35,448.5	180,735.6	180,498.6	44,330.0	44,234.9	260,735.8	260,313.8
Underground Minable	116.4	116.4	26,575.6	26,534.1	118,812.5	118,812.5	-	-	145,504 5	145,462.9
Surface Minable	15.5	15.5	8,962.8	8,914.4	61,923.2	61,686.2	44,330.0	44,234 9	115,231.4	114,850 9
U.S. Total	7,328.4	7,325.1	243,841.8	242,803.2	180,735.6	180,498.6	45,413.0	45,317.9	477,318.8	475,944.8
Underground Minable	7,200.0	7,199.2	196,341.2	195,624.1	118,812.5	118,812.5	-	-	322,353.6	321,635 7
Surface Minable	128.4	125.9	47,500.6	47,179.1	61,923.2	61,686.2	45,413.0	45,317.9	154,965 1	154 309 1

Note: Total may not equal sum of components because of independent rounding. Data are reported as of the first day of the year.
Source: State geological and mineral resource surveys, and other geological reports.

Source: *Coal Production 1986*, Energy Information Administration, 1986

Table A-27: Demonstrated Reserve Base of Coal in the U.S. By Rank (Million Short Tons)

Coal Producing Region and State	Anthracite		Bituminous		Subbituminous		Lignite		Total	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
Appalachian Total	7,196.6	7,193.2	98,357.5	97,626.4	-	-	1,083.0	1,083.0	106,637.0	105,902.6
Alabama	-	-	3,950.8	3,908.8	-	-	1,083.0	1,083.0	5,033.8	4.991 8
Georgia	-	-	3.2	3.2	-	-	-	-	3.2	3 2
Kentucky, Eastern	-	-	10,021.6	9,833.8	-	-	-	-	10.021 6	9.833.8
Maryland	-	-	787.0	780.3	-	-	-	-	787 0	780 3
North Carolina	-	-	10.7	10.7	-	-	-	-	10 7	10.7
Ohio	-	-	18,726.2	18,670.2	-	-	-	-	18.726.2	18.670 2
Pennsylvania	7,071.1	7,067.8	22,625.0	22,514.0	-	-	-	-	29.696.0	29.581 7
Tennessee	-	-	902.9	890.5	-	-	-	-	902.9	890.5
Virginia	125.5	125.5	2,911.5	2,835.1	-	-	-	-	3.037 0	2.960 6
West Virginia	-	-	38,418.7	38,179.7	-	-	-	-	38.418.7	38.179.7
Interior Total	104.1	104.1	121,042.9	120,813.0	-	-	14,187.5	14,124.7	135,334.4	135,041.8
Arkansas	104.1	104.1	288.0	287.8	-	-	25.7	25.7	417 7	417 5
Illinois	-	-	78,746.2	78,639.1	-	-	-	-	78.746.2	78.639 1
Indiana	-	-	10,370.9	10,328.5	-	-	-	-	10.370.9	10.328 5
Iowa	-	-	2,193.1	2,192.4	-	-	-	-	2.193.1	2.192.4
Kansas	-	-	984.6	982.8	-	-	-	-	984 6	982.8
Kentucky, Western	-	-	20,701.1	20,633.1	-	-	-	-	20.701.1	20.633.1
Louisiana	-	-	-	-	-	-	504.8	502.3	504 8	502.3
Michigan	-	-	127.7	127.7	-	-	-	-	127.7	127 7
Missouri	-	-	6,027.9	6,022.1	-	-	-	-	6.027 9	6.022.1
Oklahoma	-	-	1,603.3	1,599.5	-	-	-	-	1.603.3	1.599.5
Texas	-	-	-	-	-	-	13,657.0	13,596.8	13.657.0	13.596.8
Western Total	27.8	27.8	24,441.4	24,363.8	180,735.6	180,498.6	30,142.5	30,110.2	235,347.3	235,000.4
Alaska	-	-	697.5	697.5	5,436.2	5,434.2	14.0	14.0	6.147.7	6.145.7
Arizona	-	-	325.7	311.3	-	-	-	-	325.7	311 3
Colorado	25.5	25.5	8,970.0	8,954.9	3,930.2	3,922.2	4,189.9	4,189.9	17,115.5	17,092.4
Idaho	-	-	4.4	4.4	-	-	-	-	4 4	4 4
Montana	-	-	1,385.4	1,385.4	103,045.9	103,003.7	15,763.5	15,763.2	120,194 8	120,152.3
New Mexico	2.3	2.3	2,016.1	1,999.5	2,577.7	2,566.9	-	-	4,596.1	4,568.7
North Dakota	-	-	-	-	-	-	9,801.0	9,768.9	9,801 0	9,768 9
Oregon	-	-	-	-	17.5	17.5	-	-	17 5	17 5
South Dakota	-	-	-	-	-	-	366.1	366.1	366.1	366.1
Utah	-	-	6,314.8	6,286.3	1.1	1.1	-	-	6,315.9	6,287.4
Washington	-	-	303.7	303.7	1,136.7	1,131.0	8.1	8.1	1,448.5	1,442.7
Wyoming	-	-	4,423.7	4,420.9	64,590.5	64,422.2	-	-	69,014.2	68,843.1
U.S. Total	7,328.4	7,325.1	243,841.8	242,803.2	180,735.6	180,498.6	45,413.0	45,317.9	477,318.8	475,944.8

Note: Total may not equal sum of components because of independent rounding. Data are reported as of the first day of the year.
Source: State geological and mineral resource surveys, and other geological reports.

Source: *Coal Production 1986*, Energy Information Administration, 1986

DEFINITIONS AND DERIVATIONS: COAL

Reserves

Derivation of Reserve Value:

The conversion formula is from *Energy Facts - 1986*, (Washington, DC: U.S. DOE, Energy Information Administration, DOE/EIA-0469 86). The reserve value is taken from *Coal Production 1986*, (Washington, DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0118 1986), Appendix A, p. 105. The figure is equal to one half of the demonstrated reserve base (DRB), which is EIA's estimate of the DRB that is recoverable given today's technologies. This estimate was chosen to represent coal reserves because it is closest to the definition of energy reserve, even though it is not the precise amount of coal that can be profitably mined given current laws, regulations, economics, and usages.

The figure is an update of a value provided in *Coal Production, 1985*. Depletion as reported in *Coal Production, 1986* was subtracted from the 1985 figure after being calibrated to reflect a 50% recovery rate for underground mines and 80% for surface mines.[13] Estimated DRB potential from the Louisiana Dolet Hills Lignite Project was also included for the first time. The reported Dolet Hills resources were reduced for the DRB estimate by 8%, assuming a 92% recovery factor for the site.

The DRB definition and calculation are based mainly on physical characteristics. The DRB includes both "measured" and "indicated" geologic categories. Measured portions of the demonstrated reserve include coal that has been ranked and assessed in terms of quality and quantity from sample analyses from closely spaced and geologically defined sample sites. The samples are of such an extent and number that the estimated tonnage is judged accurate to within 20%. (This 20% accuracy figure is no longer used by the USGS.)

The resources have been accurately delineated within specified degrees of geologic assurance. Thinner and/or deeper beds that are already being mined or that have conclusive evidence that they could be commercially mined are also included.

All DRB coal occurs within depth and thickness ranges judged to be economically minable at the time of estimate. The DRB includes data for bituminous coal beds and anthracite 28 or more inches thick, beds of subbituminous coal 60 or more inches thick that have 1000 feet or less overburden, and beds of lignite 60 or more inches thick with 200 feet or less overburden.[14]

Economic Assumptions

The economic assumptions behind the DRB estimates are implicit in the physical specifications for resources included in the DRB.

13. The use of these two recovery rates by DOE are somewhat arbitrary but traditional. These recovery rates have been used for a number of years, and have not been changed to reflect new mining technology. The actual recovery factors at coal mines are determined by local costs and mining conditions, not technology limits.

14. This is the traditional definition of coal reserves. There is considerable question among mineral geologists whether 50% of the underground coal resources known to exist at such great depths is economical under current market conditions.

Table A-28: Coal Reserve Calculations

Value:	908 BBOE
Source Value:	239 billion short tons
Conversion Formula:	A x B = 908 x 10^9 barrels of oil
	A = 239 x 10^9 short tons of economic coal reserves
	B = 3.8 barrels of oil per ton of coal
Year Estimated:	1986

DEFINITIONS AND DERIVATIONS: PETROLEUM

Total Resource Base

Derivation of Total Resource Value

The petroleum total resource is composed of five components: identified conventional resources (including oil reserves and subeconomic resources); identified resources recoverable through conventional and advanced enhanced oil recovery (EOR) techniques; identified oil in place but not recoverable by current or advanced EOR techniques; identified unconventional resources (tar sands); and undiscovered conventional oil resources. The values for identified conventional resources (both onshore and offshore), undiscovered conventional oil resources, and unconventional tar sands resources are taken from *National Assessment of Undiscovered Conventional Oil and Gas Resources* (Denver, CO: U.S. Geological Survey and U.S. Minerals Management Service Open-File Report 88-373, 1988). The tar sand value is given by the USGS/MMS as a a range of 54-70 BBOE, and the larger value has been used here. In the case of the undiscovered conventional oil resources, the mean recoverable resource value has been used for this analysis.[16]

The data on the total oil-in-place after advanced oil recovery and on the oil resource recoverable through conventional and advanced EOR techniques are calculated from the National Petroleum Council, *Enhanced Oil Recovery* (Washington, D.C.: National Petroleum Council, June 1984), pp. 62-74. Of the 272 billion barrels in place, the NPC identifies 103 BBOE as that expected to remain in reservoirs even after advanced EOR techiques, and 67 BBOE as being in reservoirs for which current EOR techniques are not yet feasible even at prices up to $50 per barrel. Alternatively, the USGS estimates that

Table A-29: Petroleum Total Resource Base Calculations

Value:	476.6 BBOE
Source:	51.2 x 10^9 barrels, identified conventional reserves
	70 x 10^9 barrels, identified unconventional tar sand resource
	34 x 10^9 barrels, identified resources available through advanced oil recovery techniques
	272 x 10^9 barrels oil in place not analyzed or not producible through advanced oil recovery techniques
	49.4 x 10^9 barrels, undiscovered conventional oil
Conversion Formula:	NA
Years Estimated:	1988, 1984

16. The USGS and MMS are currently estimating undiscovered resources differently than in the past. Techniques adopted from the private sector, including "play analysis," are now being used in USGS/MMS documents such as Open-File 88-373.

prior production plus current and inferred reserves equal 36 percent of original oil in place. This would mean that current oil in place would be 395 BBOE, which is very close to these estimates once tar sands are added in.

DEFINITIONS AND DERIVATIONS: PETROLEUM

Accessible Resources

Derivation of Accessible Resource Value

The accessible resource is composed of four components: identified conventional reserves, identified resources available through currently available enhanced oil recovery (EOR) techniques, undiscovered recoverable conventional resources, and identified unconventional (tar sand) resources. The identified reserve figures include proved reserves, which are derived from survey data as described in the next section on reserves, indicated, and inferred reserves.[17] The values for identified conventional resources (both onshore and offshore), undiscovered conventional oil resources, and unconventional tar sands resources are taken from *National Assessment of Undiscovered Conventional Oil and Gas Resources* (Denver, CO: U.S. Geological Survey and U.S. Minerals Management Service Open-File Report 88-373, 1988). The tar sand value is given by the USGS/MMS as a a range of 54-70 BBOE, and the larger value has been used here. In the case of the undiscovered conventional oil resources, the mean recoverable resource value has been used for this analysis.

The data on the petroleum that can be extracted using current or conventional EOR techniques are calculated from the National Petroleum Council, *Enhanced Oil Recovery* (Washington, D.C.: National Petroleum Council, June 1984), pp. 62-74 and J.J. George Stosur, "The Potential of Enhanced Oil Recovery," *Energy Research*, Vol 10., 1986, pp.365-366. The 19 BBOE figure is based on current (or "implemented" technology) and oil prices of $50 per barrel.

Table A-30: Petroleum Accessible Resources Calculations

Value:	189.6 BBOE
Source Value:	51.2×10^9 barrels oil, identified conventional reserves
	19×10^9 barrels, identified resources available through current enhanced oil recovery techniques
	49.4×10^9 barrels, undiscovered recoverable conventional resources
	70×10^9 barrels, identified unconventional tar sand resource
Conversion Formula:	NA
Year of Estimate:	1987

17. It should be noted that oil and natural gas accessible resource figures have implicit economic constraints not faced by some other energy sources. Also, the undiscovered recoverable conventional resource figures also have an economic component, since this is the way the data is collected and compiled.

DEFINITIONS AND DERIVATIONS: PETROLEUM

Reserves

Derivation of Reserve Value

The reserve value was derived from *U.S. Crude Oil, Natural Gas and Natural Gas Liquids Reserves, 1986 Annual Report,* (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0216, 1986) table 1. The EIA data were the product of information gathered from oil and natural gas well operations on EIA Forms 23 and 64A. Each operator was asked to report proved reserves as defined in the EIA form. No formulas or calculations were provided by EIA, so each estimate is the product of the particular operator's approach to estimating proved reserves.[18] The definition of proved reserve provided in the document is:

> "Proved Reserves of Crude Oil: Proved reserves of crude oil as of December 31 of the report year are the estimated quantities of all liquids defined as crude oil, which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions.
>
> Reservoirs are considered proved if economic producibility is supported by actual production or conclusive formation test (drill stem or wire line), or if economic producibility is supported by core analyses and/or electric or other log interpretations.
>
> The area of an oil reservoir considered proved includes (1) that portion delineated by drilling and defined by gas-oil and/or oil-water contacts, if any; and (2) the immediately adjoining portions not yet drilled, but which can be reasonably judged as economically productive on the basis of available geological and engineering data. In the absence of information on fluid contacts, the lowest known structural occurrence of hydrocarbons controls the lower proved limit of the reservoir.
>
> Reserves of crude oil which can be produced economically through application of improved recovery techniques (such as fluid injection) are included in the "proved" classification when successful testing by a pilot project, or the operation of an installed program in the reservoir, provides support for the engineering analysis on which the project or program was based.
>
> Estimates of proved crude oil reserves do not include the following: (1) oil that may become available from known reservoirs but is reported separately as "indicated additional reserves," (2) natural gas liquids (including lease condensate); (3) oil, the recovery of which is subject to reasonable doubt because of uncertainty as to geology, reservoir characteristics, or economic factors; (4) oil that may occur in undrilled prospects; and (5) oil that may be recovered from oil shales, coal, gilsonite, and other such sources. It is not necessary that production, gathering or transportation facilities be installed or operative for a reservoir to be considered proved."

18. It is customary for oil and gas operations to drill only enough to prove a substantial supply, normally 10 years. Proved reserves reflect only this amount, not the amount that has been identified but not yet proven, thus substantially understating the actual economic reserve. Subsequent additional step-out or infield drilling will normally identify additional reserves, which will be added to the proved reserves in subsequent years.

Economic Assumptions

The assumption of economic viability at current (1986) prices is based on current production or on the respondent's assessment of near-term profitability, given the particular market situation at the time the assessment is conducted. The assumptions are not documented.

Table A-31: Petroleum Reserves Calculations

Value:	26.9 BBOE
Source Value:	26.9 BBOE
Conversion Formula:	NA
Source of Formula:	NA
Year Estimated:	1986

Table A-32: Estimated Total U.S. Proved Reserves of Crude Oil, Natural Gas, and Natural Gas Liquids, 1977 through 1986

Year	Net [1] Adjustments (1)	Revision Increases (2)	Revision Decreases (3)	Net of [2] Revisions and Adjustments (4)	Extensions (5)	New Field Discoveries (6)	New Reservoir Discoveries in Old Fields (7)	Total [3] Discoveries (8)	Production (9)	Proved [4] Reserves 12/31 (10)	Net Change from Prior Year (11)
Crude Oil [5]											
1976	—	—	—	—	—	—	—	—	—	33,502 [6]	—
1977	-40 [7]	1,503	1,117	346	496	168	130	794	2,862	31,780	-1,722
1978	366	2,799	1,409	1,756	444	267	116	827	3,008	31,355	-425
1979	337	2,438	2,001	774	424	108	104	636	2,955	29,810	-1,545
1980	219	2,883	994	2,108	572	143	147	862	2,975	29,805	-5
1981	138	2,151	880	1,409	750	254	157	1,161	2,949	29,426	-379
1982	-83	2,245	1,611	351	634	204	193	1,031	2,950	27,858	-1,568
1983	462	2,810	1,299	1,973	629	105	190	924	3,020	27,735	-123
1984	159	3,672	1,227	2,604	744	242	158	1,144	3,037	28,446	+711
1985	429	3,037	1,439	2,027	742	84	169	995	3,052	28,416	-30
1986	57	2,724	1,869	912	405	48	81	534	2,973	26,889	-1,527
Natural Gas, Dry [8]											
1976	—	—	—	—	—	—	—	—	—	213,278 [6]	—
1977	-20 [7]	13,691	15,296	-1,625	8,129	3,173	3,301	14,603	18,843	207,413	-5,865
1978	2,429	14,969	15,994	1,404	9,582	3,860	4,579	18,021	18,805	208,033	+620
1979	-2,264	16,410	16,629	-2,483	8,950	3,188	2,566	14,704	19,257	200,997	-7,036
1980	1,201	16,972	15,923	2,250	9,357	2,539	2,577	14,473	18,699	199,021	-1,976
1981	1,627	16,412	13,813	4,226	10,491	3,731	2,998	17,220	18,737	201,730	+2,709
1982	2,378	19,795	19,340	2,833	8,349	2,687	3,419	14,455	17,506	201,512	-218
1983	3,090	17,602	17,617	3,075	6,909	1,574	2,965	11,448	15,788	200,247	-1,265
1984	-2,241	17,841	14,712	888	8,299	2,536	2,686	13,521	17,193	197,463	-2,784
1985	-1,708	18,775	16,304	763	7,169	999	2,960	11,128	15,985	193,369	-4,094
1986	1,320	21,269	17,697	4,892	6,065	1,099	1,771	8,935	15,610	191,586	-1,783
Natural Gas Liquids [5]											
1978	—	—	—	—	—	—	—	—	—	6,772 [6]	—
1979	64 [7]	677	726	15	364	94	97	555	727	6,615	-157
1980	153	743	639	257	418	90	79	587	731	6,728	+113
1981	231	729	643	317	542	131	91	764	741	7,068	+340
1982	299	811	832	278	375	112	109	596	721	7,221	+153
1983	849	847	781	915	321	70	99	490	725	7,901	+680
1984	-123	866	724	19	348	55	96	499	776	7,643	-258
1985	426	906	744	588	337	44	85	466	753	7,944	+301
1986	367	1,030	807	590	263	34	72	369	738	8,165	+221

[1] Includes operator reported corrections for the years 1978 through 1981. After 1981 operators included corrections in revisions.
[2] Net of revisions and adjustments = Col. 1 + Col. 2 — Col. 3.
[3] Total discoveries = Col. 5 + Col. 6 + Col. 7.
[4] Proved reserves = Col. 10 from prior year + Col. 4 + Col. 8 — Col. 9.
[5] Million barrels of 42 U.S. gallons.
[6] Based on following year data only.
[7] Consists only of operator reported corrections and no other adjustments.
[8] Billion cubic feet at 14.73 psia and 60° F.
— = Not applicable.

Notes: •"Old" means discovered in a prior year. •"New" means discovered during the report year. •The production estimates in this table are based on data reported on Form EIA-23, "Annual Survey of Domestic Oil and Gas Reserves," and Form EIA-64A, "Annual Report of the Origin of Natural Gas Liquids Production." They may differ from the official Energy Information Administration production data for crude oil, natural gas, and natural gas liquids for 1986 contained in the publications *Petroleum Supply Annual 1986*, DOE/EIA-0340(86) and *Natural Gas Annual 1986*, DOE/EIA-0131(86).

Source: *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*, (1977 through 1986) annual reports, DOE/EIA-0216 {2-10}.

Source: U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves 1986 Annual Report

DEFINITIONS AND DERIVATIONS: NATURAL GAS/NATURAL GAS LIQUIDS

Total Resource Base

Derivation of Total Resource Base Value

The natural gas total resource is composed of three components: identified conventional resources (including reserves of natural gas and natural gas liquids, as well as subeconomic resources); identified unconventional resources (gas contained in tight formations and Devonian shales); and undiscovered conventional natural gas and natural gas liquid resources. The values for identified conventional resources (both onshore and offshore), undiscovered conventional natural gas and natural gas liquid resources, and certain unconventional natural gas (Devonian shales) resources are taken from *National Assessment of Undiscovered Conventional Oil and Gas Resources* (Denver, CO: U.S. Geological Survey and U.S. Minerals Management Service Open-File Report 88-373, 1988). The value for Western tight gas formations (tight sands) value is taken from *Unconventional Gas Resource: Part 1: Tight Gas Reservoirs* (Washington, D.C.: National Petroleum Council, 1980). This is the recoverable resource with advanced recovery technology at a price of $9.00/tcf. In its 1988 National Assessment, The USGS/MMS provided an estimate of total gas in place of 4971.27 and 419.6 trillion cubic feet, respectively, for the Green River and Piceance formations. However, this includes very large portions of gas that cannot be recovered by any currently conceivable technology and therefore does not fit the definition of a resource. In the case of the undiscovered natural gas resources, the mean recoverable resource value has been used for this analysis, and this uses a 70-80% recovery factor. The value for identified reserves and undiscovered recoverable resources was added together to provide the estimate of accessible reserves.[19] Identified reserves include both proved reserves, which are derived from survey data, as described in the next section on reserves, and a statistical estimate of expected new reservoir discoveries in known fields and reserves expected to be added by enhanced oil recovery methods. The statistical estimation is based on historic patterns of additions to proved reserves. Undiscovered resources were chosen to represent total resources above reserves and accessible resources because it comes nearest to removing economic and technological constraints on gas production in its estimates. These estimates are somewhat conservative in that they do not include coal bed methane or gas hydrates.[20] They are also less optimistic than DOE estimates of conventional gas resources, as

19. It should be noted that oil and natural gas accessible resource figures have implicit economic constraints not faced by some other energy sources. Also, the undiscovered recoverable conventional resource figures also have an economic component, since this is the way the data is collected and compiled.

20. Information is just beginning to be collected on gas hydrates, partly because of problems generated as drilling platforms are moving into deeper water (gas hydrate stability fields can be found in waters of 300 meters or greater). A recent USGS/DOE publication estimates that 10 tcf of gas hydrates are to be found in a small isolated mapped area of Alaska, and that much greater resources will be encountered elsewhere. T.F. Collett, K.J. Bird, K.V. Krenvolden, and L.B. Magoon, *Geologic Interrelations Relative to Gas Hydrate Within the North Slope of Alaska*, USGS Open-File 88-389.

reported in *An Assessment of the Natural Gas Resource Base of the United States,* (Washington, D.C.: U.S. DOE, Office of Policy, Planning and Analysis), page 2, table 1. Subtracting DOE's estimates of technically recoverable, unconventional gas from the total renders an estimate of 927 trillion cubic feet of natural gas, compatible with this report's estimate of 704 trillion cubic feet of accessible identified and undiscovered conventional natural gas resources. The DOE figures include gas recoverable from infill drilling. These figures from USGS/MMS and DOE are subject to debate due to the different approaches and definitions of natural gas resources, and valid disagreements over data interpretation.

Table A-33: Natural Gas Total Resource Base Calculations

Value:	294.17 BBOE
Source Value:	305.4×10^9 thousand cubic feet identified conventional natural gas
	574×10^9 thousand cubic feet identified tight sands natural gas
	280×10^9 thousand cubic feet identified Devonian shale natural gas
	399.1×10^9 thousand cubic feet undiscovered conventional natural gas
	12.2×10^9 barrels of natural gas liquids
	8.6×10^9 barrels of undiscovered natural gas liquids
Conversion Formula:	$[(A + B + C + D) \times G] + [(E + F) \times H/I] = 294.17 \times 10^9$ Barrels of Oil Equivalent
	A = 305.4×10^9 thousand cubic feet identified conventional natural gas
	B = 574×10^9 thousand cubic feet identified tight sands natural gas
	C = 280×10^9 thousand cubic feet identified Devonian shale natural gas.
	D = 399.1×10^9 thousand cubic feet undiscovered conventional natural gas
	E = 12.2×10^9 barrels of natural gas liquids
	F = 8.6×10^9 barrels of undiscovered natural gas liquids
	G = .18 barrels of oil equivalent per thousand cubic feet gas
	H = 3.805×10^6 Btu per barrel of natural gas liquids
	I = 5.8×10^6 Btu per barrel crude oil
Year Estimated:	1988, 1980

DEFINITIONS AND DERIVATIONS: NATURAL GAS/NATURAL GAS LIQUIDS

Accessible Resources

Derivation of Accessible Resource Value

The natural gas accessible resource is composed of three components: identified conventional resources (including reserves of natural gas and natural gas liquids, as well as subeconomic resources); recoverable unconventional resources (gas contained in tight formations and Devonian shales); and undiscovered conventional natural gas and natural gas liquid resources. The undiscovered conventional natural gas and natural gas liquid resources, and certain recoverable unconventional natural gas (Devonian shales) resources are taken from *National Assessment of Undiscovered Conventional Oil and Gas Resources* (Denver, CO: U.S. Geological Survey and U.S. Minerals Management Service Open-File Report 88-373, 1988). The value for recoverable natural gas from Western tight gas formations (tight sands) is taken from *Unconventional Gas Resource: Part I: Tight Gas Reservoirs* (Washington, D.C.: National Petroleum Council, 1980). This the recoverable resource with advanced recovery technology at a price of $9.00/tcf.

Table A-34: Natural Gas Accessible Resources Calculations

Value:	153.05 BBOE
Source Value:	305.4×10^9 thousand cubic feet identified natural gas reserves
	15.2×10^9 thousand cubic feet recoverable Devonian shale gas
	107.4×10^9 thousand cubic feet recoverable tight sands gas
	399.1×10^9 thousand cubic feet undiscovered conventional natural gas
	12.2×10^9 barrels natural gas liquids
	8.6×10^9 undiscovered natural gas liquids
Conversion Formula:	$[(A + B + C + D) \times G] + [(E + F) \times (H/I)] = 153.05 \times 10^9$ barrels oil equivalent
	$A = 305.4 \times 10^9$ thousand cubic feet identified natural gas reserves
	$B = 15.2 \times 10^9$ thousand cubic feet recoverable Devonian shale gas
	$C = 107.4 \times 10^9$ thousand cubic feet recoverable tight sands gas
	$D = 399.1 \times 10^9$ thousand cubic feet undiscovered conventional natural gas
	$E = 12.2 \times 10^9$ barrels natural gas liquids
	$F = 8.6 \times 10^9$ undiscovered natural gas liquids
	$G = .18$ barrels of oil equivalent per thousand cubic feet gas
	$H = 3.805 \times 10^6$ Btu per barrel of natural gas liquids
	$I = 5.8 \times 10^6$ Btu per barrel of crude oil
Year Estimated:	1988

The value for identified and undiscovered recoverable resources of natural gas and natural gas liquids were converted to Btus and added together to provide an estimate of accessible resources. These estimates are conservative, for the same reasons discussed in the total resource section. The DOE value, derived by subtracting undiscovered and unconventional resources from the total for technically recoverable gas, is 483 trillion cubic feet, compared to 305.4 trillion cubic feet in this report.

DEFINITIONS AND DERIVATIONS: NATURAL GAS/NATURAL GAS LIQUIDS

Reserves

Derivation of Reserve Value

The gas oil equivalents are from *Energy Facts - 1986*, (Washington, DC: U.S. DOE, Energy Information Administration, DOE/EIA-0469), page 54. Natural gas liquids and crude oil heat content information is from *Monthly Energy Review*, (Washington, DC: U.S. Department of Energy, U.S. DOE, Energy Information Administration, DOE/EIA-0035 88/01, January 1988) page 121. The reserve value was derived from *U.S. Crude Oil, Natural Gas and Natural Gas Liquids Reserves, 1986 Annual Report*, (Washington, DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0216, 1986) table 1. The EIA data were the product of information gathered from oil and natural gas well operations on EIA Forms 23 and 64A. Each operator was asked to report proved reserves as defined in the EIA form. No formulas or calculations were provided by EIA, so each estimate is the product of the particular operator's approach to estimating proved reserves. The definition of proved reserve for natural gas is as follows:

> "Proved Reserves of Natural Gas: Proved reserves of natural gas as of December 31 of the report year are the estimated quantities of all liquids defined as crude oil, which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions.
>
> Reservoirs are considered proved if economic producibility is supported by actual production or conclusive formation test (drill stem or wire line), or if economic producibility is supported by core analyses and/or electric or other log interpretations.
>
> The area of a gas reservoir considered proved includes (1) that portion delineated by drilling and defined by gas-oil and/or gas-water contacts, if any; and (2) the immediately adjoining portions not yet drilled, but which can be reasonably judged as economically productive on the basis of available geological and engineering data. In the absence of information on fluid contacts, the lowest known structural occurrence of hydrocarbons controls the lower proved limit of the reservoir.
>
> Volumes of natural gas placed in underground storage are not to be considered proved reserves.
>
> For natural gas, wet after lease separation, an appropriate reduction in the reservoir gas volume has been made to cover the removal of the liquefiable portions of the gas in lease and/or field separation facilities and the exclusion of nonhydrocarbon gases where they occur in sufficient quantity to render the gas unmarketable.
>
> It is not necessary that production, gathering, or transportation facilities be installed or operative for a reservoir to be considered proved. It is to be assumed that compression will be initiated if and when economically justified."

The definition of proved reserves of natural gas liquids is as follows:

"**Proved Reserves of Natural Gas Liquids:** Proved reserves of natural gas liquids as of December 31 of the report year are those volumes of natural gas liquids (including lease condensate) demonstrated with reasonable certainty to be separable in the future from proved natural gas reserves, under existing economic and operating conditions."

Economic Assumptions

The assumption of economic viability at current (1986) energy prices is based on actual production or on the respondent's estimate of current profitability given the particular market situation and the definition provided by EIA. The assumptions are not documented.

Table A-35: Natural Gas Reserves Calculations

Value:	39.9 BBOE
Source Value:	191.586×10^9 thousand cubic feet natural gas
	8.165×10^9 barrels of natural gas liquids
Conversion Formula:	$(A \times B) + [C \times D/E) = 39.9 \times 10^9$ Barrels of Oil Equivalent
	$A = 191.586 \times 10^9$ tcf natural gas
	$B = .18$ barrels of oil equivalent in tcf gas
	$C = 8.165 \times 10^9$ barrels natural gas liquids
	$D = 3.805 \times 10^6$ Btu per barrel natural gas liquids
	$E = 5.8 \times 10^6$ Btu per barrel crude oil
Year Estimated:	1986

Table A-36: Estimated Total U.S. Proved Reserves of Crude Oil, Dry Natural Gas, and Natural Gas Liquids, 1977 through 1986

Year	Net [1] Adjustments (1)	Revision Increases (2)	Revision Decreases (3)	Net of [2] Revisions and Adjustments (4)	Extensions (5)	New Field Discoveries (6)	New Reservoir Discoveries in Old Fields (7)	Total [3] Discoveries (8)	Production (9)	Proved [4] Reserves 12/31 (10)	Net Change from Prior Year (11)
Crude Oil [5]											
1976	—	—	—	—	—	—	—	—	—	33,502 [6]	—
1977	-40 [7]	1,503	1,117	346	496	168	130	794	2,862	31,780	-1,722
1978	366	2,799	1,409	1,756	444	267	116	827	3,008	31,355	-425
1979	337	2,438	2,001	774	424	108	104	636	2,955	29,810	-1,545
1980	219	2,883	994	2,108	572	143	147	862	2,975	29,805	-5
1981	138	2,151	880	1,409	750	254	157	1,161	2,949	29,426	-379
1982	-83	2,245	1,611	351	634	204	193	1,031	2,950	27,858	-1,568
1983	462	2,810	1,299	1,973	629	105	190	924	3,020	27,735	-123
1984	159	3,672	1,227	2,604	744	242	158	1,144	3,037	28,446	+711
1985	429	3,037	1,439	2,027	742	84	169	995	3,052	28,416	-30
1986	57	2,724	1,869	912	405	48	81	534	2,973	26.889	-1,527
Natural Gas, Dry [8]											
1976	—	—	—	—	—	—	—	—	—	213,278 [6]	—
1977	-20 [7]	13,691	15,296	-1,625	8,129	3,173	3,301	14,603	18,843	207,413	-5,865
1978	2,429	14,969	15,994	1,404	9,582	3,860	4,579	18,021	18,805	208,033	+620
1979	-2,264	16,410	16,629	-2,483	8,950	3,188	2,566	14,704	19,257	200,997	-7,036
1980	1,201	16,972	15,923	2,250	9,357	2,539	2,577	14,473	18,699	199,021	-1,976
1981	1,627	16,412	13,813	4,226	10,491	3,731	2,998	17,220	18,737	201,730	+2,709
1982	2,378	19,795	19,340	2,833	8,349	2,687	3,419	14,455	17,506	201,512	-218
1983	3,090	17,602	17,617	3,075	6,909	1,574	2,965	11,448	15,788	200,247	-1,265
1984	-2,241	17,841	14,712	888	8,299	2,536	2,686	13,521	17,193	197,463	-2,784
1985	-1,708	18,775	16,304	763	7,169	999	2,960	11,128	15,985	193,369	-4,094
1986	1,320	21,269	17,697	4,892	6,065	1,099	1,771	8,935	15,610	191,586	-1,783
Natural Gas Liquids [5]											
1978	—	—	—	—	—	—	—	—	—	6,772 [6]	—
1979	64 [7]	677	726	15	364	94	97	555	727	6,615	-157
1980	153	743	639	257	418	90	79	587	731	6,728	+113
1981	231	729	643	317	542	131	91	764	741	7,068	+340
1982	299	811	832	278	375	112	109	596	721	7,221	+153
1983	849	847	781	915	321	70	99	490	725	7,901	+680
1984	-123	866	724	19	348	55	96	499	776	7,643	-258
1985	426	906	744	588	337	44	85	466	753	7,944	+301
1986	367	1,030	807	590	263	34	72	369	738	8,165	+221

[1] Includes operator reported corrections for the years 1978 through 1981. After 1981 operators included corrections in revisions.
[2] Net of revisions and adjustments = Col. 1 + Col. 2 — Col. 3.
[3] Total discoveries = Col. 5 + Col. 6 + Col. 7.
[4] Proved reserves = Col. 10 from prior year + Col. 4 + Col. 8 — Col. 9.
[5] Million barrels of 42 U.S. gallons.
[6] Based on following year data only.
[7] Consists only of operator reported corrections and no other adjustments.
[8] Billion cubic feet at 14.73 psia and 60° F.
— = Not applicable.

Notes: •"Old" means discovered in a prior year. •"New" means discovered during the report year. •The production estimates in this table are based on data reported on Form EIA-23, "Annual Survey of Domestic Oil and Gas Reserves," and Form EIA-64A, "Annual Report of the Origin of Natural Gas Liquids Production." They may differ from the official Energy Information Administration production data for crude oil, natural gas, and natural gas liquids for 1986 contained in the publications *Petroleum Supply Annual 1986*, DOE/EIA-0340(86) and *Natural Gas Annual 1986*, DOE/EIA-0131(86).

Source: *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*, (1977 through 1986) annual reports, DOE/EIA-0216 {2-10}.

Source: U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves 1986 Annual Report

DEFINITIONS AND DERIVATIONS: PEAT

Total Resource Base

Derivation of Total Resource Base Value

The total resource value was derived from Rouse S. Farnham, et al., *Energy from Peat, Subcommittee 8 Report to the Minnesota Energy Agency,* (St. Paul: University of Minnesota, 1978), page 13. The estimates assume a uniform depth of peat bogs of 7 feet, 35% moisture content, density of 15 lbs/cubic foot, and caloric value of 6,000 Btus/lb.

Table A-37: Peat Total Resource Base Calculations

Value:	243.8 BBOE
Source Value:	117.8 billion short tons of 35% moisture content peat
Conversion Formula:	$\frac{A \times B}{C} = 243.8 \times 10^9$ barrels of oil
	$A = 117.8 \times 10^9$ short tons of 35% moisture content peat
	$B = 6000 \times 2000$, Btus per ton of peat
	$C = 5.8 \times 10^6$ Btus per barrel of oil
Year Estimated:	1978

Table A-38: Estimated Resources of Peat and Potential Energy in Selected Geographical Areas

Geographic Area	Estimated Resources[1] Acres (millions)	Estimated Resources[1] Quantity (billion tons)	Potential Energy Quads[2] (Assuming a uniform depth of 7 feet)
U.S. (including Alaska)	52.6	117.8	1,410
U.S. (minus Alaska)	25.6	57.3	690
Midwest Region U.S.	15.2	34.0	409
Southern Region U.S.	6.7	15.0	180
Northeast Region U.S.	2.7	6.0	72
Western Region U.S.	1.0	2.2	26.9
Minnesota	7.2	16.1	193
Michigan	4.5	10.1	121
Florida	3.0	6.7	80
Wisconsin	2.8	6.3	75
Louisiana	1.8	4.0	48
North Carolina	1.2	2.7	32
Maine	0.77	1.7	20.7
New York	0.65	1.4	17.4
Hawaii	0.48	0.9	12.9
Koochiching Co. Minn.	1.15	2.6	30.9
St. Louis Co. Minn.	0.81	1.8	21.4
Beltrami Co. Minn.	0.78	1.7	20.9

1 Estimates from published survey data of known peat resources. Basis of resource and potential energy: peat contains 35% moisture, bulk density equals 15 lbs/cu ft, caloric value equals 6,000 Btu/lb. Assuming 2% ditch losses, one acre of peat 7' deep equals 2240 tons or 26.9×10^9 Btu of energy.

2 1 Quad = 10^{15} Btu

Compiled by the Soil Science Department, University of Minnesota
Source: *Energy From Peat, Subcommittee 8 Report to the Minnesota Energy Agency,* Farnum, et al., 1978.

DEFINITIONS AND DERIVATIONS: PEAT

Accessible Resources

Derivation of Accessible Resource Value

The accessible resource value is derived by subtracting out the land area of the peat bogs that are currently forested and therefore counted in the biomass reserve. This is estimated to be 40 million acres, based on Minnesota data, leaving 25% of the total resource base as accessible resource.

Table A-39: Peat Accessible Resource Calculations

Value:	61 BBOE
Source Value:	29.45 billion short tons of 35% moisture content peat
Conversion Formula:	$\frac{A \times B}{C} = 61 \times 10^9$ barrels of oil equivalent
	$A = 29.45 \times 10^9$ short tons of 35% moisture content peat
	$B = 6000 \times 2000$, Btus per ton of peat
	$C = 5.8 \times 10^6$ Btus per barrel of oil
Year Estimated:	1978

DEFINITIONS AND DERIVATIONS: PEAT

Reserves

Derivation of Reserve Value

At current energy prices, peat is not being actively exploited for energy production. Peat currently sells for approximately $24.52 per ton, which is equivalent to approximately $2.04 per million Btus. The average FOB price for coal in 1984 was $25.61, or $1.16 per million Btus. Therefore peat is not economically competitive with coal for power generation. Although peat is used in significant quantities to produce energy in other countries, only 11,000 tons of peat were used for energy in the U.S. in 1984, compared to total output of 800,000 tons.

This 11,000 tons was assumed to represent peat energy that was economically viable, disregarding any incentives or noneconomic reasons for extraction. Most of the peat used for energy was not commercially economic; it was mostly devoted to experiments, demonstrations, and small-scale local use. Peat generally has a higher value in horticulture and agriculture. There are also significant unresolved environmental and economic barriers to peat energy production because of competing uses of peat land for forestry, agriculture, and wildlife habitat, and possible hydrologic and ecological damage from large-scale peat mining.

Data on peat prices, quantities, and uses are from *Mineral Commodity Summaries, 1986* (Washington DC: U.S. Department of the Interior, U.S. Bureau of Mines) pages 112 and 113, and *1984 Minerals Yearbook, Volume One, Metals and Minerals* (Washington DC: U.S. Department of the Interior, U.S. Bureau of Mines, 1985) pages 695 to 699. Coal cost information is from *Coal Data: A Reference* (Washington, D.C.: U.S. Department of Energy Energy Information Administration, DOE/EIA-0064(85)), March 1987, page 63, table 26.

Table A-40: Peat Reserve Calculations

Value:	.0007 BBOE
Source Value:	11,000 tons of peat
Conversion Formula:	$\frac{A \times B \times C}{D} = .0007 \times 10^9$ barrels of oil
	A = 11,000 tons of peat
	B = 6000 x 2000, Btus per ton of peat
	C = 30 years
	D = 5.8×10^6 Btus per barrel of oil
Year Estimated:	1984

DEFINITIONS AND DERIVATIONS: URANIUM

Total Resource Base

Derivation of Total Resource Base Value

The source values are from *Uranium Industry Annual, 1987,* Energy Information Administration, (Washington, DC: U.S. Department of Energy, DOE/EIA-0478 (87) September 1988), page 33, table 15; page 29, table 11. Reasonably assured resources (RAR) extractable at up to $100 /pound plus estimated additional resources (EAR) extractable at up to $100/pound plus speculative resources (SR) extractable at up to $100/pound were used as values for the total resource. These are the maximum uranium resource estimates available. The $100/pound cost category was chosen for EAR, RAR and SR because it is nearest to removing economic and technical restraints, in keeping with the definition of total resource.

Uranium is an element that occurs in small amounts in many geologic formations. Ideally the total resource would include a very broad measure of uranium, but available data focus on formations with characteristics that show promise of economic extraction at $100/pound or less, even though at higher prices more resources could be made available. Therefore the basic data used in assessing uranium runs counter to the definition of the total resource definition because it constrains the resource estimate by cost and technical criteria. As a result assumptions were made on the basis of the available data in order to distinguish total resources, accessible resources and reserves. The total resource includes all of the undiscovered resource, both probable and possible, while the accessible is limited to resources that are discovered or probable given available geological information. Categories used by the USGS and DOE differ in

Table A-41: Uranium Total Resource Base Calculations

Value:	202.6 BBOE
Source Value:	$3{,}700 \times 10^6$ lbs U_3O_8, EAR at $100/lb.
	$1{,}592 \times 10^6$ lbs U_3O_8, RAR at $100/lb.
	$3{,}200 \times 10^6$ lbs U_3O_8, SR at $100/lb.
Conversion Formula:	$\frac{(A + B + C) \times D}{F} \times (1/E) = 202.6 \times 10^9$
	$A = 3{,}700 \times 10^6$ lbs U_3O_8, EAR at $100/lb.
	$B = 1{,}592 \times 10^6$ lbs U_3O_8, RAR at $100/lb.
	$C = 3{,}200 \times 10^6$ lbs U_3O_8, Speculative Resources
	$D = 13{,}381$ kWh per pound U_3O_8, lightwater reactor
	$E = .33$ efficiency factor of a boiling water reactor
	$F = 1700 \times 10^9$ kWh per billion barrels of oil
Year of Estimate:	1988

Table A-42: Reasonably Assured Resources at the End of the Year, 1947-1987 (Million Pounds U_3O_8)

Year	Forward-Cost Category in Nominal Dollars				
	$8 per pound	$15 per pound	$30 per pound	$50 per pound	$100 per pound
1947	4	(a)	(a)	(a)	(a)
1948	4	(a)	(a)	(a)	(a)
1949	4	(a)	(a)	(a)	(a)
1950	6	(a)	(a)	(a)	(a)
1951	12	(a)	(a)	(a)	(a)
1952	15	(a)	(a)	(a)	(a)
1953	30	(a)	(a)	(a)	(a)
1954	55	(a)	(a)	(a)	(a)
1955	135	(a)	(a)	(a)	(a)
1956	240	(a)	(a)	(a)	(a)
1957	333	(a)	(a)	(a)	(a)
1958	364	(a)	(a)	(a)	(a)
1959	394	(a)	(a)	(a)	(a)
1960	374	(a)	(a)	(a)	(a)
1961	348	(a)	(a)	(a)	(a)
1962	332	(a)	(a)	(a)	(a)
1963	320	(a)	(a)	(a)	(a)
1964	302	(a)	(a)	(a)	(a)
1965	290	(a)	(a)	(a)	(a)
1966	282	(a)	(a)	(a)	(a)
1967	296	496	(a)	(a)	(a)
1968	322	530	(a)	(a)	(a)
1969	408	634	(a)	(a)	(a)
1970	492	782	(a)	(a)	(a)
1971	546	1,040	(a)	(a)	(a)
1972	546	1,040	(a)	(a)	(a)
1973	554	1,040	1,268	(a)	(a)
1974	400	840	1,200	(a)	(a)
1975	(a)	860	1,280	(a)	(a)
1976	(a)	820	1,360	1,680	(a)
1977	(a)	740	1,380	1,780	(a)
1978	(a)	580	1,380	1,840	(a)
1979	(a)	450	1,290	1,872	2,244
1980	(a)	224	940	1,574	2,068
1981	(a)	(a)	410	1,188	1,788
1982	(a)	(a)	360	1,152	1,778
1983	(a)	(a)	360	1,140	1,770
1984	(a)	(a)	[b] 359	[b] 1,106	[b] 1,719
1985	(a)	(a)	[b] 345	[b] 1,072	[b] 1,675
1986	(a)	(a)	[b] 322	[b] 1,036	[b] 1,630
1987	(a)	(a)	[b] 304	[b] 1,005	[b] 1,592

[a] For 1974, separate evaluations were made of the amounts of Reasonably Assured Resources (RAR) that could be exploited at the maximum forward-costs of $8, $15, and $30 per pound U3O8. Forward-cost RAR were not estimated for the $8 per pound category in 1975, largely because sharp increases in production costs and market prices in the 1972-1975 period focused attention on the economic availability of RAR at higher forward-cost categories. After January 1, 1975, the $8 per pound forward-cost category was no longer reported for domestic RAR. Rapidly rising production costs during 1980-1982 resulted in greatly reduced amounts of forward-costs RAR in the $15 per pound category in each of those years. The quantity estimated for 1981 was insignificant, and this category of forward-cost RAR was not reported after January 1, 1982.

[b] Does not include uranium reserves from byproduct recovery facilities, which for 1987 were 51 million pounds U_3O_8 at $30 per pound. This amount was calculated by the EIA staff by multiplying the capacity of byproduct plants as of December 31, 1987, by the number of years until the year 2000.

Sources: 1947-1963--U.S. Department of Energy, Grand Junction Project Office, *Statistical Data of the Uranium Industry* (January 1978). 1964-1982--U.S. Department of Energy, Grand Junction Project Office, *Statistical Data of the Uranium Industry* (January 1983). 1983-1987--Estimated by staff of the Nuclear and Alternate Fuels Division, Office of Coal, Nuclear, Electric and Alternate Fuels, Energy Information Administration, based on U.S. Department of Energy, Grand Junction Project Office data files and Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey" (1984, 1985, 1986, 1987).

Source: *Uranium Industry Annual 1987*, Energy Information Administration, 1988

Table A-43: Estimated Additional Uranium Resource (EAR) and Speculative Resources (SR) at the End of the Year, 1974-1987

(Million Pounds U_3O_8)

Year	Forward-Cost Category in Nominal Dollars[a]									
	$10 per pound		$15 per pound		$30 per pound		$50 per pound		$100 per pound	
	EAR	SR	EAR	SR	EAR	SR	EAR	SR	EAR	SR
1974	900	1,000	1,400	1,700	2,300	3,500	(b)	(b)	(b)	(b)
1975	900	1,100	1,300	1,900	2,100	3,700	(b)	(b)	(b)	(b)
1976	600	400	1,200	1,400	2,200	3,200	2,700	3,900	(b)	(b)
1977	(b)	(b)	1,100	1,300	2,000	3,100	2,800	4,200	(b)	(b)
1978	(b)	(b)	800	600	2,000	2,000	3,000	3,400	(b)	(b)
1979[c]	(b)	(b)	800	600	2,000	2,000	3,000	3,400	(b)	(b)
1980	(b)	(b)	600	300	1,800	1,300	2,900	2,200	4,200	3,400
1981	(b)	(b)	(b)	(b)	1,200	900	2,200	1,800	3,500	2,900
1982	(b)	(b)	(b)	(b)	1,300	900	2,300	1,800	3,800	3,000
1983	(b)	(b)	(b)	(b)	1,300	1,000	2,400	2,000	3,800	3,200
1984	(b)	(b)	(b)	(b)	1,300	1,000	2,300	2,000	3,700	3,200
1985	(b)	(b)	(b)	(b)	1,300	1,000	2,400	1,900	3,800	3,200
1986	(b)	(b)	(b)	(b)	1,300	1,000	2,400	1,900	3,800	3,200
1987	(b)	(b)	(b)	(b)	1,300	1,000	2,300	2,000	3,700	3,200

[a] Values shown are the mean values for the distributions of estimates for each forward-cost category, rounded to the nearest 100 million pounds U_3O_8.

[b] *Not estimated for the indicated forward-cost category.*

[c] No new estimates were released for the end of 1979, since the NURE program was to publish estimates of undiscovered resources by October 1980.

Sources: 1974-1982–U.S. Department of Energy, Grand Junction Project Office, *Statistical Data of the Uranium Industry*(January 1983). 1983-1986–Estimates based on uranium resources data developed under the DOE National Uranium Resource Evaluation (NURE) program, 1974-1983, using methodology described in *An Assessment Report on Uranium in the United States of America* (October 1980), and in U.S. Department of Energy, *Uranium Industry Seminar* (October 1980).

terms of treating identified versus undiscovered resources. While RAR would fall completely within USGS' identified categories, EAR overlaps the categories of identified and undiscovered, and SR falls completely within undiscovered. The overlap of EAR with the undiscovered category of USGS is in the area of hypothetical resources which are indicated by geologic information, but are not actually confirmed. In terms of DOE's former resource terminology, EAR is a "probable potential resource," versus the speculative category which is a "possible" resource. The difference is mainly in the confidence with which the resources can be predicted to exist, with the SR estimate less certain than the EAR estimate. The definition of RAR provided in the Uranium Industry Annual is:

> "Reasonably Assured Resources (RAR). This resource category refers to uranium that occurs in known mineral deposits of such size, grade, and configuration that it could be recovered within the given production cost ranges, with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics."

The estimates of RAR are based on adjustments to previous figures, which add RAR from new properties and subtractions for mined out areas and production-related depletion. The earlier measures were based on direct radiometric and chemical measurements of drill holes and other sampling. Mineral grades and thicknesses, spatial relationships, depths, mining and reclamation methods, distance to milling facilities, and amenability of ores to processing are all considered. The cutoff grade; percentage of U_3O_8 that can be economically mined and milled for a given forward cost; and the material quantities adjusted for mining recovery and dilution are also considered.

The RAR value used here includes all ore deposits that have been physically assessed as extractable at a cost of $100/pound or less. Dollar values are in 1983 dollars, the year of the assessment. The estimation procedure used the formula provided below.

$$CG = \frac{(Mn + H + R + M1) \times (100)}{(CC) \times (MR) \times (2{,}000)}$$

CG = Cutoff grade for ore quality, in percent

Mn = Cost of mining per ton of ore

H = Cost of hauling per ton of ore

R = Royalty costs per ton of ore

M1 = Cost of milling per ton of ore

CC = Chosen cost /pound U_3O_8

MR = Mill Recovery Ratio

Once the above formula was used to establish the cutoff grade, the quantity of material in known deposits that meet or exceed the cutoff grade was estimated, in tons of material and average grade adjusted for mining recovery and dilution. Forward operating and capital costs not yet incurred were applied to determine average cost for mining and processing, then compared to the cutoff value of $100 to see if the resource qualified for that category of costs.

The definition of EAR provided in the Uranium Industry Annual is as follows:

> "Estimated Additional Resources: The uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence, in extensions of well-explored deposits, little explored deposits, and undiscovered deposits believed to exist along well-defined geological trends with known deposits, such that uranium can subsequently be recovered within the given cost ranges. Estimates of tonnage and grade are based on available sampling data and on knowledge of the deposit characteristics, as determined in the best known parts of the deposit or in similar deposits. EAR corresponds to DOE's Provable Potential Resource category."

The EAR estimate is based on an historical database of geologic information including gamma-ray drill hole logs; chemical assays of core samples; geochemical surveys of water and sediments; aerial radiometric surveys; limited drilling; and geologic field studies. Estimates are of the quantity of uranium-bearing material with a grade of at least .01% U_3O_8. Extraction cost estimates are applied to the estimates, but by using the highest forward cost category the majority of the accessible resource is captured in the estimate.

Speculative resources is defined below.

> "Speculative Resources (SR): Uranium in addition to EAR that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The locations of deposits in this category can generally be specified only as being somewhere within given regions or geological trends. As the term implies, the existence and size of such deposits are speculative. The estimates in this category are less reliable than estimates of EAR. SR correspond to DOE's Possible Potential Resource plus Speculative Potential Resource categories."

In order to calculate the energy value of the uranium resource, an assumption had to be made about the conversion process for extracting the energy. Unlike fossil fuels, solar energy, or even wind energy, uranium has no inherent mechanical or calorific energy value that can be meaningfully measured in isolation from the fission energy conversion process. In this assessment a lightwater reactor was chosen because it is the most technically known and accepted process for creating fission energy. Note that the reactor was assumed to have a roughly 33% efficiency in converting thermal to electrical energy, so the electrical energy value of the uranium was multiplied by three to remove the thermal efficiency bias and thus approximate a measure of the intrinsic energy value of the uranium going into the reactor before its conversion into heat and electricity. This efficiency value was derived from *Technology Characterizations: Environmental Information Handbook*, (Washington, DC: U.S. Department of Energy, Office of Environmental Programs, DOE/EP-0028, June, 1981), p. 16. The calculation formula is shown in Table A-44.

This technical component of the uranium analysis is separate from the technical assessment of extraction considered in the accessible resource estimate, in that it is related to energy conversion rather than the basic issue of being able to find and extract the raw resource. A breeder reactor, such as a High-Temperature Gas-Cooled Reactor (HTGR) or a liquid metal fast breeder reactor, would greatly expand the available energy value of uranium. Several types of breeder reactors have been investigated and/or operated, although the technology is far from commercial use in the U.S. Breeder reactors create more fissible materials than they use, turning much of the non-fissible portions of the uranium resource, which have no energy value in a normal lightwater reactor, into fissible materials that do have an energy value. The potential for multiplying the energy potential of the uranium resource, and opening the possibility of converting thorium resources into an energy resource, are enormous, and should be considered in looking at the future potential of the uranium resource. The calculations used here are conservative in that they reflect the current state of the nuclear energy system as it exists in the U.S., without extrapolating to possible future technologies.

Table A-44: Uranium Energy Calculations

The kWh produced per pound U_3O_8 was provided by the U.S. DOE Energy Information Agency and was calculated using the following equations.

(1) $$\frac{28{,}500\ MWDt}{MTU_e} \times \frac{24\ hrs}{Day} \times \frac{10^3\ kWht}{MWh_t} \times \frac{3412\ Btu\ per\ kWhe}{10809\ Btu\ nuclear\ per\ kWh}$$

$$= 215.9 \times 10^6\ kWh_e/MTU_e$$

(2) $$\frac{3.11 - .25\ MTU_n}{.711 - .25\ MTU_e} \times \frac{1\ St\ U_3O_8}{.769MTU_n} \times \frac{2000\ lbs\ U_3O_8}{St\ U_3O_8}$$

$$= \frac{16135\ lbs\ U_3O_8}{MTU_e}$$

(3) Therefore:

$$\frac{215.9 \times 10^6 kWh}{MTU_e} \div \frac{16135\ lb\ U_3O_8}{MTU_e} = \frac{13{,}381\ kWh}{lb\ U_3O_8}$$

Where:

MWD_t = Megawatt days production, thermal

MTU_e = Metric tons enriched uranium

kWh_t = Kilowatt hours thermal

MWh_t = Megawatt hours thermal

3412/10809 = Conversion factor, thermal to electric

kWh_e = Kilowatt hours electric

MTU_3O_8 = Metric tons natural uranium

StU_3O_8 = Short tons natural uranium

U_3O_8 = Natural uranium

$\frac{3.11 - .25\ MTU_n}{.711 - .25\ MTU_e}$ = the feed to product ratio for enrichment

DEFINITIONS AND DERIVATIONS: URANIUM

Accessible Resources

Derivation of Accessible Resource Value

The accessible resource value is from the *Uranium Industry Annual, 1987* (Washington, DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0478 (87), September, 1988), page 33, table 15 and page 29, table 11. Reasonably assured resources (RAR) extractable at up to $100 /pound plus estimated additional resources (EAR) extractable at up to $100/pound were used as values for accessible resources. The $100/pound cost category was chosen for both EAR and RAR because it is nearest to removing economic restraints, which is in keeping with the definition of accessible resource. A more detailed definition of each source value and its derivation is provided in the total resource discussion. Note that EAR does include some undiscovered resources, but they are based on stronger geologic information than speculative resources. Speculative resources were not included in the accessible resource, even though they are believed to be technically accessible, simply because they are more uncertain and are closer to the nature of the total resource in that they are predicted to exist, but relatively little is known about their true extraction potential.

Table A-45: Uranium Accessible Resource Calculations

Value:	126.2 BBOE
Source Value:	$3{,}700 \times 10^6$ lbs U_3O_8, EAR at $100/lb.
	$1{,}592 \times 10^6$ lbs U_3O_8, RAR at $100/lb.
Conversion Formula:	$\frac{(A + B) \times C}{E} \times (1/D) = 126.2 \times 10^9$
	A = $3{,}700 \times 10^6$ lbs U_3O_8, EAR at $100/lb.
	B = $1{,}592 \times 10^6$ lbs U_3O_8, RAR at $100/lb.
	C = 13,381 kWh per pound U_3O_8, lightwater reactor
	D = .33 efficiency factor of a boiling water reactor
	E = 1700×10^9 kWh per billion barrels of oil
Year of Estimate:	1988

DEFINITIONS AND DERIVATIONS: URANIUM

Reserves

Derivation of Reserve Value

The reserve value was derived from *Uranium Industry Annual 1987,* (Washington, DC: U.S. Department of Energy Report, Energy Information Administration, DOE/EIA-0478 (87) September, 1988) page 33, table 15. It corresponds to RAR less than $30/pound. The forward cost category of $30/pound was chosen because it is nearest current average contract prices for uranium ($30.01 in 1986, $27.37 in 1987), as reported by the EIA in *Uranium Industry Annual, 1987,* (Washington, DC: U.S. Department of Energy Report, Energy Information Administration, DOE/EIA-0478 (87) September, 1988) table 36, p. 60.

Table A-46: Uranium Reserve Calculations

Value:	7.25 BBOE
Source Value:	304×10^6 pounds RAR up to $30/lb.
Conversion Formula:	$\frac{A \times B}{D} \times (1/C)$
	A = 304×10^6 pounds RAR up to $30/lb.
	B = 13,381 kWh per pound U_3O_8, lightwater reactor
	C = .33 efficiency factor of a boiling water reactor
	D = 1700×10^9 kWh per billion barrels of oil
Year of Estimate:	1988

DEFINITIONS AND DERIVATIONS: HYDROPOWER

Total Resource Base

Derivation of Total Resource Base Value

The basic approach for estimating the total hydropower resource (mass of runoff times gravity times the average elevation of the land area) is from *Renewable Energy,* (Copenhagen, Denmark: The Niehls Bohr Institute, University of Copenhagen, Academic Press, 1979) by Bent Sorenson. The values for runoff, precipitation, and gravitational force are from *Energy Economics and Technology,* (Baltimore, MA: The Johns Hopkins University Press, 1982) by Phillip G. LeBel, page 176. The surface area and average elevation of the U.S. are from *Statistical Abstract of the United States, 1987,* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 107th edition, 1986) page 181, table 316; and page 186, table 324, respectively. The value for the density of water is from an unpublished DOE paper on hydroelectric resources.

This approach to measuring the total resource potential was adopted because it comes nearest to capturing the complete energy potential of falling water in the U.S. without regard to economic or other constraints on its extraction, which is in keeping with the definition of total resources. It is a purely physical approximation. The first calculation provided is based on runoff, not precipitation, in order to adjust for on-land evaporation, which removes a large amount of the falling water potential before it passes completely from the highest average elevation to the lowest, and thus eliminates some of the precipitation's energy potential. This lends to a conservative estimate because at least part of the evaporation would occur after the water had fallen through part of the elevation. This equation treats evaporative losses as if they all occurred before the precipitation had a chance to travel from any elevation and embody any gravitational energy.

Using average annual precipitation (approximately .76 m per year) rather than runoff results in an estimated total hydropower resource of 260.5 billion barrels of oil equivalent, an optimistic estimate because it does not account for evaporative losses. The average of the two calculations is used for the final estimate, based on a simplifying assumption that evaporative losses would occur evenly over the entire range of elevation. Thus, some of the evaporation would remove water at the top elevation before any energy value could be gained, and some would occur at the lowest elevation, when the energy potential of the falling water had been fully realized. If evaporative losses are distributed evenly throughout the elevation, then half of the potential energy of the evaporation should be theoretically available in the total resource, resulting in a total resource value equal to the average of the low and high figure calculated.

Table A-47: Hydropower Total Resource Base Calculations

Value:	169.7 BBOE
Source Values:	.23 m per year average U.S. runoff .76 m per year average U.S. precipitation 9.37×10^6 km^2 U.S. surface area 1000 kg per m^3 water density 2500 feet, average U.S. land elevation 9.8 m per second^2, gravitational force
Conversion Formula:	$\frac{[A \times (B \times C) \times D] \times [(E \times F) \times G] \times H}{(I \times J)} = 78.8 \times 10^9$ $\frac{\text{runoff mass} \times \text{height} \times \text{gravity} \times 30 \text{ years}}{\text{joules per barrel oil}} = 78.8 \times 10^9$ $\frac{[K \times (B \times C) \times D] \times [(E \times F) \times G] \times H}{(I \times J)} = 260.5 \times 10^9$ $\frac{78.8 \times 10^9 + 260.5 \times 10^9}{2} = 169.7 \times 10^9$ Barrels of Oil Equivalent A = .23 m per year average U.S. runoff B = 9.37×10^6 km^2 U.S. surface area C = 1000^2 meters per km^2 D = 1000 kg per m^3 water density E = 2500 feet, average U.S. land elevation F = .3048 meters per foot G = 9.8 m per second^2, gravitational force H = 30 years I = 5.8×10^6 Btus per barrel of oil J = 1055.87 joules per Btu K = .76 m per year average U.S. precipitation
Year of Estimate:	See previous discussion

Table A-48: Extreme and Mean Elevations: States and Other Areas

[One foot = .305 meter]

STATE OR OTHER AREA	HIGHEST POINT			LOWEST POINT			APPROXIMATE MEAN ELEVATION	
	Name	Elevation		Name	Elevation			
		Feet	Meters		Feet	Meters	Feet	Meters
U.S.	**Mt. McKinley (AK)**	**20,320**	**6,198**	**Death Valley (CA)**	**-282**	**-86**	**2,500**	**763**
AL	Cheaha Mountain	2,407	734	Gulf of Mexico	(1)	(1)	500	153
AK	Mount McKinley	20,320	6,198	Pacific Ocean	(1)	(1)	1,900	580
AZ	Humhreys Peak	12,633	3,853	Colorado River	70	21	4,100	1,251
AR	Magazine Mountain	2,753	840	Ouachita River	55	17	650	198
CA	Mount Whitney	14,494	4,421	Death Valley	-282	-86	2,900	885
CO	Mt. Elbert	14,433	4,402	Arkansas River	3,350	1,022	6,800	2,074
CT	Mt. Frissell, on South slope	2,380	726	Long Island Sound	(1)	(1)	500	153
DE	Ebright Road, New Castle County	442	135	Atlantic Ocean	(1)	(1)	60	18
DC	Tenleytown	410	125	Potomac River	1	(Z)	150	46
FL	Sec. 30, T6N, R20W, Walton County[2]	345	105	Atlantic Ocean	(1)	(1)	100	31
GA	Brasstown Bald	4,784	1,458	Atlantic Ocean	(1)	(1)	600	183
HI	Mauna Kea	13,796	4,208	Pacific Ocean	(1)	(1)	3,030	924
ID	Borah Peak	12,662	3,862	Snake River	710	217	5,000	1,525
IL	Charles Mound	1,235	377	Mississippi River	279	85	600	183
IN	Franklin Twp., Wayne Co	1,257	383	Ohio River	320	98	700	214
IA	Sec. 29, T100N, R41W, Osceola County[2]	1,670	509	Mississippi River	480	146	1,100	338
KS	Mount Sunflower	4,039	1,232	Verdigris River	680	207	2,000	610
KY	Black Mountain	4,145	1,264	Mississippi River	257	78	750	229
LA	Driskill Mountain	535	163	New Orleans	-5	-2	100	31
ME	Mount Katahdin	5,268	1,607	Atlantic Ocean	(1)	(1)	600	183
MD	Backbone Mountain	3,360	1,025	Atlantic Ocean	(1)	(1)	350	107
MA	Mount Greylock	3,491	1,065	Atlantic Ocean	(1)	(1)	500	153
MI	Mount Arvon	1,979	604	Lake Erie	572	174	900	275
MN	Eagle Mountain, Cook Co	2,301	702	Lake Superior	602	184	1,200	366
MS	Woodall Mountain	806	246	Gulf of Mexico	(1)	(1)	300	92
MO	Taum Sauk Mountain	1,772	540	St. Francis River	230	70	800	244
MT	Granite Peak	12,799	3,904	Kootenai River	1,800	549	3,400	1,037
NE	Johnson Twp., Kimball Co.	5,426	1,655	Southeast corner of State	840	256	2,600	793
NV	Boundary Peak	13,143	4,009	Colorado River	470	143	5,500	1,678
NH	Mount Washington	6,288	1,918	Atlantic Ocean	(1)	(1)	1,000	305
NJ	High Point	1,803	550	Atlantic Ocean	(1)	(1)	250	76
NM	Wheeler Peak	13,161	4,014	Red Bluff Reservoir	2,817	859	5,700	1,739
NY	Mount Marcy	5,344	1,630	Atlantic Ocean	(1)	(1)	1,000	305
NC	Mount Mitchell	6,684	2,039	Atlantic Ocean	(1)	(1)	700	214
ND	White Butte, Slope Co	3,506	1,069	Red River	750	229	1,900	580
OH	Campbell Hill	1,550	473	Ohio River	433	132	850	259
OK	Black Mesa	4,973	1,517	Little River	287	88	1,300	397
OR	Mount Hood	11,239	3,428	Pacific Ocean	(1)	(1)	3,300	1,007
PA	Mount Davis	3,213	980	Delaware River	(1)	(1)	1,100	338
RI	Jerimoth Hill	812	248	Atlantic Ocean	(1)	(1)	200	61
SC	Sassafras Mountain	3,560	1,086	Atlantic Ocean	(1)	(1)	350	107
SD	Harney Peak	7,242	2,209	Big Stone Lake	962	293	2,200	671
TN	Clingmans Dome	6,643	2,026	Mississippi River	182	56	900	275
TX	Guadalupe Peak	8,749	2,668	Gulf of Mexico	(1)	(1)	1,700	519
UT	Kings Peak	13,528	4,126	Beaverdam Creek	2,000	610	6,100	1,861
VT	Mount Mansfield	4,393	1,340	Lake Champlain	95	29	1,000	305
VA	Mount Rogers	5,729	1,747	Atlantic Ocean	(1)	(1)	950	290
WA	Mount Rainier	14,410	4,395	Pacific Ocean	(1)	(1)	1,700	519
WV	Spruce Knob	4,863	1,483	Potomac River	240	73	1,500	458
WI	Timms Hill	1,951	595	Lake Michigan	581	177	1,050	320
WY	Gannett Peak	13,804	4,210	Belle Fourche River	3,100	946	6,700	2,044
Other areas:								
PR	Cerro de Punta	4,389	1,339	Atlantic Ocean	(1)	(1)	1,800	549
Am. Samoa	Lata Mountain	3,160	964	Pacific Ocean	(1)	(1)	1,300	397
GU	Mount Lamlam	1,329	406	Pacific Ocean	(1)	(1)	330	101
VI	Crown Mountain	1,556	475	Atlantic Ocean	(1)	(1)	750	229

Z Less than .5 meter. [1] Sea level. [2] "Sec." denotes section; "T," township; "R," range; "N," north; "W," west.

Source: U.S. Geological Survey, *Elevations and Distances in the United States*, 1980.

Source: *Statistical Abstract of the United States, 1987*

Table A-49: Area of States and Other Areas: 1980

Division and State or Other Area	Year admitted to statehood	Total Area: Rank	Total Area: Sq. mi	Total Area: Sq. km	Land Area [1]: Sq. mi	Land Area [1]: Sq. km	Water Area [2]: Sq. mi	Water Area [2]: Sq. km
United States	(x)	(x)	3,618,770	9,372,614	3,539,289	9,166,759	79,481	205,856
New England	(x)	(x)	66,672	172,681	63,012	163,201	3,660	9,480
Maine	1820	39	33,265	86,156	30,995	80,277	2,270	5,879
New Hampshire	[3] 1788	44	9,279	24,032	8,993	23,292	286	739
Vermont	1791	43	9,614	24,900	9,273	24,017	341	883
Massachusetts	[3] 1788	45	8,284	21,456	7,824	20,265	460	1,191
Rhode Island	[3] 1790	50	1,212	3,140	1,055	2,732	158	408
Connecticut	[3] 1788	48	5,018	12,997	4,872	12,618	147	380
Middle Atlantic	(x)	(x)	102,203	264,707	99,733	258,308	2,470	6,398
New York	[3] 1788	30	49,108	127,190	47,377	122,707	1,731	4,483
New Jersey	[3] 1787	46	7,787	20,169	7,468	19,342	319	827
Pennsylvania	[3] 1787	33	45,308	117,348	44,888	116,260	420	1,088
East North Central	(x)	(x)	248,540	643,719	243,861	631,839	4,679	11,880
Ohio	1803	35	41,330	107,044	41,004	106,201	325	843
Indiana	1816	38	36,185	93,720	35,932	93,064	253	656
Illinois	1818	24	56,345	145,934	55,645	144,120	700	1,814
Michigan	1837	23	58,527	151,586	56,954	147,511	1,573	4,075
Wisconsin	1848	26	56,153	145,436	54,426	140,964	1,727	4,472
West North Central	(x)	(x)	517,825	1,341,166	508,132	1,316,063	9,693	25,104
Minnesota	1858	12	84,402	218,601	79,548	206,030	4,854	12,571
Iowa	1846	25	56,275	145,753	55,965	144,950	310	803
Missouri	1821	19	69,697	180,516	68,945	178,568	752	1,948
North Dakota	1889	17	70,702	183,119	69,300	179,486	1,403	3,633
South Dakota	1889	16	77,116	199,730	75,952	196,715	1,164	3,014
Nebraska	1867	15	77,355	200,350	76,644	198,508	711	1,842
Kansas	1861	14	82,277	213,098	81,778	211,805	499	1,293
South Atlantic	(x)	(x)	278,926	722,420	266,910	691,296	12,017	31,123
Delaware	[3] 1787	49	2,045	5,295	1,932	5,005	112	290
Maryland	[3] 1788	42	10,460	27,092	9,837	25,477	623	1,615
District of Columbia	(x)	(x)	68	178	63	162	6	16
Virginia	[3] 1788	36	40,767	105,586	39,704	102,832	1,063	2,754
West Virginia	1863	41	24,232	62,760	24,119	62,468	112	291
North Carolina	[3] 1789	28	52,669	136,413	48,843	126,504	3,826	9,909
South Carolina	[3] 1788	40	31,113	80,582	30,203	78,227	909	2,355
Georgia	[3] 1788	21	58,910	152,576	58,056	150,365	854	2,211
Florida	1845	22	58,664	151,939	54,153	140,256	4,511	11,683
East South Central	(x)	(x)	181,947	471,243	178,824	463,154	3,123	8,089
Kentucky	1792	37	40,410	104,660	39,669	102,743	740	1,917
Tennessee	1796	34	42,144	109,152	41,155	106,591	989	2,561
Alabama	1819	29	51,705	133,915	50,767	131,487	938	2,428
Mississippi	1817	32	47,689	123,515	47,233	122,333	457	1,183
West South Central	(x)	(x)	437,701	1,133,646	427,271	1,106,633	10,430	27,013
Arkansas	1836	27	53,187	137,754	52,078	134,883	1,109	2,872
Louisiana	1812	31	47,752	123,677	44,521	115,310	3,230	8,366
Oklahoma	1907	18	69,956	181,186	68,655	177,817	1,301	3,369
Texas	1845	2	266,807	691,030	262,017	678,623	4,790	12,407
Mountain	(x)	(x)	863,563	2,236,628	855,193	2,214,951	8,370	21,677
Montana	1889	4	147,046	380,848	145,388	376,555	1,658	4,293
Idaho	1890	13	83,564	216,432	82,412	213,447	1,153	2,985
Wyoming	1890	9	97,809	253,326	96,989	251,202	820	2,125
Colorado	1876	8	104,091	269,596	103,595	268,311	496	1,285
New Mexico	1912	5	121,593	314,925	121,335	314,258	258	667
Arizona	1912	6	114,000	295,260	113,508	293,986	492	1,274
Utah	1896	11	84,899	219,889	82,073	212,569	2,826	7,320
Nevada	1864	7	110,561	286,352	109,894	284,624	667	1,728
Pacific	(x)	(x)	921,392	2,386,408	896,253	2,321,296	25,140	65,112
Washington	1889	20	68,139	176,479	66,511	172,264	1,627	4,215
Oregon	1859	10	97,073	251,419	96,184	249,117	889	2,302
California	1850	3	158,706	411,049	156,299	404,814	2,407	6,235
Alaska	1959	1	591,004	1,530,700	570,833	1,478,458	20,171	52,243
Hawaii	1959	47	6,471	16,759	6,425	16,641	46	118
Other areas:								
Puerto Rico	(x)	(x)	3,515	9,104	3,459	8,959	56	145
American Samoa	(x)	(x)	77	199	77	199	-	-
Guam	(x)	(x)	209	541	209	541	-	-
Virgin Islands of the U.S.	(x)	(x)	132	342	132	342	1	3
Pacific Islands, Trust Territory of the [4]	(x)	(x)	533	1,381	533	1,381	-	-
No. Mariana Islands [4]	(x)	(x)	184	477	184	477	-	-

- Represents zero. X Not applicable. [1] Dry land and land temporarily or partially covered by water, such as marshland, swamps, etc., streams and canals under one-eighth statute mile wide; and lakes, reservoirs, and ponds under 40 acres in area. [2] Permanent inland water surface, such as lakes, reservoirs, and ponds having an area of 40 acres or more; streams, sloughs, estuaries, and canals one-eighth statute mile or more in width; deeply indented embayments and sounds, and other coastal waters behind or sheltered by headlands or islands separated by less than 1 nautical mile of water, and islands under 40 acres in area. Excludes areas of oceans, bays, sounds, etc., lying within U.S. jurisdiction but not defined as inland water. [3] Year of ratification of Constitution; one of the original 13 States. [4] Under trusteeship; see table 3, footnote 5.

Source: U.S. Bureau of the Census, *1980 Census of Population*, vol. I, part A (PC80-1-A), and unpublished data.

Source: *Statistical Abstract of the United States, 1987*

DEFINITIONS AND DERIVATIONS: HYDROPOWER

Accessible Resource

Derivation of Accessible Resource Value

The accessible resource includes existing capacity, thoroughly identified potential for expanding capacity at existing sites, and potential hydropower capacity at new sites. The general approach used by the Corps of Engineers (COE) for estimating these values is explained in the reserves discussion. Note that even the potential new sites were subjected to an economic evaluation by the COE, so these resources are both extractable with current technology and potentially economic. They were included in accessible rather than reserves simply because the data and the potential for their development are much more tenuous than for capacity at existing sites. The original values for current capacity were for energy production, and so were increased by the reciprocal of large-scale hydroelectric plant efficiency (82.5%) to estimate the true resource potential before conversion.

Table A-50: Hydropower Accessible Resource Calculations

Value:	26.5 BBOE
Source Values:	2.85×10^{14} Wh average annual hydropower output
	2.23×10^{14} Wh annual hydropower potential, existing
	9.35×10^{14} Wh annual hydropower potential, new sites
Conversion Formula:	$\frac{(A/B + C + D) \times E}{F} = 26.5 \times 10^9$ Barrels of Oil Equivalent
	A = 2.85×10^{14} Wh average annual hydropower output
	B = .825 efficiency of a large-scale hydropower plant
	C = 2.23×10^{14} Wh annual hydropower potential, existing
	D = 9.35×10^{14} Wh annual hydropower potential, new sites
	E = 30 years
	F = 1.7×10^6 Wh equivalent to one barrel oil
Years Estimated:	1979 and 1987

Table A-51: Inventory of Hydroelectric Power Resources

CAPACITY RANGES

	Number of Sites	Capacity (MW)	Energy (GWH)
Small-Scale (.05-15 MW)			
Existing[a]	842	2,957	15,048
Potential/Incremental[b]	4,813	5,455	17,267
Undeveloped[c]	2,642	8,010	28,843
Total	8,297	16,422	61,158
Intermediate (15-25 MW)			
Existing	81	1,317	6,717
Potential/Incremental[b]	166	3,320	7,859
Undeveloped[c]	387	7,722	23,503
Total	634	12,559	38,079
Large Scale (Greater than 25 MW)			
Existing	328	59,230	258,239
Potential/Incremental[b]	445	85,859	198,087
Undeveloped[c]	1,503	338,217	883,519
Total	2,279	483,306	1,339,845
All Sizes (Total)			
Existing	1,251	63,702	280,004
Potential/Incremental[b]	5,424	94,636	353,948
Undeveloped[c]	4,532	353,948	935,867
TOTAL	11,207	512,286	1,439,085

a Existing hydroelectric power facilities currently generating power.
b Existing dams and/or other water resource projects with the potential for new and/or additional hydroelectric capacity.
c Undeveloped sites where no dam or other engineering structure presently exists.

Source: Data from *U.S. Army Corp of Engineers National Hydroelectric Power Resource Study,* AD-A075 962/1, June 1979, p. 7.

DEFINITIONS AND DERIVATIONS: HYDROPOWER

Reserves

Derivation of Reserve Value

The reserve value for current hydropower capacity is based on average annual U.S. hydroelectric generation between 1977 and 1987, based on *Electric Power Monthly,* November 1987, (Washington DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0226 87/11, February 1987), page 10, table 4. The incremental annual hydropower potential that is technically and economically available is based on *U.S. Army Corps of Engineers National Hydroelectric Power Resources Study: Preliminary Inventory of Hydropower Resources, Volume One: Pacific Northwest Region,* (Fort Belvoir, VA: U.S. Army Corps of Engineers Institute for Water Resources, AD-AO75 962/1, June 1979), page 7. Capacity value for large-scale hydropower from *Technology Characterizations: Environmental Information Handbook,* (Washington DC: U.S. Department of Energy, Office of Environmental Programs, DOE/EP-0028, Second Edition, June 1981), page 188.

The reserve value is a combination of existing hydroelectric power production, which is clearly economic, and potential hydroelectric power production at existing dam sites which has a very clear potential for economic development. Only this category of identified hydropower potential was included because the analysis used to estimate this potential is more certain than for completely new sites. The original values for current capacity were for energy production, and so were increased by the reciprocal of large-scale hydroelectric plant efficiency (82.5%) to estimate the true resource potential before conversion.

In studying these resources the Corps of Engineers (COE) looked at both existing dams and undeveloped sites. The COE then used computer models to analyze head, storage, and streamflow estimates to compute the capacity and energy potential of each existing dam and undeveloped site. Generally, the sites included in the analysis have a capacity of 50 kW or more. Sites that passed this initial examination were then examined in more detail and were related to equipment and construction costs and generalized regional power values to ascertain economic feasibility. The estimates may be high because of the COE's inability to control factors such as turbine inefficiencies, dam impacts on the resource, interactions between sites, and social, economic and political constraints.

From an economic and environmental standpoint the potential additional capacity at existing sites was chosen to represent reserves because it is based on the most complete data and is the most likely source of new capacity. New sites are more speculative simply because they are more difficult to develop for environmental reasons and are based on less reliable data. They are included in accessible resources instead.

Economic Assumptions

The economic assumptions included in the COE study cover both the costs of equipment and construction and the price of competing sources of electric power in the specific regions where the potential was located. A range of regional electricity values was used for comparison. The calculations were performed in 1978, so the cost and price comparisons are in then-current dollars and reflect prices at that time. The exact assumptions are not available in the documentation; they are incorporated into the computer program used to conduct the analysis.

Table A-52: Hydropower Reserve Calculations

Value:	10 BBOE
Source Values:	2.85×10^{14} Wh average annual hydropower output
	2.23×10^{14} Wh annual hydropower potential, existing
Conversion Formula:	$\frac{(A/B + C) \times D}{E} = 10 \times 10^9$ Barrels of Oil Equivalent
	A = 2.85×10^{14} Wh average annual hydropower output
	B = .825 efficiency of a large-scale hydropower plant
	C = 2.23×10^{14} Wh annual hydropower potential, existing
	D = 30 years
	E = 1.7×10^6 Wh equivalent to one barrel oil
Year Estimated:	1979 and 1987

APPENDIX B:

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Averitt, Paul. *Coal Resources of the United States, January 1, 1974,* (Washington, D.C.: U.S. Geological Survey Bulletin 1412, 1974).

2. Pacific Northwest Laboratory. *Wind Energy Resource,* 1980-1981 (Battelle Pacific Northwest Laboratory PNL-3195-WERA, 1981).

3. Pacific Northwest Laboratory. *Wind Energy Resource Atlas,* v. 1-12, (PNL-3195-WERA-1/12), 1980-1981.

4. Pacific Northwest Laboratory. *Wind Energy Resource Atlas of the United States,* (DOE/CH 10093-4), October 1986.

5. Cherry, Neil. "An Estimate of the Known Wind Resource of the United States", Pacific Northwest Laboratory, 1981.

6. *Coal Production 1986,* (Washington, D.C.: Energy Information Administration, DOE/EIA-0118 1986).

7. *Energy Potential of Texas Crops and Agricultural Residues,* (Texas A&M University, The Texas Agricultural Experiment Station Center for Energy and Mineral Resources), February 1978.

8. Farnham Rouse S., et al. *Energy from Peat, Subcommittee 8 Report to the Minnesota Energy Agency,* (St. Paul: University of Minnesota, 1978).

9. Knapp, Stoffel, and Whitaker. *Insolation Data Manual* (Golden, Colorado: Solar Energy Research Institute, October 1, 1980).

10. LeBel, Phillip. *Energy, Economics, and Technology,* (Baltimore, MD: John Hopkins University, 1982).

11. Mast, R.F.; Dalton, G.L.; Crovelli, R.A.; Powers, R.B.; Charpentier, R.R.; Root, D.H.; and Attanasi E.D. "Estimates of Undiscovered Recoverable Oil and Gas Resources for the Onshore and State Offshore Areas of the United States," *The McKelvey Forum Papers,* 1988, pp. 31-32.

12. Meridian Corporation. *Waste to Energy: A Primer for Utility Decisionmakers,* (Washington DC: Meridian Corporation for the Western Area Power Administration and American Public Power Association, Dec. 1986).

13. Muffler, L.J.P., ed., *Assessment of Geothermal Resources of the United States - 1978.* (Washington, D.C.: U.S. Department of Interior, U.S. Geological Survey, Circular 790, 1978).

14. *National Assessment of Undiscovered Conventional Oil and Gas Resources* (Denver, Colorado: U.S. Geological Survey and U.S. Minerals Management Service, Open-File Report 88-373, 1988).

15. *National Hydroelectric Power Resources Study: Preliminary Inventory of Hydropower Resources, Volume One: Pacific Northwest Region,* (Fort Belvoir Virginia: U.S. Army Corps of Engineers Institute for Water Resources, AD-A075 962/1, June 1979).

16. National Petroleum Council. *Enhanced Oil Recovery* (Washington, D.C.: National Petroleum Council, June 1984).

17. National Petroleum Council. *Unconventional Gas Resource Part 1: Tight Gas Reservoirs* (Washington, D.C.: National Petroleum Council, 1980).

18. Office of Technology Assessment. *Energy from Biological Processes: Technical and Environmental Analyses,* (Washington DC: Congressional Office of Technology Assessment, Ballinger Press, 1983).

19. "Premature and Off the Mark, Says Hodel of Gas Reserves Flap, " *The Energy Daily,* March 18, 1988, p. 3.

20. *Principles of the Mineral Resource Classification System of the U.S. Bureau of Mines and U.S. Geological Survey,* (Washington, D.C.: Geological Survey Bulletin 1450-A, 1976).

21. Sorenson, Brent. *Renewable Energy,* (Copenhagen, Denmark: The Niehls Bohr Institute, University of Copenhagen, Academic Press, 1979).

22. U.S. Department of Agriculture. *Agricultural Statistics, 1986, (Washington, DC: U.S. Department of Agriculture, 1986).*

23. U.S. Department of Agriculture. *Fuel Ethanol and Agriculture: An Economic Assessment,* (Washington, DC: Office of Energy, U.S. Department of Agriculture, Agricultural Economic Report Number 562, August 1986).

24. U.S. Department of Commerce. *Statistical Abstract of the United States - 1987,* Bureau of the Census.

25. U.S. Department of Energy. *Electric Power Monthly, November 1987,* (Washington DC: U.S. Department of Energy, Energy Information Administration, DOE/EIA-0226 87/11).

26. U.S. Department of Energy. *Energy Facts 1986,* (Washington, D.C.: Department of Energy; DOE/EIA-0469 (86).

27. U.S. Department of Energy. *National Photovoltaics Program Five Year Research Plan, 1987-1991,* (Washington, D.C.: Department of Energy, DOE/CH10093-7, 1987).

28. U.S. Department of Energy. *National Solar Thermal Technology Program Five Year Research and Development Plan, 1986-1990,* (Washington, D.C.: U.S. Department of Energy, DOE/CE - 0160, 1986).

29. U.S. Department of Energy. *Technology Characterizations: Environmental Information Handbook,* (Washington, D.C.: U.S. Department of Energy, DOE/EP-0028, June, 1981).

30. U.S. Department of Energy. *Technology Characterizations: Environmental Information Handbook,* (Washington DC: U.S. Department of Energy, Office of Environmental Programs, DOE/EP-0028, Second Edition, June 1981).

31. U.S. Department of Energy. *Uranium Industry Annual 1987,* (Washington, D.C.: Energy Information Administration, October 1988).

32. U.S. Department of Energy. *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1986 Annual Report,* (Washington, D.C.: Energy Information Administration, 1987).

33. U.S. Department of Energy. *U.S. Crude Oil, Natural Gas and Natural Gas Liquids Reserves, 1986 Annual Report,* (Washington, D.C.: U.S. Department of Energy DOE/EIA-0216, 1987).

34. U.S. Environmental Protection Agency. *Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry,* (Washington DC: Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA, PB87-206140, June 1987).

35. U.S. Geological Survey, *U.S. Mineral Resources,* Washington, D.C.: U.S. Geological Survey Professional Paper 980, 1973).

36. Utility Data Institute, Washington, D.C., 1985.

37. White, D.E., and Williams, D.L. *Assessment of the Geothermal Resources of the United States - 1975,* (Washington, D.C.: U.S. Department of Interior, United States Geological Survey Circular 726, 1975).