

*Is there a thing of which it is said,
"See, this is new" ?
It has been already, in the ages before us.
There is no remembrance of former things,
nor will there be any remembrance of later things
yet to happen among those who come after.*

--Ecclesiastes 1: 10-12

The estimates of the oil reserves in the proved and discovered fields are reasonably reliable, and those for regions regarded by the geologists as embracing "probable" future oil fields are based on all the available data and are entitled to high respect, but the committee wishes it most clearly understood that the estimates of oil in "possible" territory are absolutely speculative and hazardous and that, although they represent the best judgment of the geologists, they nevertheless may be, at least in part, wildly erroneous. The questions involved are not only how much a particular doubtful region will yield, but whether it will furnish any oil whatever. On the whole the estimates are undoubtedly the best that have ever been made for the United States and better than have hitherto been prepared for any oil country or district of the world.

--Hearings on House Resolution 441 (September 17-22, 1934, part 2, p. #1071).

The last general survey of the oil resources of the United States made in 1921 by the United States Geological Survey in cooperation with the American Association of Petroleum Geologists--a most thorough and painstaking effort--was proven within 12 months . . . to be a gross underestimate.

--Hearings on House Resolution 441. (September 17-22, 1934, part 2, p. #1074).

It has been repeatedly questioned whether estimates of oil reserves are of any practical value, as the greater number of such calculations previously made have subsequently been proved to be grossly inaccurate. . . . The value of these estimates, therefore, hinges on the clear understanding that they can only apply within the limited time when the controlling factors remain unchanged.

--Valentin R. Garfias, AIME Transactions, v. 103, p. 352, 1933).

INTRODUCTION

By Donald L. Gautier

The purpose of the National Oil and Gas Resource Assessment Project is to develop scientifically based hypotheses concerning the quantity of oil and gas that might be added to the reserves of the United States, as of January 1, 1994. This publication presents the results and principal documentation of the project.

The word "assessment" can be misleading. To some, relying on an oil and gas assessment is not far removed from the Romans basing national policy upon the reading of animal entrails. To others, assessment implies the measurement, evaluation, or enumeration of some well-defined and uniquely determined quantity or commodity. This second, more charitable view suggests a procedure analogous to counting cans of green beans on the shelves in a supermarket, a process that is clearly defined, and yields results that are certain within any specified tolerance. Both views are wrong.

The National Assessment is an attempt to bound the uncertainties concerning potential additions to oil and gas reserves under a specific set of conditions. As such, the assessment consists of a set of constructs, based upon the best information and theory available to the U.S. Geological Survey (USGS) scientists charged with this effort. A better green-bean analogy might be an attempt to estimate food supplies of some distant country based upon high-altitude satellite images of warehouses thought to contain groceries, observing the coming and going of trucks and trains depleting and restocking inventories, and measuring rates of food consumption through time. The National Assessment is neither inventory nor superstition. Rather, it is a process. Each successive assessment is a refinement of previous work.

This National Assessment is essentially a geological evaluation that makes no attempt to predict what part of potential additions will actually be added to reserves. Additions to reserves require access, drilling, infrastructure development, and marketing, which, in turn, are affected by economics, politics, and various other factors in addition to geologic considerations. For the purposes of the National Assessment, resources and potential reserve additions are evaluated regardless of political or aesthetic considerations. Thus, resources and potential reserve additions are reported, whether they exist under the most pristine parts of the most popular National Park or beneath privately held lands within existing oil fields.

The estimates presented in this document reflect USGS understanding as of January 1, 1994, and are intended to capture the range of uncertainty, to provide indicators of the relative potential of various petroleum provinces and regions considered in this assessment, and to provide a guide useful in considering possible effects of future oil and gas exploration and recovery within the United States.

The USGS has responsibility for resource evaluation in all onshore areas and in State waters. Since 1982, the Minerals Management Service has had sole responsibility and authority for evaluation of the Federal offshore areas. For the purposes of assessment, the onshore and State offshore areas of the United States were divided into 71 geologic provinces comprising eight regions. The regions correspond, in general, to those addressed by Mast and others (1989). Hawaii was not included in this assessment because its volcanic terrain is not considered prospective for additions to oil and gas reserves.

In certain tables, graphs, and other displays, reference may be made to the proven reserves of the United States. Any information presented herein concerning known reserves of discovered oil and natural gas was derived from "U.S. crude oil, natural gas, and natural gas liquids reserves-1993 annual report," published by the Energy Information Administration of the U.S. Department of Energy.

SCOPE OF THE ASSESSMENT

The commodities considered in this study are crude oil, natural gas, and natural gas liquids that can be expected to be produced through a well. Specifically excluded from quantitative assessment of technically recoverable resources are intractable heavy oil deposits, gas in geopressured shales and brines, resources in tar deposits, clathrate hydrates, and oil shales. However, specifically included in this assessment are gas from low-permeability tight-sandstone reservoirs, gas and oil from fractured shale reservoirs, and coal-bed gas. Tar sands and gas hydrates are discussed in terms of in-place resources in "Heavy oil resources of the United States" by Mark J. Pawlewicz and in "Gas hydrate resources of the United States" by Timothy S. Collett. The inclusion of these unconventional resources marks a significant departure from previous USGS assessments.

Crude oil, as considered in this assessment, is a natural liquid, consisting mainly of a mixture of complex hydrocarbon molecules. Natural gas is mainly a mixture of hydrocarbon gases, principally methane, and certain nonhydrocarbon gases such as

carbon dioxide, hydrogen sulfide, nitrogen, and helium. Natural gas liquids (NGL) are those portions of reservoir gas that are liquefied at the surface in various field facilities such as lease separators or in gas processing plants. NGL commonly includes propane, ethane, butane, pentane, natural gasoline, and condensate.

Previous USGS assessments focused upon the evaluation of undiscovered conventionally recoverable accumulations of oil and gas. This assessment is broader in scope, as it considers three categories of resources: (1) conventional undiscovered technically recoverable accumulations of oil and gas, (2) oil and gas in continuous-type accumulations (largely equivalent to many analysts' unconventional categories), and (3) additions to reserves of known fields.

1. **Undiscovered technically recoverable conventional accumulations of oil and gas** are the traditional fare of the oil and gas industry and of most previous USGS oil and gas assessments. These resources include those postulated to exist outside known fields or accumulations, and which, if found, could be extracted using traditional development practices. They are discrete accumulations, usually, but not invariably, defined, controlled, or limited by a hydrocarbon-water contact.

2. **Continuous-type accumulations**, as defined for this assessment, include those oil and gas resources that commonly exist as broad-based accumulations and that generally lack a well-defined oil-water or gas-water contact. This geologically grounded definition is in keeping with the mission of the USGS and provides a set of consistent geological criteria to be applied in the determination. It thus avoids the regulatory criteria of the Federal Energy Regulatory Commission designations and does not rely on any particular permeability as a defining criterion. Included in this category are coal-bed gas, gas in many of the so-called "tight gas" sandstone reservoirs, autosourced oil and gas shale reservoirs, and gas in clathrate-hydrate structures. Because of the immense quantities of oil and gas that can be included in this category, only those resources that, in our judgment, could be added to U.S. oil and gas reserves during the next few decades (by approximately 2020) are considered and reported upon in this study. Those resources judged to be potential additions to reserves are further subdivided into undiscovered and reserve-growth categories. The analysis of continuous-type accumulations assumes the application of existing technology as of the date of this assessment.

3. **Reserve growth** includes those resources expected to be added to reserves as a consequence of extensions of known fields, through revisions of reserve estimates, and

by additions of new pay zones in discovered fields. Also included in this category are resources expected to be added to reserves through application of improved recovery techniques. This category thus includes both the *indicated reserves* and the *inferred reserves* described in earlier USGS assessment publications. Predictions of reserve growth are considered with respect to fields found before 1992 (the date of most reserve data used in this report). The analysis of reserve growth is based upon the proprietary Oil and Gas Integrated Field File of the Energy Information Administration.

Each of these three broad categories of resources requires a different technique for evaluation. Each of these resources is thus described and considered in separate sections of this document. The methods for assessment of the undiscovered, recoverable conventional accumulations as discussed in a "Methodology for assessment of undiscovered conventional accumulations" by Donald L. Gautier and Gordon L. Dolton. The techniques used for evaluation of various unconventional resources are discussed in "Method for assessing continuous-type (unconventional) hydrocarbon accumulations" by James W. Schmoker, "Methodology for assessment of technically recoverable resources of coalbed gas" by Dudley D. Rice, and "Gas hydrate resources of the United States" by Timothy S. Collett. Results of these various resource evaluations are generally reported as separate categories.

TERMINOLOGY

The terminology used in this report is intended to represent standard definitions and usage practiced by the oil and natural gas industry and the resource assessment community. No attempt has been made to include a detailed listing of common industry definitions; however, several definitions that are essential to the proper understanding of the materials in this report are presented. The definitions are intended to be generally explanatory rather than strictly technical.

Undiscovered Resources.--Resources postulated from geologic information and theory to exist outside of known oil and or gas fields.

Technically Recoverable Resources.--Resources producible using current recovery technology but without reference to economic profitability. These are oil and natural gas resources that may be produced at the surface from a well as a consequence of natural pressure within the subsurface reservoir, artificial lifting of oil from the reservoir to the surface, and the maintenance of reservoir pressure by fluid injection. (Definition modified from the National Petroleum Council). These resources are

generally conceived as existing in accumulations of sufficient size to be amenable to the application of existing recovery technology.

Measured (proved) Reserves.--That part of the identified economic resource that is estimated from geologic evidence supported directly by engineering data. Measured reserves are demonstrated with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions. Resources in this category are not a principal focus of this assessment. Data reported are from the Energy Information Administration (EIA, 1994).

Conventional Accumulation.--A discrete deposit, usually bounded by a downdip water contact, from which oil, gas, or NGL can be extracted using traditional development practices including production at the surface from a well as a consequence of natural pressure within the subsurface reservoir; artificial lifting of oil from the reservoir to the surface where applicable; and the maintenance of reservoir pressure by means of water or gas injection.

Continuous-Type Deposit.--A hydrocarbon accumulation which is pervasive over a large area, which is not significantly affected by hydrodynamic influences, and for which the standard methodology for assessment of sizes and numbers of discrete accumulations is not appropriate.

Unconventional Accumulation.--A broad class of hydrocarbon deposits of a type that historically has not been produced using traditional development practices, such as tight gas sands, gas shales, and coalbed gas. Such accumulations include most continuous-type deposits.

Field Growth (Inferred Reserves).--that part of the identified resources over and above measured (proved) reserves that will be added through extension, revision, improved recovery efficiency, and the addition of new pools or reservoirs. Throughout this CD-ROM, the terms "reserve growth" and "field growth" are used interchangeably. Both terms indicate growth of reserves in known fields.

Inferred Reserves.--For this report inferred reserves includes two resource categories used in previous USGS oil and gas assessment documents (Mast and others, 1989): Indicated Reserves and Inferred Reserves.

Indicated Reserves.--that part of the identified oil resources in known productive reservoirs in existing fields in addition to measured reserves which are expected to

respond to improved recovery techniques. For this report, indicated reserves are included as part of inferred reserves.

Barrels of Oil Equivalent (BOE).--Gas volume that is expressed in terms of its energy equivalent in barrels of oil. For this assessment , 6,000 cubic feet of gas is one barrel of oil equivalent (BOE).

Gas-Oil Ratio (GOR).--Average ratio of associated-dissolved gas to oil; a point estimate of the volume of gas (in cubic feet) dissolved in oil or otherwise associated with a barrel of oil in known or postulated oil accumulations. As in the past National Assessment, an accumulation with a GOR in excess of 20,000 is considered a gas accumulation.

NGL to Non-Associated Gas Ratio.--The volume of natural gas liquids (in Barrels) contained in a million cubic feet of gas in a known or postulated gas accumulation.

NGL to Associated-Dissolved Gas Ratio.--The volume of natural gas liquids (in Barrels) contained in a million cubic feet of associated-dissolved gas in a known or postulated oil accumulation.

Field.--An individual producing unit consisting of a single pool or multiple pools of hydrocarbons grouped on, or related to, a single structural or stratigraphic feature.

Accumulation.--The basic geologic unit of this assessment, consisting of a single oil or gas deposit as defined by the trap, charge, and reservoir characteristics of the play.

Play.--A play is a set of known or postulated oil and (or) gas accumulations sharing similar geologic, geographic, and temporal properties such as source rock, migration pathway, timing, trapping mechanism, and hydrocarbon type.

Play Area.--The two dimensional plan extent over which a play concept is considered to be valid and within which all known accumulations and potential for undiscovered accumulations or other additions to reserves within the play exist.

Play Attributes.--Geologic characteristics that describe principal properties of and necessary conditions for the occurrence of oil and (or) gas accumulations of the minimum size (1 MMBO or 6 BCFG) within the defined parameters of a play. Although many combinations of individual underlying elements are possible, three attributes were considered in the evaluation of play risk in this assessment. These attributes are as follows:

1. **Charge.**--The occurrence of conditions of hydrocarbon generation and migration adequate to cause an accumulation of the minimum size. Included in

this attribute are subsidiary elements including existence of source rocks with sufficient organic matter of the appropriate composition, appropriate temperature and duration of heating to generate and expel sufficient quantities of oil and (or) gas, and timing of expulsion of oil and gas from source rocks appropriate for filling available traps.

2. **Reservoir.**--The occurrence of reservoir rocks of sufficient quantity and quality to permit the containment of oil and (or) gas in volumes sufficient for an accumulation of the minimum size.

3. **Trap.**--The occurrence of those structures, pinchouts, permeability changes and similar parameters necessary for the entrapment of oil and (or) gas in at least one accumulation of the minimum size. Included in this attribute are existence of seals sufficient for entrapping hydrocarbons and capable of holding oil and gas accumulations during appropriate ranges of geologic time.

Play Probability.--Play probability represents the product of the probabilities of the three play attributes considered in this assessment (charge, reservoir, and trap). It is an estimate expressed as a decimal fraction, of the chance that oil or natural gas exist within the area of a particular play. For recoverable resources, the play probability represents the likelihood that technically recoverable quantities of oil or natural gas exist in at least one accumulation of the minimum size (1 MMBO or 6 BCFG) in the area being assessed.

Conditional Estimates.--Estimates of sizes, numbers, or volumes of oil or natural gas which may exist in an area, given they are present. Conditional estimates, therefore, do not incorporate the risk that the area may be devoid of oil or natural gas.

Risked (Unconditional) Estimates.--Estimates of the resources that may exist, including the possibility that the area may be devoid of oil or natural gas. Statistically, the risked mean may be determined through multiplication of the mean of a conditional distribution by the related probability of occurrence. Resource estimates presented in this report are risked estimates.

Cumulative Probability Distributions for Resource Estimates.--Graphical depictions of estimated possible resource volumes presented with associated cumulative probabilities of occurrence. These distributions are used to derive the 95 percent, 5 percent, and mean resource levels reported in this publication; a low case, with a 95 percent probability of that amount or more occurring (a 19 in 20 chance), a high case,

with a 5 percent probability of that amount or more occurring (a 1 in 20 chance), and an average (mean) case representing an arithmetic average of all the possible resource occurrences weighted by their probabilities.

DATA SOURCES

The USGS portion of the National Assessment Project relies largely upon data that are either published or commercially available. Some USGS geologic data are from in-progress studies and have not necessarily been entirely published. In several areas, drilling and production information was especially sparse or unreliable. Seven major data sources were used by the USGS in this assessment:

1. USGS geologic data, both published and unpublished, were used in the development of play definitions, play boundaries, and in the analysis of geologic information concerning undiscovered conventional oil and gas accumulations and possible future developments in continuous-type oil and gas accumulations.
2. The Significant Oil and Gas Fields of the United States file (NRG) is a database commercially available from NRG Associates, Inc., which includes reserves, cumulative production and various other types of information for most oil and gas fields of the United States larger than one million BOE. The NRG release dated December 31, 1992 was a major source of reservoir level information for this assessment.
3. The Well History Control System (WHCS) is a commercially available database of computerized drilling and completion data from almost 2.5 million exploratory and development wells available from Petroleum Information Corporation (PI). Data were used to construct various exploration and development intensity maps and various plots and statistical analyses of drilling, discovery, and drilling. For most of the areas assessed, the 1993 and 1994 versions of WHCS were used. In most provinces, the WHCS contains essentially all wells drilled. However, in certain areas, especially the Eastern Interior, Appalachian basin, California, and parts of Oklahoma and Louisiana, drilling information is incomplete.
4. Petroleum Information Corporation production data files, including monthly, yearly, and cumulative production information from numerous recent wells in the United States were employed to construct decline curves and estimated ultimate recovery (EUR) distributions used in the analysis of potential additions to reserves from continuous-type deposits.

5. Energy Information Administration (EIA) Oil and Gas Integrated Field File (OGIFF) is a proprietary file of field-level reserves and production information. The data in OGIFF are collected according to legal mandate by the Department of Energy from operators of significant oil and gas fields of the United States. This file, which includes yearly estimates of reserves from each of the significant fields of the United States was used mainly as a database for the prediction of potential additions to reserves of known fields. In a few areas of sparse data, especially Oklahoma and the Appalachian region, the OGIFF was used to supplement NRG for estimation of field sizes. Because of the sensitivity of the OGIFF data, however, the output provided in this report has been generalized, rounded, or eliminated to avoid releasing any of those data. This is particularly apparent in the output for provinces 055 (Nemaha Uplift), 056 (Forest City basin), 060 (Cherokee Platform), and 067 (Appalachian basin).

6. Energy Information Administration, 1994, U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1993 Annual Report, is the basis of measured (proved) reserve information reported here.

7. Other data, including publications, State records, proprietary energy company reports, and other sources were used by individual province geologists, and are cited in appropriate sections of this report. Contributions of time, information, and insight by numerous individuals working in the United States oil and gas industry and State geological surveys were particularly helpful in play definition. Many of these individuals are acknowledged individually in appropriate sections of the text. In certain areas of the country where drilling, completion, reserves, or production data are sparse, absent, or unreliable, province geologists devoted significant effort to compiling original data bases for reservoir and field level information. This was particularly the case for Oklahoma, the States of the Appalachian basin, Louisiana, and California.

PUBLICATION MEDIA

In addition to those media traditionally used for the publication of the results and documentation of USGS projects, such as paper maps, USGS Circulars, and non-USGS scientific journals, the results and documentation for the National Assessment are being released as digital files on CD-ROM. The use of this CD-ROM and procedures for accessing and using the data are described in "CD-ROM design notes" by Kenneth I. Takahashi (this CD-ROM).

GEOLOGIC NAMES DISCLAIMER

This report has not been reviewed for conformity with the North American Stratigraphic Code nor for conformity with U.S. Geological Survey information pertaining to lithostratigraphic units or regarding stratigraphic nomenclature. To simplify the task of end users who may have reason to consult the original data sources, no attempt has been made to alter the original nomenclature, unless specifically noted. The stratigraphic nomenclature used in this assessment is that of the original source(s) upon which the play discussions are based.

REFERENCES

- Mast, R.F., Dolton, G.L., Crovelli, R.A., Root, D.H., Attanasi, E.D., Martin, P.E., Cooke, L.W., Carpenter, G.B., Pecora, W.C., and Rose, M.B., 1989, Estimates of undiscovered conventional oil and gas resources in the United States--a part of the nation's energy endowment: U.S. Geological Survey and Minerals Management Service, 44 p.
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