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Comparison of Natural Gas Assessments

by

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INTRODUCTION

Resource assessments of natural gas differ in almost every respect. No two assessments have been done in exactly the same way, based on the same set of geologic and production data, or based on the same set of ground rules and methods. The obvious conclusion might be that assessments cannot really be compared.

On the other hand, one might conclude that all natural gas assessments are seeking **the right answer**, some fundamental truth about remaining oil and gas resources, e.g. XX trillion cubic feet (Tcf) of technically recoverable gas remain to be discovered, no more or no less! Based on this assumption, assessments can be compared at face value, without concern for details, because they all represent different approaches to finding out some truth, and should ultimately converge.

We subscribe to a view that the Earth's gas resource is a continuum, extending from very high quality (e.g. wells and reservoirs with high production potential and good economics) to very low quality (e.g. gas dissolved in lakes and rivers). Certain assumptions, conditions, and data parameters of an assessment define the cutoff point in this continuum associated with a particular assessment. When the cutoff points differ, the results differ.

Our own U.S. Geological Survey (USGS) assessments illustrate this point. For example, in our 1989 assessment, lower quality (unconventional) gas accumulations were excluded. The assessment results were low overall when compared to other current assessments, but defensible for the portion of the continuum that was assessed. In the 1995 USGS assessment, the volume of undiscovered gas was much higher, in part because we assessed lower quality gas resources that lie further along the continuum.

In order to understand assessments of natural gas by different organizations, the variables and assumptions underlying each assessment need to be identified. "Apples and oranges" comparisons are very deceiving and provide erroneous conclusions. For a more realistic comparison (apples and apples), resource categories need to be subtracted from or added to some assessments. Even when this is done, comparisons may still be difficult to make because of differing methodologies, quantitative techniques, and databases used.

Even after a thorough analysis of assessments, the most comparable ones may be those conducted by the same organization through time. In this way, the evolution of thinking of a single organization can be analyzed, and trends in methodology through time can be used to understand how similar assessments change.

The purpose of this report is to compare the six most frequently-referenced National petroleum assessments of the last 5 years. We first identify the assessments we have chosen and then describe the factors which are most important in contributing to the differences in their results. Our discussion includes a section describing both "process" and "method" factors. Process factors include non-methodological differences in assessments such as the nature of the intended audience and the composition and structure of the assessment team, whereas method factors include differences due to quantitative techniques, data, and categories of resources. Finally, we discuss the overall differences in the resource estimates resulting from these assessments in light of the many factors controlling them. We use the 1992 National Petroleum Council (NPC) assessment as a convenient baseline from which to compare the other assessments (National Petroleum Council, 1992). Our report only deals with natural gas assessments, but most factors equally apply to oil assessments as well.

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IDENTIFICATION OF ASSESSMENTS COMPARED

For this study, we selected six major U.S. natural gas assessments of the last 5 years (Table 1). We treated the USGS 1995 and MMS 1996 assessments as a single total for Table 1. The Minerals Management Service (MMS) is the U.S. Interior Department (DOI) agency responsible for assessing undiscovered resources in the U.S. Outer Continental Shelf (OCS), whereas the USGS only assesses onshore and State offshore areas (U.S. Geological Survey Assessment Team, 1995; Minerals Management Service, 1996). We included the ENRON 1993 assessment in this study, rather than the ENRON 1995 assessment because the focus of the ENRON 1995 assessment was primarily international (ENRON, 1995). Also included here are assessments by NPC in 1992, PGC in 1995, and GRI in 1995 (Potential Gas Committee, 1995; Woods, 1995). The PGC 1997 assessment was published just before this report was completed but is not included here. The 1989 USGS/MMS and 1990 U.S. Department of Energy (DOE)/Energy Information Administration (EIA) assessments are not evaluated here with the other, more recent assessments (Mast and others, 1989). The 1989 USGS/MMS assessment did not include unconventional resources and used methods which are very similar to those of the 1995 USGS and 1996 MMS assessments. The 1990 DOE/EIA assessment was largely a derivative assessment using data and results of others.

Information for this report was taken directly from published documents of each organization, and an expert from each organization reviewed an early version of our analysis.

ASSESSMENTS NOT INCLUDED IN THIS STUDY

USGS/MMS 1989 Assessment

The 1989 USGS/MMS assessment was not included in the assessment comparison, but we include a brief summary here (Mast and others, 1989). This assessment was superseded by the USGS and MMS assessments in 1995 and 1996 respectively. Methods used by the USGS and MMS in 1989 were similar to those used in 1995 and 1996, but the assessments differ in part because different data sets were used. The USGS 1989 assessment did not include estimates of unconventional resources, whereas the 1995 USGS assessment did in the form of continuous-type accumulations in which the play definition was based on geologic characteristics rather than on narrowly-defined regulatory criteria such as less than 0.1 md. Continuous-type accumulations of coalbed gas, tight sandstone gas, chalk and shale gas, and some shallow biogenic gas were excluded from the 1989 assessment.

The USGS 1989 assessment included about 250 plays from 80 provinces, whereas the 1995 assessment included 562 plays (Tables 2 and 3). The MMS assessment included 35 provinces, but the total number of plays was not identified in the final report. Reserve growth functions for the USGS 1989 assessment were calculated from DOE/EIA data published in 1987 (Energy Information Administration, 1987), whereas the 1995 USGS assessment used data from the DOE/EIA Oil and Gas Integrated Field File (OGIFF) based on fields discovered before 1992. MMS data for reserve growth estimates were from proprietary industry production and reserve data available to MMS.

DOE/EIA 1990

The 1990 DOE/EIA National petroleum assessment was partly a derivative one in which data for undiscovered resources from conventional plays were taken from the USGS/MMS 1989 assessment. The DOE/EIA assessment was internally funded, and work was done in support of U.S. National Energy Strategy (NES). NES was developed to serve as a long-term strategy for energy security, environment, economic growth, and government policy decisions. The primary constituency for the DOE/EIA assessment was government policy makers (Energy Information Administration, 1990). The DOE/EIA also publishes annual reserve reports which have a broader constituency, (for example Energy Information Administration, 1994). Coalbed gas estimates were modified from PGC, ICF-Lewan Energy (lower-48 states only), and American Association of Petroleum Geologists reports. NPC estimates of 1980 were modified for tight gas sandstones and carbonates (Energy Information Administration, 1990).

ASSESSMENT FACTORS

This section describes the factors that we feel are important in comparing assessments. It is subdivided into process and methods sections, where process factors include the nature of the group conducting the assessment, the intended audience, the composition and structure of the assessment team, use of expert judgment, assessment frequency, and review and publication procedures. Methods factors include all aspects of the assessment methodology used to estimate undiscovered resources and resources attributed to the growth of existing fields. Process and methods factors are summarized in Tables 2 and 3 and are discussed below with specific examples from the six assessments.

Process Factors

Nature of group conducting assessment, audience, and funding

This factor includes the nature of the organization and its individuals responsible for each assessment, and how these individuals and the funding source may affect the results (Table 1). For example, the NPC is an industry and government advisory board that advises the Secretary of Energy. Alternatively, the PGC is supported and funded by the American Gas Association (AGA), a trade organization. The PGC consists of volunteer members from all areas of the petroleum industry and works independently with guidance from the Potential Gas Agency at Colorado School of Mines. USGS assessors, on the other hand, are salaried in-house scientists within a DOI agency that is directly funded by the U.S. Congress. Some organizations have a mandated audience or constituency, whereas others do not. The USGS assesses petroleum resources partly for Congressional policy makers but also for petroleum explorationists and the general public. ENRON is a private corporation with a broad constituency including industry and the general public. The ENRON assessment was internally funded.

Composition and nature of assessment team

The internal organization of assessment teams varies significantly for each study. For example, in the 1995 USGS assessment, one or two in-house experts were responsible for each assessment province. These regional experts estimated sizes and numbers of undiscovered accumulations for conventional plays to regional coordinators and an evaluation team of project leaders. An assessment review committee composed of several regional assessment experts ensured uniformity within the assessment process.

Based on background and current job status, does the province geologist or assessment team have a vested interest in large or small estimates? Some critics have stated that USGS assessors are inherently conservative because they have no vested interest in the estimates for each province, and the logical "human" approach is conservative. Other critics have said the opposite. Both the USGS and MMS held regional workshops with members of industry and government in order to best define play boundaries and characteristics. For other assessments, some members of the assessment team are volunteers from the oil and gas industry who may be promoting plays or prospects in the same region they are assessing. The PGC, which utilizes volunteers, has addressed this potential problem by creating an internal review structure at the Board of Directors level within the PGC. Members of the GRI assessment team are GRI employees or contractors that may or may not have a broad geological/engineering background in a region. The background and experience of the expert, whether from government, industry, or academia may have a significant effect on the results of the assessment.

Expert judgment-- level applied and extent of use

All natural gas assessments are based on expert judgment, the special knowledge of geologists, geophysicists, and engineers which make them experts. Assessment often involves developing a consensus from a group of experts, each with slightly or significantly differing opinions and ideas about geologic and engineering information. Key questions include: At what level were expert judgments made? If more than one individual was involved in the process, how was consensus reached? The 1993 ENRON assessment used expert judgment at a high level (near final stage), whereas the PGC in 1995, USGS in 1995, and MMS in 1996 used it at a low level (fundamental input parameters) when defining plays.

Assessment frequency

Is an assessment part of an ongoing series or is it a one-time study? The USGS and MMS each have completed a National assessment about once every 5 to 6 years since 1975. PGC, ENRON, and GRI have updated their assessments every 2 years. The NPC assessment was part of the Secretary of Energy's National Energy Strategy and may not be repeated. Does history allow for an intraorganizational comparison or not? Changes in thinking and evolution of conceptual ideas within an organization are significant indicators of paradigm shifts and can be deduced from an assessment series.

Review process

What was the structure of the review process for each assessment? Were reviews conducted at different stages of each assessment? Was a single review conducted at the end of the assessment? Were outside reviews conducted, wherein individuals from other organizations were allowed to review the assessment? How were interpretations treated in the review process versus errors in documenting data from databases, the published literature, and proprietary gas company data? Were a series of computer checks and balances used to detect errors? The PGC conducted a peer review by area at the Board of Directors level. For the NPC 1992 assessment, several levels of review were conducted by the Conventional Gas Working Group (CGG) of the NPC which reviewed the results of contractors. GRI conducted an internal review process involving both GRI and its contractors. As an internal review, ENRON assessors compared their estimates to those of outside consultants' projections. For the MMS 1995 assessment, an industry advisory board reviewed the play definitions developed by MMS staff and consultants. Recommendations from previous assessments by the American Association of State Geologists (AASG) and National Academy of Sciences (NAS) were included in the 1995 USGS and 1996 MMS assessments.

Published results

Published reports from different assessing organizations vary considerably in detail and format. Some assessors describe their methods and processes only in broad terms, whereas others describe them in exhaustive detail. Problems may develop when trying to compare assessments of one assessing organization to another.

Assessments may have been conducted at the play or formation level, but were subsequently aggregated and results published only at the regional level. Comparing these aggregated assessments to those published at the play level is difficult or impossible. In 1995, the USGS published a summary circular describing the results of its assessment (U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995), but also published a CD-ROM containing maps, charts, tables, and a discussion of results in far more detail than the circular (Gautier and others, 1995). ENRON published only a summary report, whereas the NPC published a multivolume assessment report in which the first volume was a summary of the results. Assessment organizations often publish derivative reports such as the PGC comparison of estimates of ultimately recoverable quantities of natural gas in the U.S. (Curtis, 1995), the GRI baseline projection of U.S. energy supply and demand (Woods, 1995), and the MMS Gulf of Mexico and Atlantic OCS summary report (Lore and others, 1996). In addition to many derivative published reports and maps, the 1995 USGS assessment, and 1996 MMS assessment are summarized on the World Wide Web.

Methodology Factors

Definitions, terms, and limiting considerations

Many terms and concepts must be defined when estimating natural gas resources. Not all assessing organizations use the same terms or mean the same thing even when they use the same terms. Many questions arise when considering the definition of gas. What is the difference between non-associated and associated gas? What gas/oil ratio (GOR) was used and how was associated gas treated versus non-associated gas methodologically? Non-hydrocarbon gases strongly affect the economics of production. How were these gases treated in an assessment? Of the six assessments included in this report, four estimate both gas and oil resources. The GRI and PGC assessments do not include oil. The USGS established a GOR of 20,000 ft^3/barrel as the lower limit for a non-associated gas accumulation as opposed to an oil accumulation. Other gas was considered associated gas and was assessed separately in conjunction with oil. How comparable are these different classes of gas, and how do the different methods affect the final volumes assessed? The PGC in 1995 assessed both associated and non-associated natural gas together.

Petroleum plays are based on ideas supported by the thermal and structural history of basins, geochemical models, and source and reservoir rock interpretations. Concepts related to the definition of thermal gas plays may vary significantly from concepts related to biogenic gas plays. Shallow biogenic gas may be overlooked when only the thermal history of a basin is considered and when shallow gas reservoirs are under-pressured. Mixing of thermal and biogenic gas may occur in a reservoir. How is this information integrated into the play or province model?

Natural gas resources are subdivided into different categories by the various assessing organizations. The USGS assessed volumes of technically-recoverable gas, whereas, the PGC assessed potential gas resources. These terms are different, but do they mean the same thing? The use of specific terms may direct assessors toward different ways of thinking. Many other terms are used by different assessment organizations. In 1996, the MMS assessed established, frontier, and conceptual plays, whereas the USGS in 1995 assessed confirmed and hypothetical plays. Often, two different organizations may use the same term, but with different meanings.

The USGS in 1995 assessed technically-recoverable continuous-type resources using a special methodology (Tables 4 and 5; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995); these resources were previously referred to as unconventional. The PGC, NPC, and GRI identified separate categories of unconventional resources based on different geologic and regulatory criteria. How do estimators define the word unconventional? The Federal Energy Regulatory Commission definition (permeability not exceeding 0.1 md) is arbitrary. The USGS in 1995 defined continuous-type accumulations based on continuity of production and absence of downdip gas-water contacts. What happens in terms of resource assessment in a transition zone between conventionally-trapped accumulations and a FERC-designated or USGS-defined continuous-type accumulation? What happens in terms of resource assessment of coalbed gas when it migrates into adjacent sandstones? Is this reservoir treated as part of the coalbed play or as a sandstone play? Often, a resource may be defined as unconventional, but is conventionally produced. The PGC in 1995 included low-permeability sandstones together with its conventional sandstone resources. In 1993 ENRON embraced a resource pyramid concept where resources grow continuously with advancing knowledge and technology. Lower quality gas requiring higher costs and greater technology resides near the base of the pyramid, whereas high grade gas accumulations such as conventionally-trapped gas in high permeability reservoirs reside near the top. How are resources compared when such diverse methods and classification schemes are used?

Time and technology

An assessment uses data current to a specific date. For example, the PGC and GRI assessments used data through 1994 for their assessments which were published in 1995. The ENRON 1993 assessment indicated a reporting date of January 1, 1992, whereas the NPC 1992 study reported data current to January 1, 1991. The NPC estimates were slightly larger than the ENRON estimates for some regions; ENRON suggested that some of this difference could be due to the one-year difference in report dates (ENRON, 1993).

Data for a gas play current to a specific date may create certain perceptions about that play which may be different from the perceptions at another time. A hypothetical assessment, conducted in year X, was done at a time when a new play became popular and preliminary data suggested large volumes of undiscovered resources for that play. A second assessment was conducted the year after the play was drilled with disappointing results. The second assessment may have yielded far lower gas estimates than the first assessment.

Also, how "forward looking" is the assessment (that is, how far out into the future does an assessment extrapolate with respect to technology and economic considerations). "Technically recoverable" resources have a different meaning in different assessments. What is the rate of technology growth and how is it calculated into natural gas estimates? Was technology growth specifically included in an assessment? Was the rate of increase incremental through time? Through what time (year) was technology addressed? The GRI in 1995 estimated the technically recoverable lower-48 gas resource base for both 1990 and 2010 technology. The resource base exhibited a 30 percent increase based on technology alone during the 30 year period of comparison. Other assessors including the USGS, MMS, and PGC assessed technically-recoverable undiscovered resources based on current technology only. However, reserve growth, included in the USGS 1995 assessment, involves technology improvement.

Categories or components excluded from assessments

Different categories of resources are treated differently by different assessors (e.g. coalbed gas by NPC versus PGC). Inherent differences in final total estimates occur when certain resource categories are assessed differently. For example, the PGC in 1995 did not separate low-permeability sandstone or shale gas from higher permeability (conventional) gas resources, whereas the USGS did. The USGS in 1995 used a different method to assess its "continuous-type" plays. Continuous-type plays are essentially large, potentially productive areas that cannot be defined in terms of discrete units with down-dip hydrocarbon-water contacts. The definition is based on geology rather than on government regulations that define unconventional gas. Continuous-type plays may not be included in the unconventional resource category of the other assessors. ENRON did not separate undiscovered resources into conventional and unconventional categories for their 1993 estimate, but instead used a resource-pyramid model to estimate total resources. The USGS 1995 assessment only included onshore oil and gas resources and those in State waters. Federal OCS resource estimates were made by MMS using a different method than the USGS.

The size of the smallest fields used in discovery-process modeling to identify future undiscovered fields may vary. In 1995, the USGS assessed undiscovered small fields (less than 1 MMBOE) separately using a separate method. The PGC, NPC, MMS, ENRON, and PGC did not separately estimate small undiscovered fields. The MMS in 1996 did not identify a minimum field size. In 1989, however, the MMS included all undiscovered fields greater than 1 MMBOE in their recoverable category of resources.

Geographic areas assessed and depth differences

In some assessments, undiscovered gas resources were estimated for individual stratigraphic (reservoir) zones, petroleum systems, or plays. In others, all stratigraphic units were combined, and undiscovered gas volumes were estimated for a geographic area including the entire stratigraphic column. Structural plays are commonly assessed in this way.

Were geographically restricted areas included, such as Federal lands, wildlife areas, National parks, etc.? In the NPC 1992 assessment, only the lower-48 states were assessed, whereas in others such as the PGC, GRI, and USGS 1995 assessments, Alaska was included.

Different assessors treat the same geographic entities differently, resulting in different local or regional resource totals. In the 1995 PGC assessment, the Williston basin (province 500) extends westward to central Montana, whereas in the NPC assessment Williston basin (using the Hydrocarbon Supply Model region) extended westward to the thrust belt in northwestern Montana. The two Williston basins are significantly different.

Plays, provinces, or other assessed entities have spatial boundaries. What continuity exists between adjacent provinces or regions for each of the assessed entities? The 1995 USGS Niobrara continuous-type play terminated at the South Dakota-Nebraska state line because of uncertainties in facies definitions south of that line which was also a province boundary. To what degree were resource estimates affected? What methods were used to insure that experts from adjacent regions or provinces were safeguarding the continuum of geology that exists at province boundaries?

Assessments may or may not include resource estimates by depth interval. In 1995 GRI subdivided resources into depth intervals for each state except Alaska using the GRI HSM. The 1995 PGC assessment subdivided undiscovered resources into two depth categories, 0-15,000 feet, and greater than 15,000 feet. In 1995 the USGS assessed all depth categories together, then later subdivided them into depth slices using mathematical models (see Dyman and others, 1996).

Economic assumptions

Economic models differ in the variables that are included, and the way in which they are quantified. If an economic model was used, how does it differ from the model used by others? If a fixed price limit was used (e.g. $2.00/MCF of gas), how was it integrated into the assessment? The MMS in 1996 presented estimates of economically recoverable gas as continuous curves of resource supply corresponding to changing gas prices. Pool-size distributions and risk data were inserted in the Probabilistic Resource Estimates, Offshore Model (PRESTO). PRESTO determined the economically-recoverable resources at the basin level and higher. In 1995 GRI used expenditures and profitability data to generate price trends in its GRI HSM model.

Data input and databases used

What sources of data were used to identify drilling and production histories and the geologic makeup of the play or province? The choice of databases such as the Petroleum Information Corp. files, Dwight's Energydata production and well files, the OGIFF file of field sizes maintained by the EIA, and NRG Associates, Inc. reservoir files may strongly affect results. Databases and other geologic data must be clearly identified in the assessment report. For example, in the 1995 USGS National assessment, the increase in inferred gas resources (reserve appreciation) from 93 TCF (1989) to 291 TCF (1995) resulted almost entirely from a change in databases.

The Dwight's Energydata production file contains information for reservoirs of all sizes, whereas the NRG Associates reservoir file only contains information for large fields. If an assessing organization used the NRG file, how did they accommodate data for small undiscovered field sizes? MMS used proprietary industry data related to its regulatory responsibilities, whereas GRI used Dwight's Energydata files. Some PGC area specialists used Dwight's Energydata files, whereas others did not.

Methodology for conventional resources

What approach was used to calculate or define the numbers and sizes of undiscovered accumulations? Was a discovery-process, analog, counting, or other quantitative model used to define the undiscovered population or were many methods used? Do gas estimates result from probability functions derived from the sizes and numbers of accumulations or from some other method?

For the USGS 1995 assessment, province geologists estimated the sizes and numbers of undiscovered accumulations for plays, but used slightly different methods to make their estimates depending on the known production within plays and available data. The PGC in 1995 estimated the volume of potential gas-bearing reservoir rock, incorporated a yield factor, and applied risk factors for provinces. They also extrapolated field-size distributions when field data were available.

What computer programs were used to aggregate resource estimates? The PGC used a program called @RISK; ENRON, NPC, and GRI used the HSM, and the USGS used both unpublished and published programs (see Discussion section below) (Charpentier and others, 1996).

How was uncertainty dealt with and how are final volumes presented? Different organizations use different methods. For example, the USGS in 1995 used a range of fractiles of undiscovered resources, whereas the PGC used fractiles to develop their probable, possible, and speculative resource categories. How can the PGC resource terms be compared to the USGS fractiles? ENRON published only a single point estimate (1,303 TCF).

How do assessors deal with highly speculative or uncertain plays or entities? In some assessments, regional experts may not believe that a highly speculative play exists, whereas other experts do. Often, some plays are very popular, then fade out of existence as a few wells are drilled or the geopolitical winds change direction. In 1995 the USGS did not assess unconventional gas in Alaska. The USGS took a conservative approach to Alaska compared to other assessors and estimated 68 TCF of undiscovered gas. The 1995 GRI assessment included far more natural gas resources in Alaska basins using both their volumetric method and the GRI HSM (121 TCF of ultimate resources, which included reserve growth) (Thomas Woods, written communication, 1996). The PGC estimated more than 115 TCF of speculative resources for Alaska in 1995.

Also, some poorly understood plays are interpreted as conventional, whereas they may actually be unconventional (depending on the definition used). The deep structural play of the Anadarko basin was assessed as a conventional play by the USGS in 1995. Only the large structures have been drilled. An alternative interpretation suggests that this play might represent a large basin-centered or continuous-type gas accumulation. Few off-structure wells have been drilled, making such an alternative interpretation highly speculative. The alternative interpretation of a continuous-type accumulation would require a different assessment methodology, resulting perhaps in significantly larger estimate of undiscovered gas.

The PGC, MMS, and USGS risked plays that were speculative (hypothetical). It was difficult to determine how other groups addressed this issue because data for the remaining assessments were aggregated to the regional level, and play or local level estimates were not published.

Methodology for unconventional resources

Comparing estimates of unconventional resources is difficult not only because methods may be different, but because the same resources may be included in different resource categories by different assessors. In 1995 the PGC assessed low-permeability tight sandstone gas with conventional resources. The PGC assessed coalbed gas separately using a similar methodology as for conventional resources. The NPC estimated coalbed gas, tight gas, and shale gas separately, but used different methods which were only broadly defined in their report (NPC, 1992). The USGS defined continuous-type accumulations based on geologic characteristics and assessed tight sandstone, carbonate, shale, and coalbed gas in basically the same way. Some of the USGS continuous-type (unconventional) resources may reside in the conventional categories of other assessors, and vice-versa.

Reserve growth

Many assessments include the growth of fields through time. How are these numbers calculated? Is reserve growth calculated into the reserves category? How is it done? Reserve growth factors may differ based on differences in historic data in different regions of the country, different reservoir and source rocks, different economic and technologic conditions, and different completion practices. Is reserve growth included in estimates of unconventional accumulations? Are unconventional resources double-counted, in that they feed into reserve growth statistics of so-called "fields"?

In the MMS 1996 assessment, reserve growth was calculated using proprietary reserve data from their own files. The MMS projected fields to the year 2020 for the offshore Gulf Coast region. The PGC in 1995 estimated their probable reserve category using a subjective volumetric yield method.

Assessment level at which estimates are available in published form

Of the six assessments presented, the level varies from play level publication (USGS, 1995), to only a single National estimate (ENRON, 1993). The PGC and MMS published their data by province or region.

DISCUSSION

The six assessments compared here can be subdivided into those that used a version of the Gas Research Institute HSM (NPC, 1992; ENRON, 1993; GRI, 1995), and those that used a play or geologic analysis and quantitative methods incorporating discovery histories (USGS, 1995; PGC, 1995; MMS, 1996). In this report, we do not discuss the details of the GRI HSM and how results from it differ from results using a geologic analysis of plays and formations. In simple terms, the GRI HSM is a computer-based analytical model designed to simulate and forecast natural gas and crude oil supply and cost trends. The GRI HSM includes databases of oil and gas fields, and exploratory and producing wells. The contents of these databases are critical to the resource assessment part of the model. The GRI HSM characterizes oil and gas resources for 24 regions in the U.S. and Canada. Each region is subdivided into subregions which have their own resource base, finding-rate equations for discovery process, and drilling costs and well production profiles. Several versions of the GRI HSM have been used since the first was published in June 1985. The most recent report (Vidas and others, 1993) discusses updates to the program and data.

Only the USGS published data at the play and province level (Gautier and others, 1995). The remaining studies published resource estimates at either a regional level (involving one or more provinces) (GRI, PGC, MMS, NPC), or at the National level (ENRON). Resource comparisons including all but ENRON can be made at the regional level. Care must be taken when these regional comparisons are made because region/province boundaries often differ. The USGS, PGC, and MMS discussed the petroleum geologic makeup of each region and province in their reports, whereas other assessors did not.

Few comparisons of National natural gas assessments have been published, but the comparisons of Curtis (1995; 1997) are the most detailed that we have found in the recent literature. In these studies, Curtis normalized each estimate to the end of December 1994 or 1996 by adjusting resources, and compared estimates with respect to current and advanced technology. In our study, we make no adjustments to estimates and only compare results based on current technology.

In this comparison, the 1992 NPC assessment is used as a baseline from which to compare other assessments. We are following the method used by Schmoker and Dyman (1996) in which continuous-type resources in the 1995 USGS assessment were compared to those of the 1992 NPC assessment. The NPC total estimate is near the lower end of the range of estimates with 1,065 TCF. ENRON, with 1,303 TCF, does not include gas estimates for Alaska. For comparison, the PGC and USGS/MMS include a total of 143 and 194 TCF of technically recoverable gas respectively in Alaska.

The USGS/MMS total estimate (1,412 TCF) exceeds the NPC total estimate (1,065 TCF) by 347 TCF, and even if only conventional resources are considered, the USGS/MMS estimate exceeds the NPC estimate (USGS/MMS 1,054 TCF versus NPC 719 TCF) (Table 1). When Alaska estimates are subtracted from the USGS/MMS total, the NPC and USGS/MMS total estimates are much closer (USGS/MMS 860 TCF versus NPC 719 TCF). For unconventional gas resources, the two estimates are very close, with the NPC estimating 346 TCF in all categories and the USGS estimating 358 TCF.

GRI 's estimate of 1,140 TCF of gas is only slightly larger than the NPC estimate; however, the NPC assessment did not include Alaska and was completed three years before the GRI assessment. GRI only identifies a discoveries category through December 1990 in their baseline projection (Woods, 1995, Table 6) and tabulated 900 TCF of gas in this category which includes about 160 TCF of proved reserves and about 740 TCF of past production.

Comparing the ENRON estimate to those of the other assessments is not possible using the published data because it is unclear exactly which categories of resources, particularly unconventional resources, are included or excluded in the ENRON assessment. Although the PGC total estimate is the lowest, the PGC estimated the most undiscovered (new fields) gas, in part because tight sandstones and shales were included in this category.

When all of the assessments are analyzed with respect to each other, the final estimates are reasonably close, considering the many different data sets used, methods applied, and procedures followed. One very interesting aspect of these six assessments is the issue of the reserve growth categories. Because the U.S. is a mature gas producing nation, the fraction of remaining gas resources attributed to reserve growth should increase through time. An analysis of several assessments by the same organizations through time reveals mixed results with respect to reserve growth. Earlier studies of the 1970s focused on new field discoveries and potential undiscovered of gas resources. As fewer new fields are discovered each year, a greater emphasis is being placed on the role of reserve growth in assessments. For example in 1989, the USGS estimated only 99

TCF in the inferred reserves (reserve growth) category for the onshore U.S., whereas in 1995 it estimated 322 TCF.

RECOMMENDATIONS

Based on our analysis of the six most recent comprehensive natural gas assessments, we recommend the following:

1. Regardless of which assessment methods and procedures are used, each assessing organization should describe their methods and procedures in detail so that others can clearly identify what was done.
2. Future National petroleum assessments should emphasize estimates of reserve appreciation as contrasted to estimates of undiscovered resources.
3. Economics will play a continuing important role in gas estimates, and future assessments should include both technically- and economically recoverable resources. Economic models used should be clearly described.
4. The importance of unconventional resources will increase through time as the price of gas increases and recovery technologies improve. We need to focus more efforts on unconventional resources in future assessments.

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Appendix

Identification of abbreviations used in report.

@RISK	Potential Gas Committee statistical aggregation program used to aggregate resource estimates. Program available from Palisade Corp., Newfield, NY
AGA	American Gas Association
AASG	American Association of State Geologists
ARI	Advanced Resources International Inc. of Arlington, Virginia.
BCF	Billions of cubic feet of gas
BOE	Barrels of oil equivalent
CGG	Conventional Gas Working Group of National Petroleum Council resource assessment
DDS	Digital Data Series publication series of the U.S. Geological Survey
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
EEA	Energy and Environmental Analysis (Contractor to Gas Research Institute)
EIA	Energy Information Administration of the U.S. Department of Energy
ENRON	ENRON Corporation, Houston, Texas
ERM	Enhanced Recovery Module of Gas Research Institute's Hydrocarbon Supply Model
EUR	Estimated ultimate recoverable resources
GOR	Gas-oil ratio
GRASP	Geologic Resource Assessment Program of the U.S. Minerals Management Service
GRI	Gas Research Institute
HSM	Hydrocarbon Supply Model of Gas Research Institute
ICF	ICF Lewan Resources Inc.
md	Millidarcies of permeability
MMBOE	Millions of barrels of oil equivalent

MMS	U.S. Minerals Management Service
NAS	National Academy of Sciences
NES	National Energy Strategy of the U.S. Department of Energy
NPC	National Petroleum Council
NPS	National Production System of Petroleum Information Corporation which contains production data for wells.
NRG	NRG Associates of Colorado Springs, Colorado, compiles reservoir data and markets a database entitled The Significant Oil and Gas Fields of the United States File
PRESTO	Probable Resource Estimates, Offshore model of the U.S. Minerals Management Service
OCS	United States Outer Continental Shelf
OGIFF	Oil and Gas Integrated Field File of the Energy Information Administration
PDS	Dwights Energydata Petroleum Data System
PGC	Potential Gas Committee
PI	Petroleum Information Corporation, Denver, Colorado
SSG	Source and Supply Task Group of the National Petroleum Council petroleum assessment
TCF	Trillions of cubic feet of gas
USGS	U.S. Geological Survey
WHCS	Well History Control System of Petroleum Information Corporation

Table 1. Estimates of undiscovered conventional and unconventional natural gas resources of six recent assessments. Asterisk (*) indicates that resources are listed under different category. A dash (--) indicates that this category not assessed. Blank indicates that data are not subdivided into separate categories in published report. All estimates are for technically-recoverable resources and based on current technology. Estimates are in trillions of cubic feet (TCF) and are rounded to nearest whole TCF.

		Unconventional resources				Conventional			
Organization	Date	Coal gas	Shale gas	Tight Ss gas	Total Unconventional	New fields (Undiscovered)	Proved reserves[6]	Reserve growth	Total resource
NPC	[1]1992	62	37	247[4]	346	375	160	184	1,065
PGC	1995	134	*	*[5]	134	547	161	176	1,018
USGS	[2]1995	50	308	*[5]	358	259	135	322	1,074
MMS	[2]1996	–	–	–	–	268	31	39[7]	338
USGS & MMS		50	308	*	358	527	166	361	1,412
ENRON	[3]1993						158		1,303[8]
GRI	1995	60	36	159[4]	255	482	162	241	1,140

[1] Includes only lower-48 States assessment.

[2] The MMS in 1996 estimated a mean value of 268 TCF of technically recoverable conventional gas for four regions of the OCS. The MMS did not assess unconventional resources. The USGS 1995 assessment only assessed onshore and State offshore areas of the U.S. These two estimates are added together to arrive at a U.S. total of 1,412 TCF of gas.

[3] The 1995 ENRON assessment is primarily a World energy summary and does not include new data for the U.S. The 1993 assessment includes only the lower-48 states.

[4] Includes 15 TCF of low-BTU gas for both NPC and GRI.

[5] For USGS, unconventional tight sandstone resources included with shale gas category. For PGC, shale gas and gas from tight sands are combined under the conventional new fields (conventional undiscovered resources) category.

[6] Data on proved reserves taken from either published documents by each organization or from the American Gas Association (1996). Data do not indicate that proved reserves were estimated by each organization.

[7] Includes 6.2 TCF of unproved reserves.

[8] Separate estimates for conventional and unconventional resources were not published.

Table 2. Process factors associated with the six major National petroleum assessments of the last 5 years. Refer to Appendix for identification of abbreviations used.

Organization	Process Factor
	Nature of Group Conducting Assessment, Audience, and Funding
NPC, 1992	Industry advisory board drawn from industry and government. NPC is an advisory board to the Secretary of Energy. General audience. Funded by U.S. Department of Energy.
PGC, 1995	Supported by AGA, GRI, and others. PGC consists of volunteer members from all disciplines within the petroleum industry. The committee works independently but with guidance of the Potential Gas Agency of Colorado School of Mines. Many industry volunteers do assessment work by region. General audience. Funded through grants and donations.
USGS, 1995	Agency of U.S. Interior Dept. Salaried in-house scientists. Primary constituency is U.S. Congress but work done for broad audience. No direct access to proprietary data from industry or government. Federally funded.
MMS, 1996	Agency of U.S. Interior Dept. Salaried in-house scientists. Primary constituency is U.S. Congress but work done for broad audience. Regulatory agency within DOI with access to proprietary data from industry. Federally funded.
ENRON, 1993	Private exploration company and staff. Directed at a very broad audience, but restricted use because of the general data presentation. Internally funded.
GRI, 1995	Not-for-profit research and development organization. GRI funds research conducted by academia, government agencies, and private contractors. Directed at a broad audience. Work done by GRI staff and/or contractors. Internally funded.
	Composition and Nature of Assessment Team
NPC, 1992	Conventional Gas Work Group (CGG) composed of industry, government, and trade association representatives. Three subgroups of CGG dealt with specific issues: undiscovered resources, reserve appreciation, and cost/economic. Detailed technical analysis done by EEA, a contractor to GRI.
PGC, 1995	Team of estimators used for each region of country. Teams were called area work committees, and corresponded to 7 geographic areas of country. Several to many provinces within each region. Committee heads recruited volunteers from exploration and development sectors of industry.
USGS, 1995	Province geologists were responsible for plays within their provinces. They met with industry representatives and State agencies in their regions. Methodology team coordinated quantitative analysis and estimates.

Organization	Process Factor
	Composition and Structure of Assessment Team continued:
MMS, 1996	Province geologists were responsible for plays within their provinces. They worked closely with State geological surveys, DOE, and industry. Regional chiefs were responsible for all provinces within region. Methodology team coordinated quantitative analysis and estimates.
ENRON, 1993	Assessment conducted by "in-house geologists, engineers, economists, and gas-market specialists" (ENRON, 1993, p. 13).
GRI, 1995	Assessment conducted by GRI staff and contractors by region.
	Expert Judgment-- level applied and extent of use
NPC, 1992	Two levels of consensus building: at subgroup level and CGG level. Consensus-building process done separately at subgroup level, then redone at higher CGG level for undiscovered gas resources. "Each member of committee brought an estimate to discussion based on a variety of assumptions and methods" (NPC, 1992, p. 55).
PGC, 1995	"Judgment of estimator" was the most significant factor in estimates of potential supply. This process was used at the province level where several/many plays are included. "PGC members have the detailed knowledge and experience necessary to select adjustments for a province...." (PGC, 1990, p. 8).
USGS, 1995	Best estimate applied at play level based on data input and interpretations of province geologist. A range of fractiles was estimated. Best estimate is mode, a point estimate.
MMS, 1996	Best estimate applied at play level based on data input and interpretations of province geologist. 5th and 95th fractiles and mean estimates published.
ENRON, 1993	Same as GRI method.
GRI, 1995	Best estimate was used for areas or unconventional GRI 1995 plays that lacked sufficient data to develop projections of future industry results. Best estimate was also used to develop the premises for technology advances.
	Assessment Frequency
NPC, 1992	Conducted as one-time study associated with National Energy Strategy for Secretary of Energy.
PGC, 1995	Assessments conducted in 2-year cycles.
USGS, 1995 time	Assessments conducted in 5 to 7 year cycles. Estimates published in same frame with MMS.
MMS, 1996	Assessments conducted in 5 to 7 year cycles. Coordinated with USGS.
ENRON, 1993	Assessments conducted in 2-year cycles.
GRI, 1995	Assessments conducted in 2-year cycles.

Organization	Process Factor
	Review Process
NPC, 1992	Conventional Gas Work Group reviewed EEA's extrapolations for future drilling activity and how conventional gas was characterized in GRI HSM. Several levels of internal review (NPC, 1992, p. 40).
PGC, 1995	Review process within area committees for each province. Broad review by Potential Gas Committee Board of Directors, a subset of PGC membership.
USGS, 1995	Province geologists met with region chiefs and assessment team to evaluate undiscovered volumes for plays. Internal USGS review at several levels. Preliminary play evaluation by regional advisory committees representing industry, and state and national government organizations.
MMS, 1996	Province geologists met with region chiefs and methodology team to evaluate undiscovered volumes for plays. Separate review by industry advisory committee.
ENRON, 1993	"Estimates were assembled, compared to outside consultants' projections, as well as other information sources (ENRON, 1993, p. 13).
GRI, 1995	Internal to GRI, EEA, and other contractors. The resource specifications also had a thorough internal review during the 1992 NPC study.
	Publication Format
NPC, 1992	Published as multi-volume report entitled "The Potential for Natural Gas in the United States". Volume 1 was a summary report. Data available in form of NPC working papers.
PGC, 1995	Results published biennially as "Potential Supply of Natural Gas in the United States." Other derivative reports periodically published.
USGS, 1995	Three publication formats: (1) Summary circular showing regional and provincial totals. (2) CD-ROM detailed report (USGS DDS 30) by province showing geologic input and resource totals by play. Geologic data included. (3) Derivative and special reports on unconventional resources. Many province geologists also published regional/ province reports through peer-reviewed media. World Wide Web site.
MMS, 1996	Summary document describing methods, data bases used, and regional results. Regional papers also published. World Wide Web site.
ENRON, 1993	Results published biennially. 1993 report published as "The Outlook for Natural Gas."
	Publication Format continued:
	GRI, 1995 Results published biennially in Gas Research Insights series: "The Long-Term Trends in U.S. Gas Supply and Prices: Annual Edition of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2010." Other derivative reports periodically published.

Table 3. Methodology factors for the six major National natural gas resource assessments of the last 5 years. See Appendix for definitions of abbreviations used.

Organization	Methodology Factors
	Definitions, Terms, and Limiting Considerations
NPC, 1992	Conventional resources are discrete accumulations and do not include coalbed gas, gas in geopressured brines, shales, and gas hydrates. Gas resources in reservoirs with <0.1 md not included. Reserve appreciation = reserve growth (NPC,1992, p. 39).
PGC, 1995	Probable, possible, and speculative resources are included in category called potential resources. Proved reserves not included. Reserve growth includes new pools within fields and productive formations in areas not yet tested (PGC, 1995, p. 7). Drilling depths below 30,000 ft not included. Water depths exceeding 3,300 ft not included except in Gulf of Mexico offshore. Federal lands are included but permanently withdrawn areas are not.
USGS, 1995	Only onshore and offshore State waters included. MMS assessed Federal waters. Federal onshore and restricted areas included. New use of term "continuous-type accumulations" for some unconventional accumulations. Continuous-type accumulations are large areas with gas production that have no discrete gas-water contacts. The entire region is productive. Data on proved reserves (1977 through 1991) from DOE-EIA. Inferred reserves = reserve growth.
MMS, 1996	Only offshore Federal waters included. USGS assessed State waters and onshore areas. Unconventional resources not included. Reserves not estimated, but the MMS assesses and publishes reserves estimates annually for fields of the Gulf of Mexico OCS and Pacific OCS. Assessment included undiscovered conventionally recoverable and economically recoverable resources.
ENRON, 1993/1995	1995 assessment is a slight modification of 1993 with an emphasis on World Energy. Data and results aggregated to National level. 1995 ENRON outlook is a "Gas resources of the World outlook". The 1993 outlook deals with details of the U.S. The U.S. resource base only slightly changes between reports.
GRI, 1995	Resource subdivided into: new fields, and resource incremental to historic activity directed at new field exploration, and reserve appreciation (generally unconventional resources) (GRI, 1995, p. 19). Alaska estimates taken from USGS 1989 assessment. Technology advances through 2010 included.
	Time and Technology
NPC, 1992	NPC estimates of ultimately recoverable resources increase with technologic advances through time. See NPC, 1992, Table 1-1, Figs. 1-1, 1-2. 2010 is final year in current study period. Continued technological development and moderate growth assumed through 2010. Estimates current to January 1991.

Organization	Methodology Factors continued:
	Time and Technology continued
PGC, 1995	Level of technology growth modest compared to NPC. Assumptions based on adequate but reasonable prices and normal improvements in technology. Estimates current to December 1994.
USGS, 1995	Assessment assumed existing technology. "Technically recoverable resources" assessed only. No attempt to predict at what time or what part of potential additions will be added to reserves. Estimates current to January 1994.
MMS, 1996	Included were conventionally recoverable resources using technology and development and exploration efficiency available at time of assessment or in the reasonably foreseeable future. Estimates current to January 1995.
ENRON, 1993	Supply and demand studies through 2010. Strong technology input but details not defined. Technologic impact varies by region. Also, updated historic trends in EUR/completion in 4 major basins where ENRON has expertise. 1303 TCF assessment does not include major technologic breakthroughs (e.g., hydrates). Estimates current to March 1993. Advanced technology through 2010. Both current and advanced technology cases included. Low permeability gas resource current to January 1990 (GRI, 1993, p. 18).
GRI, 1995	The resource is defined in terms of industry activity and results as of a base year (December 31, 1990) and expected technology advances through 2010 that will expand the producing areas and improve recovery per well.
	Categories or components excluded from assessments
NPC, 1992	Separate assessments for proved reserves, conventional new gas fields, reserve appreciation or growth, coalbed methane, shale gas, and tight gas. Excluded resources include those poorly defined or unlikely to be developed during time period. See NPC (1992) table 1-1. Gas hydrates, geopressured brines, and other unconventional resources excluded. These include tight gas locations unlikely to be developed in time frame of study (NPC, 1992, p.33). No separate breakdown for biogenic gas.
PGC, 1995	PGC assessed probable, possible, and speculative resource categories. Possible and speculative probably same as NPC's "new fields" category. Shale and low-permeability gas part of PGC conventional category. PGC's probable category includes NPC's reserve appreciation. Coalbed gas separately assessed. No separate breakdown for biogenic gas.
USGS, 1995	Oil shale, geopressured brines, and tar deposits excluded. Assessed resources included: undiscovered conventional, reserve growth, and continuous-type accumulations (coalbed gas, sandstones, chalks, shale gas). Separate plays identified for conventional and continuous-type resources for some categories of gas. Aggregated with other plays on regional basis. Reserve appreciation included.

Organization	Methodology Factors continued:
	Categories or components excluded from assessments continued:
MMS, 1996	Unconventional resources not included. Undiscovered conventionally and economically recoverable resources included for plays. Reserve appreciation included.
ENRON, 1993	Conventional and unconventional resources assessed. Conventional gas subdivided into high and low permeability categories. Tight gas, coalbed gas, enhanced recovery gas, and shale gas also included.
GRI, 1995	Unconventional resources included under the GRI-HSM Enhanced Recovery Module (ERM). Low-permeability reserves, coalbed gas, Devonian shale included under ERM on an in-place basis (GRI, 1995, p. . Geopressured brines and tar sands not included. All biogenic gas included with thermal gas under various resource categories. Some of this resource under unconventional categories, including shale gas and tight sandstone gas.
	Geographic Areas Assessed/Depth Zones
NPC, 1992	Separate assessments for 18 regions within lower-48 states for each gas category. GRI HSM version recognized 4 depth zones (5,000 ft intervals, onshore) and 4 water depth zones (offshore).
PGC, 1995	89 geologic provinces. Boundaries very close to those of AAPG-CSD. Provinces with poor potential combined with more productive adjacent ones. Alaska provinces not CSD related, but independently defined by PGC. Provinces combined into 7 areas (PGC, 1995, p. 7).
USGS, 1995	562 plays in 69 provinces and 8 regions of U.S. Province boundaries based on county and State lines, but with geologic significance. A few changes from 1989 USGS assessment. All depth zones done together for 1995 assessment. Assessment subdivided by depth below 15,000 ft in subsequent report (Dyman and others, 1996). Modified triangular function used to extract resources by depth. Based on minimum, median, and maximum depth of play.
MMS, 1996	U.S. OCS divided into 4 regions: Alaska, Atlantic, Gulf of Mexico, and Pacific. These OCS regions were subdivided into provinces and basins or areas. All depth zones and water depth zones done together.
ENRON, 1993	Four depth intervals, 20 field sizes, and 18 supply regions investigated for undiscovered resource base. San Juan basin listed separately. Same geographic subdivisions as GRI . Data may be available in company records, but published only at aggregated level.

Organization	Methodology factors continued:
	Geographic Areas Assessed/Depth Zones continued:
GRI, 1995	13 onshore and 3 offshore regions for lower-48 states resource. Regions originally patterned after PGC regions as of December 31, 1982. Regional boundaries modified to better accommodate gas transmission corridors and geologic basins (GRI, 1993, p. 67). Data available by depth increments. Although unconventional resources are defined by play, they are also defined by GRI HSM region and depth interval.
	Economic Assumptions
NPC, 1992	Estimated technically recoverable resources. Detailed economic analysis of future exploration and development activity. Minimum size and quality of resource accumulations considered (NPC, 1992, p. 37). Assessed economically recoverable resources, but no price assumed.
PGC, 1995	Two-year reporting cycle deals with unforeseen technological improvements. Definition of potential resources includes "normal improvements in technology". Economic policy considerations taken into account are related to economic definition of proved reserves as "recoverable under existing economic and operating conditions". (PGC, 1995, p. 10).
USGS, 1995	Only included technically-recoverable resources.
MMS, 1996	Study includes economically recoverable undiscovered resources. These resources are the portion of undiscovered conventionally recoverable resources that can be explored, developed, and produced commercially at given cost and price considerations using present or reasonably foreseeable technology. Assumptions included flat prices, and fixed discount rate, royalty rates, tax rate, and inflation rate. Data presented as cost-supply functions. PRESTO model used.
ENRON, 1993	Cost algorithms of GRI HSM linked to each element of resource base to include: exploration/development costs, economics in field development, discovery-process efficiency and economic limits of new discoveries. Market conditions, drilling cost trends, and price forecasts all included.
GRI, 1995	Economic assessment is based on exploration plus development expenditures and the effects of hydrocarbon revenues on gas profitability. Resource specifications in the GRI HSM are used to generate gas production and price trends in the GRI Baseline Projection. GRI does not generate absolute resource cost curves because they reflect both resource and technology specifications plus market effects on cost factors, such as drilling charges and the cost of capital.

Organization	Methodology factors continued:
	Data input and databases
NPC, 1992	Decline curves for GRI Hydrocarbon Supply Model (HSM) used published data from databases for wells/fields. Data for proved reserves taken from EIA annual reports of oil and gas reserves. Data at State level. Data for reserve appreciation taken from API/EIA database on published reserves by year of discovery (NPC 1992, p. 33). Includes activity level and maturity. DOE-OGIFF estimates (AGA data not used). Data for undiscovered new fields uncertain--consensus approach (NPC, 1992, p. 33). Low-permeability gas estimates based on confidential survey of operators (NPC, 1992, p. 34). Coalbed methane estimate based on review of known basins using proprietary and public domain data. Shale gas estimates from well recovery and in-place data by Energy Environmental Analysis (EEA), and using production data from Columbia Natural Resources Co.
PGC, 1995	Much proprietary data at play and prospect level. Aggregated into province and area totals. Dwights Energy Data files used. Petroleum Information Corporation (PI) Well History Control System (WHCS) and other well files used at province/area level.
USGS, 1995	Data sources included: published and unpublished USGS data; the Significant Oil and Gas Fields of the United States File for field-size distributions (NRG Associates); PI WHCS well file, and National Production System (NPS) production file for wells; EIA-OGIFF file of reserves and production; and other data to include energy company proprietary data as available well logs, published State and Federal agency data, and DOE-EIA annual reports. See Gautier and others (1995).
MMS, 1996	Data sources included geological, geophysical, and engineering data obtained from industry through lease operations performed under permits or leases. MMS has accumulated geologic and production information on thousands of wells, and 2-D and 3-D seismic profiles are available. Internet data access at: http://www.mms.gov/omm/gomr/
ENRON, 1993	Data include database from GRI HSM and a variety of in-house information sources. Data on oil and gas fields from GRI HSM (except for Appalachian basin). Details of data input not identified in published reports.
GRI, 1995	Industry production data taken from Dwight's Energydata PDS and gas well files. Gas data further described in terms of general reservoir types (e.g. conventional, tight sands, coal seams, shale). Production and discoveries are correlated with gas completions.

Organization	Methodology Factors continued: **Undiscovered Conventional Resources Methodology**
NPC, 1992	Attribution method--apply attributes of known to unknown. GRI-HSM used here. Known and speculative plays identified (same as USGS confirmed and hypothetical). Each region and depth zone (= cell) has unique "finding rate" and "field-size" distribution developed from analysis of historical data. Twenty field-size classes per cell. (NPC 1992, p. 52). Done for both known and speculative plays. GRI HSM uses (1) finding rates, and (2) field-size distributions that are unique for each of 18 total regions of lower-48 states. Lower threshold of 4000 BOE field size. Analogs used in frontier areas. Used modified Arps-Roberts finding-rate equation. Consensus approach used to estimate size of undiscovered resource. See also NPC 1992, p. 55-56. See Vidas and others (1993).
PGC, 1995	"Each PGC estimator may use different approaches and modifications of the basic estimation procedure" (see PGC 1995, p. 9 for explanation of procedure). For "possible resources", anticipated field-size distribution of undiscovered fields based on extrapolation of field-size distribution of discovered fields. Method includes: (1) estimating volume of potential gas-bearing reservoir rock, (2) multiplying by yield factor, and (3) allowing for probability of traps. Variations in this due to data availability. @RISK computer program used to derive area and National totals. It uses Monte Carlo simulation to derive a probability distribution of expected outcomes (PGC, 1995, p. 14).
USGS, 1995	Conventional undiscovered resources assessed by combining play risk and estimates of the sizes, numbers, and types of accumulations. Reservoir simulation, discovery process, analog, and spatial analysis techniques used to make these estimates. (Confirmed and hypothetical plays treated separately). A confirmed play has at least 1 accumulation with >1 MMBOE. Plays were not assessed if play probability <0.1. Size-frequency of known accumulations used truncated-shifted Pareto distribution to estimate undiscovered population.
MMS, 1996	Established, frontier, and conceptual plays were first defined based on geological and geophysical interpretation of analogs, information in data bases, and published reports. Methodology for conventional undiscovered resources included use of PETRIMES (Lee and Wang, 1984) which provides estimated resources in aggregated numbers and estimates of the number and size of undiscovered pools. PETRIMES was modified to include mixed plays (mixed commodities) for the economic analysis requirements. The resultant modified version was called GRASP. MMS also modified the PRESTO model used in previous MMS assessments to use GRASP outputs for the number and sizes of pools to determine the economically recoverable resources at the geologic basin level and higher (MMS, 1996).
ENRON, 1993	Uses GRI Energy Overview Model in modified form. Very similar or identical to NPC and GRI approach. Simulates exploration, production, and development. Cost algorithms allow economic interpretations.

Organization	Methodology Factors continued:
	Undiscovered Conventional Resources Methodology continued:
GRI, 1995	The GRI-HSM describes new field resources by field size, type (oil, high permeability gas, low permeability gas etc.), and location. For areas and depth intervals with sufficient exploration data, the 1990 technology undiscovered resource is developed by extrapolating historical find-rate trends. For areas that have insufficient data or possible new exploration plays, the aggregate resource estimates are developed using geologic analogs, volumetric yields, and available data. The find-rate equations for these "frontier" areas are then developed by analogy to the areas with sufficient data. Finding-rate equations are defined for each field size and location. 20 field sizes based on USGS subdivision. More than 1,200 separate find-rate equations used to project the probability of new fields in each region by depth. See Vidas and others (1993) for explanation of GRI HSM.
	Unconventional Resources Methodology
NPC, 1992	Level of recoverability is uncertain due to technology. Tight gas was estimated based on a confidential survey of tight gas operators. Shale gas was estimated based on well recoveries and resource in-place estimates made by EEA. Coalbed gas was estimated based on a review of known coal basins using both proprietary and public data.
PGC, 1995	Separate method and results for coalbed gas. Volumetric calculations used where net-coal thickness is multiplied by area to determine coal volume. Data are combined with coal density, yield, and recovery factors. In absence of other data, USGS coal map used.
USGS, 1995	Continuous-type gas plays defined as unconventional resources. Definition based on geologic characteristics rather than permeability (<0.1 md). Coalbed gas, tight sandstones, chalk and shale gas, and some shallow biogenic gas plays treated this way. Gas hydrates treated separately and only an in-place assessment number generated. Oil shale, geopressured brines, and tar deposits excluded.
MMS, 1996	Unconventional resources not included in MMS assessment.
ENRON, 1993	Uses "resource pyramid" concept where resource grows with advancing knowledge and technology (ENRON, 1993, p. 9). ENRON uses HSM to estimate unconventional resources by simulating exploration, development, and production for 17 supply regions, 4 depth intervals, and 20 field sizes.
GRI, 1995	Unconventional resource descriptions based on trends in industry results by resource type and location by and within play. Impacts of technology advances based on review of industry trends and expectations. The advanced technology descriptions have generally lagged improvements in industry results since 1990.
	Reserve Growth Methodology
NPC, 1992	Modified existing technique for estimating future field growth. Technique assumes that EUR of gas in existing fields increases through time and rate of increase is dependent on drilling activity since field discovery. EEA extrapolated past drilling to determine future trends.

Organization	Methodology factors continued:
	Reserve Growth Methodology continued:
PGC, 1995	Estimates of probable reserves for lower-48 states (same as inferred reserves of USGS). Volumetric yield technique used. Separated into "discovered but unconfirmed", and "undiscovered". For discovered, volume of potential rock is calculated to limits of pool development based on available data. Volume is multiplied by "yield factor". This total then multiplied by a probability factor. Undiscovered probably uses more geoscientific interpretation (PGC, 1990, p. 11-12).
USGS, 1995	Inferred reserves equal reserve growth. Based on successive estimates of reserves in older fields. Reserve growth is difference of proved reserves in known fields and remaining recoverable resources. EIA-OGIFF field file used to determine pattern of field growth from 1977 through 1991. Field growth in conventional and continuous-type plays is part of regular assessment.
MMS, 1996	Reserve appreciation only calculated for Gulf Coast region. Calculated using in-house reserves data for active fields in the Gulf of Mexico. Annual growth factors were calculated by dividing the estimate of reserves for all fields of the same age by the estimate of reserves for the same fields in the previous year. Reserve appreciation was applied to a point in time (the year 2020) by applying regression analysis to the observed field level growth factors to develop a function relating the annual growth factors to the age of the field. Cumulative growth factors were then calculated from the annual growth factors.
ENRON, 1993	Part of appraised category of resource pyramid (ENRON, 1993, p. 9). GRI HSM used.
GRI, 1995	Reserve growth is specified separately by model, region and depth interval. It is based on a well-recovery basis, not a temporal or field-size basis. Well recovery declines to a minimum recovery as reserve appreciation resource is depleted.
	Assessment level at which estimates are available in published form
NPC, 1992	By region with 13 onshore and 5 offshore regions. Also by depth.
PGC, 1995	By "area" for seven areas. Also by producing depth and water depth. Minimum, most-likely, and maximum values for probable, possible, and speculative resources. Separate chapters in final report for resource totals by region. Large maps published with gas distribution and provinces. Area committees may have results at play level but not published at this level.
USGS, 1995	Resource estimates presented at play level and aggregated to province and region level.
MMS, 1996	Resource estimates presented at play level and aggregated to province and region level.
ENRON, 1993	Estates available for the entire country only.

Organization	Methodology factors continued:
	Assessment level at which estimates are available in published form continued:
GRI, 1995	Data available by resource category and region for lower 48 states, Canada, and offshore U.S. Further subdivided by base and advanced technology. Gas-in-place volumes for unconventional resources also available. Data available also for 5,000 ft . intervals. Data unavailable at play level.
	Resource Estimates
NPC, 1992	U.S. total as of Jan. 1, 1991: Proved reserves = 160 TCF. Reserve appreciation = 184 TCF. New fields (undiscovered) = 375 TCF. Coalbed gas = 62 TCF. Shales gas = 37 TCF. Tight sands = 247 TCF. Incorporates technology advancement through 2010. Current technically recoverable resources = 1,065 TCF (NPC, 1992, p. 5).
PGC, 1995	U.S. mean total as of Dec. 31, 1994: Proved reserves = 161 TCF. Reserve appreciation (probable resources)= 176 TCF, Coalbed gas= 134 TCF. New fields = 547 TCF. Based on normal improvements in technology. Total U.S. mean =1,018 TCF.
USGS, 1995	U.S. mean total as of Jan. 1, 1995: Proved reserves = 135 TCF. Reserve growth (inferred reserves) = 322 TCF. Undiscovered conventional = 259 TCF. Federal offshore estimates by MMS. Continuous-type accumulations = 308 TCF (includes sandstone, shale, chalk). Coalbed gas = 50 TCF (probably does not include speculative of others). Total = 1,074 TCF.
MMS, 1996	U.S. OCS totals as of Jan. 1, 1995: Remaining proved reserves = 31 TCF. Reserve appreciation = 39 TCF (all Gulf of Mexico). Undiscovered conventionally recoverable gas resources mean total = 268 TCF.
ENRON, 1993	U.S. total as of Jan. 1, 1993: 1,303 TCF. This includes 158 TCF of proved reserves. Data not published at regional level or broken out by specific resource types.
GRI, 1995	Lower-48 total as of 1995: New fields = 482 TCF. Reserve appreciation = 241 TCF. Total unconventional resources = 255 TCF. Total = 1,140 TCF.
	Summary
NPC, 1992	Current and advanced technology proved reserves. Presented only at regional level. Depth zones available. Unconventional resources included. HSM model used. Current to January 1991.
PGC, 1995	No proved reserves. Depth zones available. Technology advances included, but advanced versus current numbers not included. Presented at province and area level. Unconventional resources included. Geologic probabilistic quantitative method used at province level. Current to December 1994.

Organization	Methodology Factors continued: Summary continued:
USGS, 1995	Proved reserves. Unconventional resources included. Small undiscovered accumulations assessed separately. Only current technology. Separate methodology for most unconventional resources. Depth zones published separately. Resources presented by play. Geologic probabilistic quantitative method used at play level. Published in digital form as U.S. Geological Survey Digital Data Series (DDS) 30. Current to January 1994.
MMS, 1996	Proved reserves. Unconventional resources not included. Only current technology. Resources presented by province in published report, but calculated by play. Geologic probabilistic quantitative method used at play level incorporating PETRIMES and GRASP programs. Published as MMS OCS report 96-0034 as well as regional papers. Current to January 1995.
ENRON, 1993	Proved reserves. Data published at National level. Unconventional resources included. No separate depth zones published. Advanced technology included. Proved reserves included. GRI HSM model used. Current to January 1993.
GRI, 1995	Data published at regional and National level. Unconventional resources included. Depth zone available. GRI HSM model used.