Global Petroleum Resources

A View to the Future

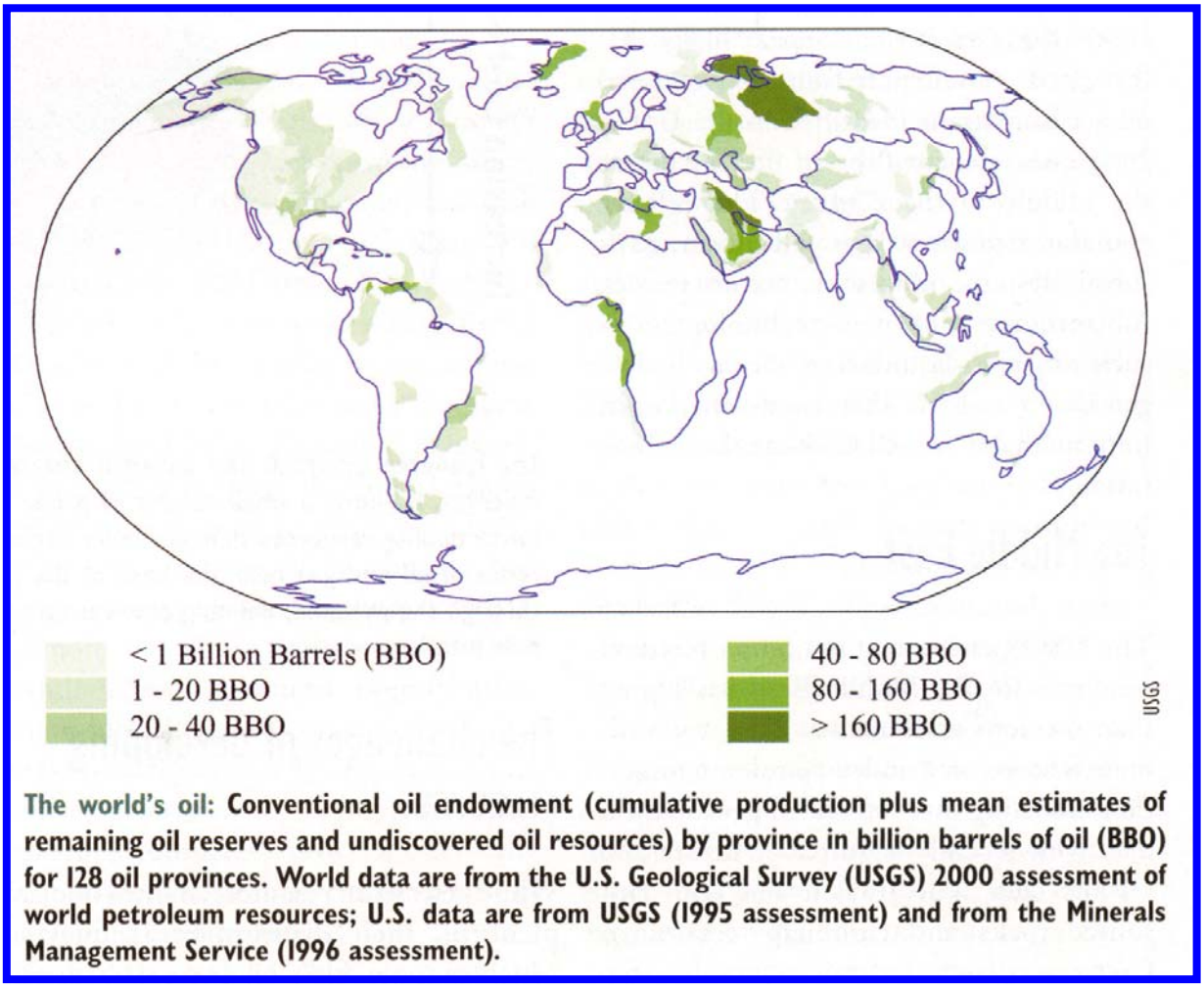
Geologists are often asked: How much oil and gas is left in the world? There is no simple answer to this question. Geology, economics, politics, technology and social science all play a role in assessing our resources and determining the economic viability of those resources.

The terms *petroleum, crude oil, natural gas* and *natural gas liquids* each have precise scientific definitions. But appending the word *resource* to any of them creates a term that crosses the boundary between science and social science and includes economics. Many geologists begin to feel uncomfortable in this area between science and social science. *Webster's Dictionary* defines a resource as "a natural source of wealth or revenue." A fossil fuel resource is one that can be profitably extracted. Compared to scientific terms, social science terms are fluid. What is profitable or societally acceptable one day may not be the next and vice versa. We must ask: How much profit is necessary extraction? What time frame are we considering?

USGS estimate of petroleum resources

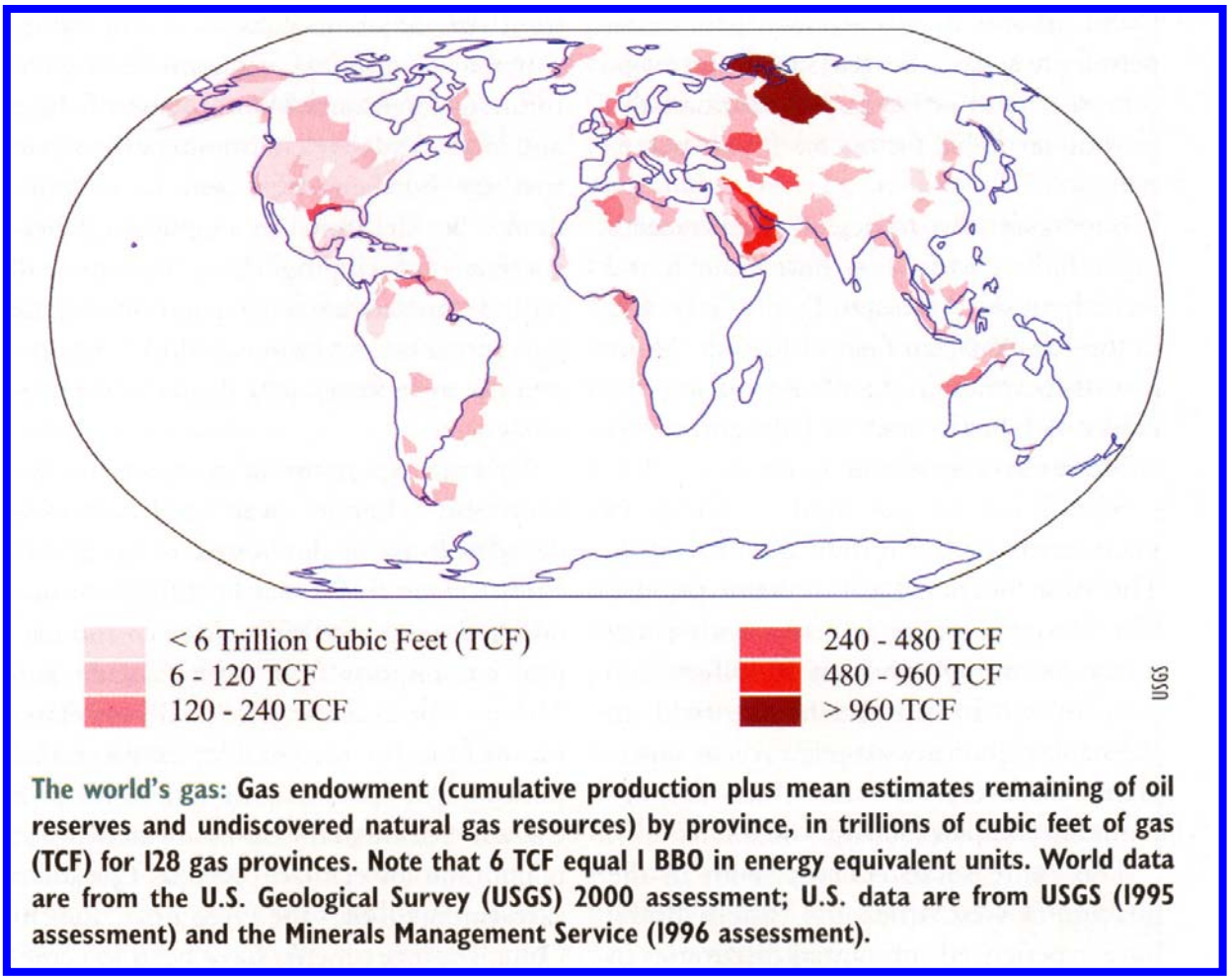
It is necessary to periodically reassess petroleum resources, not only because new data become available and better geologic models are developed, but also because many non-geologic factors determine which part of the crustal abundance of petroleum will be economic and acceptable over the foreseeable future.

In 2000, the U.S. Geological Survey completed an assessment of the world's conventional petroleum resources, exclusive of the United States. This assessment is different from those before it: Overall the 2000 assessment of potential petroleum resources is higher than previous assessments, largely because it is the first USGS world assessment to include field growth estimates.



The world's oil: Conventional oil endowment (cumulative production plus mean estimates of remaining oil reserves and undiscovered oil resources) by province in billion barrels of oil (BBO) for 128 oil provinces. World data are from the U.S. Geological Survey (USGS) 2000 assessment of world petroleum resources; U.S. data are from USGS (1995 assessment) and from the Minerals Management Service (1996 assessment).

Based on a *thorough* investigation of the petroleum geology of each province, the assessment couples geologic analysis with a probabilistic methodology to estimate remaining potential. Including the assessment numbers for the United States from USGS and the Minerals management Service (MMS), the world's endowment of recoverable oil which consists of cumulative production, remaining reserves, reserve growth and undiscovered resources is estimated at about 3 trillion barrels of oil. Of this, about 24 percent has been produced and an additional 29 percent has been discovered and booked as reserves. The natural gas endowment is estimated at 15.4 quadrillion cubic feet (2.5 trillion barrels of oil equivalent), of which only about I I percent has been produced and an additional 31 percent has been discovered and booked as reserves.



The world's gas: Gas endowment (cumulative production plus mean estimates remaining of oil reserves and undiscovered natural gas resources) by province, in trillions of cubic feet of gas (TCF) for 128 gas provinces. Note that 6 TCF equal 1 BBO in energy equivalent units. World data are from the U.S. Geological Survey (USGS) 2000 assessment; U.S. data are from USGS (1995 assessment) and the Minerals Management Service (1996 assessment).

The USGS assessment is not exhaustive, because it does not cover all sedimentary basins of the world. Relatively small volumes of oil or gas have been found in an additional 279 provinces, and significant accumulations may occur in these or other basins that were not assessed. The estimates are therefore conservative.

Areas that contain the greatest volumes of undiscovered conventional oil include the Middle East, western Siberia, the Caspian region, and the Niger and Congo deltas. Significant undiscovered oil resource potential was suggested in a number of areas that do not have important production history, such as northeast Greenland and offshore Suriname. Areas that contain the greatest volumes of undiscovered conventional gas include the West Siberian Basin, the shelves of the Barents and Kara Seas, the Middle East and offshore Norway. Significant additional undiscovered gas resources may occur in a number of areas where large discoveries have been made but remain undeveloped. Examples include East Siberia and the Northwest Shelf of Australia. About half of the assessed undiscovered petroleum potential of the world is offshore, especially outside the established provinces of the United States, former Soviet Union, Middle East and North Africa. Arctic basins, which hold about 25 percent of the undiscovered petroleum resources, make up the next great frontier.

The assessment suggests that some recent claims of an imminent oil shortage cannot be suported. Furthermore, large volumes of natural gas can replace oil in most market sectors. The rate of production of resources depends on many factors including investments in exploration and development, political conditions and the growth or decline in demand from the global economy

It is impossible to forecast rates of production purely from geologic information. Given this fact, it does appear likely that the global- production from conventional oil accumulations identified in the USGS 2000 assessment will be in decline before the middle of the century. The relative abundance of natural gas will encourage its substitution for oil in some market sectors. Advancements in new technologies -such as gas-to-liquids and various hydrogen-based systems that extract hydrogen from methane - will facilitate this substitution.

The Middle East

The USGS assessment of undiscovered oil resources for the Middle East was higher than previous assessments. This new estimate is based on detailed petroleum migration modeling that integrated geochemical data with recently acquired structure and seismic data. The Jurassic has both rich source rocks and carbonate reservoirs. Cretaceous and Tertiary reservoirs trap hydrocarbons in a currently generating petroleum system. Several significant evaporite seals and active trap formations also provide favorable factors for future potential.

Supergiant discoveries - those exceeding I billion barrels - have been found recently in the Azadegan field of Iran and in the Kra Al Maru field of Kuwait. Many new discoveries in Saudi Arabia on the flanks of Ghawar and in Paleozoic reservoirs are also very encouraging.

Significant oil potential is found in many areas of the former Soviet Union. The West Siberian Basin remains prolific. The Caspian region is active with enormous discoveries (at least 20 billion barrels) of oil in the Kashagan field in Paleozoic carbonates. Another recent supergiant discovery is the Azeri-ChiragGunashli complex (at least 5 billion barrels).

The entire south Atlantic, both in the offshore of West Africa and eastern Brazil have experienced substantial discoveries in deepwater clastic deposits and will continue to do so as evidenced by new discoveries in the Santos Basin.

The challenges of developing resources

While petroleum resources in the world are plentiful, their distribution is uneven. Much of the world's oil and gas is distant from the major markets - a continuing concern for political, economic and environmental reasons. Many of the offshore and arctic areas are environmentally sensitive far from markets and in environments hostile from an engineering perspective. Developing these regions will require international cooperation among governments, environmentalists and the petroleum industry to a degree not previously seen.

Existing export and import patterns will inevitably change over the next few decades. In particular, results of the USGS study suggest that it may be difficult to sustain U.S. oil imports from Mexico and natural gas imports from both Canada and Mexico. For example, the USGS estimates for technically recoverable, conventional natural gas resources in the Western Canada Sedimentary Basin are an order of magnitude lower than previous Canadian assessments of the region. Recent Canadian assessments have been lowered. The differences among assessments are related to the minimum size at which a field is considered economically viable.

Smaller fields are more numerous than larger fields. The smallest field size that USGS considered viable on a world scale was 3 billion cubic feet of gas for a Canadian gas pool.

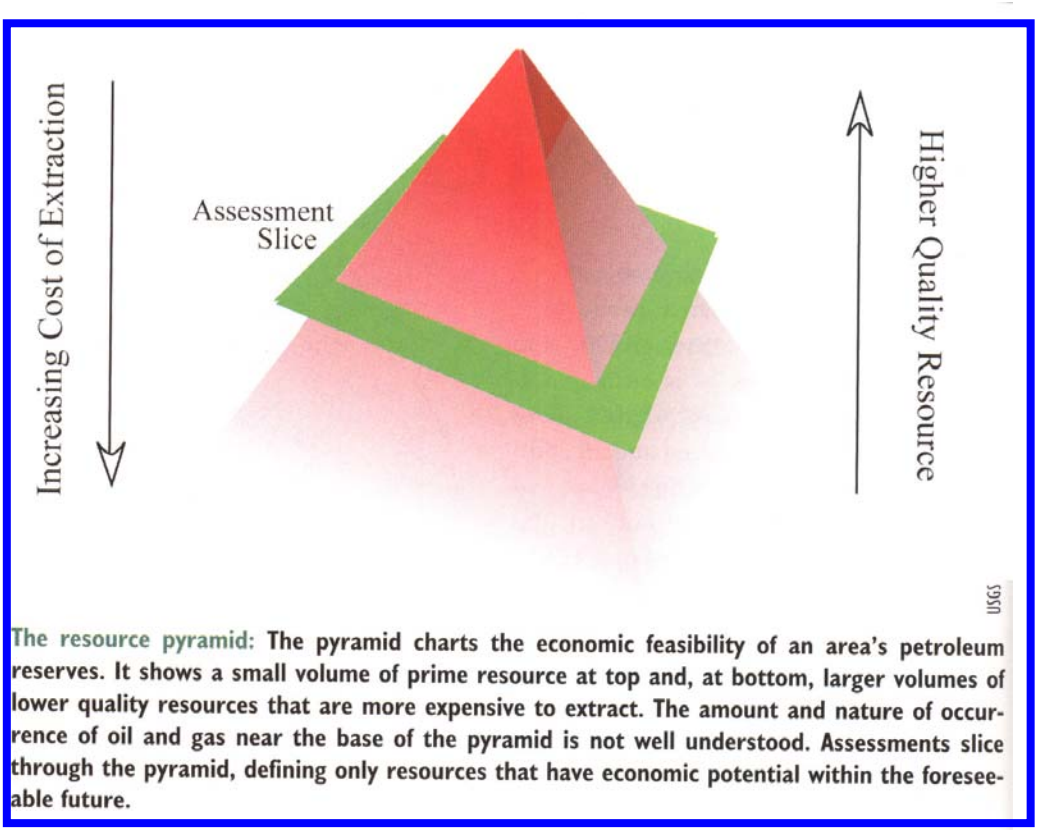
Although many energy scenarios call for increased natural gas consumption in the United States, we may need to increase imports of liquefied natural gas or make major domestic natural gas discoveries to meet this new demand. Currently, the United States imports about 15 percent of its natural gas from Canada.

Many organizations and individuals regard the USGS 2000 assessment as the most credible and scientific world petroleum assessment available. However, assessments are dynamic and each represents a snapshot in time. It is worth considering the evolution of some of the nongeologic factors that necessitated a revision from previously published USGS assessment numbers. Because these parameters are still evolving, we can also speculate how they may impact future assessments.

The resource pyramid

In an abstract way, the amount of oil or gas in the world can be viewed as a pyramid with a small amount of high quality resource that is cheap to extract, and with increasing amounts of lower quality resource that cost more to extract. The upper part of the pyramid is well defined, as these resources are mostly known and are generally considered "conventional." The lower part of the pyramid is less well understood and the amount of petroleum in accumulations that are now largely uneconomic – such as hydrates or basin centered gas – is highly speculative. An assessment draws a slice

through the pyramid defining the resource of oil or gas that is estimated to become economic within the foreseeable future.



The resource pyramid: The pyramid charts the economic feasibility of an area's petroleum reserves. It shows a small volume of prime resource at top and, at bottom, larger volumes of lower quality resources that are more expensive to extract. The amount and nature of occurrence of oil and gas near the base of the pyramid is not well understood. Assessments slice through the pyramid, defining only resources that have economic potential within the foreseeable future.

Over time, the relative positions within the pyramid of the various accumulations of the world's oil and gas vary. The geological abundance of petroleum (prior to extraction) remains the same, but our perception of it changes for a variety of reasons. Hydrocarbon accumulations that were once thought to be only of scientific interest are transformed into unconventional resources" and eventually become "conventional" as they rise higher in the pyramid. For example, the recovery costs for oil from Alberta's oil sands have fallen dramatically over the last 20 years and are now about $8 per barrel. By 2005, fully 10 percent of North America's oil production will come from Alberta's oil sands.

The Alberta oil sands contain 1.6 trillion barrels of oil, of which 311 billion barrels are recoverable with current technology. Similarly, a significant amount of U.S. natural gas production now comes from sources once considered unconventional but now viewed as conventional Resources may also fall in the pyramid. In1860, Titusville was the oil resource at the top of the pyramid. In 1901, Spindletop was. Although they still produce, western Pennsylvania and eastern Texas are no longer near the top of the pyramid. At the beginning of the 20th century, the Middle East as an oil resource was viewed at the bottom of the pyramid.

Elements influencing the pyramid

The human and social factors affecting data and imformation incorporated into a resource assessment can be viewed schematically as a sphere of interacting factors that circle outside the pyramid and act on it. In large part, these factors determine the relative position of various petroleum accumulations within the pyramid and ultimately determine what a viable petroleum resource is. Human and social factors are dynamic and appear to change at an ever-increasing pace. USGS gains insights into potential future viable resources related to these factors by talking with petroleum industry leaders.

Elements affecting the pyramid are:

Geoscience Technology

The last decade has seen rapid advances in the science and technology of oil and gas exploration and production. Global, satellite-derived data and detailed topographic and spectral images allow us to see our planet as never before. Deep seismic data and earth tomography allow us to perceive the structure of the planet. The digital revolution and the personal computer have put our own data and vast amounts of public domain data at our fingertips. Two key technologies have enhanced our ability to 11 see" the subsurface realm: 3-D seismic reflection data and DHIs (Direct Hydrocarbon Indicators determined from seismic attributes) viewed in visualization centers. More sensitive and precise logging and geochernistry tools provide new insights. Recent research also has given us more clues about fluid flow and hydrocarbon migration.

Petroleum Engineering and Chemistry

The drilling and completion of wildcat tests and production wells have advanced rapidly in the last decade. Drilling in deep water in the Arctic and other hostile environments has allowed the industry to venture into regions once thought "out of reach." Long horizontal reach wells -which stretch laterally up to several kilometers, extend the reach of drilling and enhance recovery - have become common. Well stimulation and improved fracing technologies – which increase the rate of petroleum flow from a reservoir by injecting hydraulic fluids to fracture the rocks - have greatly increased recovery factors and improved recovery economics for many accumulations.

Extraction of heavy oil, tight gas and coalbed methane is now economically viable in North America, but still considered "unconventional" in many parts of the world. The increasing ability to process huge data sets promises advanced models of fluid flow and geochemistry that will continue to improve the ability to i ify prospects, and will help to boost recovery factors. A small percentage rise in recovery factors worldwide would increase recoverable oil and gas resources considerably

The International Oil and Gas Business

The complex interrelations of national oil companies, large international integrated energy companies, and independent operators all contribute to our perceptions of world oil and gas resources. Sanctions, subsidies, taxes, regulations and environmental policies all impact the potential availability of resources and our relative understanding of them. Despite all of our geological expertise, much oil and gas is still found by drilling, and if large geographic areas are "off limits" for long periods, there is no chance of serendipitous discoveries.

Gas is assuming a more prominent role in the petroleum industry. Much needs to be learned about the viability of unconventional gas deposits such as coalbed methane, tight gas, fractured shale gas, gas hydrates and dissolved saltwater gas. We have many questions to answer: Can we effectively find and produce these dispersed, low concentration hydrocarbons? Will markets be found for geographically stranded gas? If a coalbed methane accumulation is found in Siberia, is it a reserve, a resource or something that has no potential to be developed within the foreseeable fiiture?

The Political Domain

Thirty years ago it was common to speak of the "500 sedimentary basins" of the world. At that time, the Cold War divided the world, and most western geoscientists knew little of eastern block basins. Now we speak of more than 1,500 sedimentary basins worldwide. Political agendas and policies have a major impact on whether or not a particular hydrocarbon accumulation is considered a resource. Regulations, environmental policies, subsidies and economic agendas in one region may have a global impact.

Global Economics

In the competitive petroleum business of finding and producing oil and gas, performance is measured by the value created. The energy business floats on an economic sea of high and low tides and periodic storms. The health of the global economy, the price of oil, and cycles of demand a oversupply raise and lower all boats. such dynamic, commodity-driven enviro ments, the deflnition of a resourcee cchann with time and market conditions.

The Human Element

A critical component in the resource equ tion is the human mind. The mind c create models of the dynamic subsurfa realm and intelligently estimate t resource base. But we face two problems. In this time of prodigious quantities of da and information, the number of know edgeable and experienced oil finders is decreasing because fewer are being trained. The annual survey of universities conducted by the American Geological Institute shows that the number of geosciene degrees granted in 2001 was a third of the number granted 20 years ago.

The second problem is that the average citizen has little knowledge of the subsurface realm and even less about the fluid dynamics of oil and gas deposits. Thus, most policyrnakers and users of energy are not equipped to enter the debate about the nature of the world's oil and ga resources. As a consequence, the debate often has migrated to the end members – Malthusians and Cornucopians – each one with a set of personal, corporate political or environmental agendas. In large part, it is a misunderstanding of the nature of resources that allows those with agendas to argue vehemently over the size of remaining resources.

The resource pyramid will continue to evolve. An understanding of the geological, technological, economic, political and social forces that drive that change is critical to understanding resources Raw oil and gas resource numbers, use out of context, are the shot and powde of manipulators. The economic petrole um geoscientist must clearly be at th table when corporate managers, politi cians, lawyers, economists and activis groups discuss world energy resources.

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