



Reserve Growth During Financial Volatility in a Technologically Challenging World

By Timothy R. Klett and Donald L. Gautier

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Abstract

Reserve growth (growth-to-known) is the addition of oil and gas quantities to reported proved or proved-plus-probable reserves in discovered fields. The amount of reserve growth fluctuates through time with prevailing economic and technological conditions. Most reserve additions are the result of investment in field operations and in development technology. These investments can be justified by higher prices of oil and gas, the desire to maintain cash flow, and by greater recovery efficiency in well established fields. The price/cost ratio affects decisions for field abandonment and (or) implementation of improved recovery methods. Although small- to medium-size fields might show higher percentages of reserve growth, a relatively few giant fields contribute most volumetric reserve growth, indicating that companies may prefer to invest in existing fields with low geologic and production risk and an established infrastructure in order to increase their price/cost relationship. Whereas many previous estimates of reserve growth were based on past trends of reported reserves, future reserve growth is expected to be greatly affected by financial volatility and fluctuating economic and technological conditions.



Reserve Growth During Financial Volatility in a Technologically Challenging World

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**Society of Petroleum Engineers
Hydrocarbon Economics and Evaluation Symposium, Dallas, TX
8-9 March 2010**

**U.S. Department of the Interior
U.S. Geological Survey**

1. Talk given at Society of Petroleum Engineers Hydrocarbon Economics and Evaluation Symposium, Dallas, Texas, March 8–9, 2010. This talk is about reserve growth during financial volatility in a technologically challenging world. I would like to thank my coauthor, Don Gautier, and my colleague, Emil Attanasi, for their contributions to this presentation.

Outline

- **Background**
- **Financial and Technological Factors**
- **Inventory Concept**
- **Conclusions**



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2. I will first give you some background on what reserve growth is and why it is important. Next, I will describe the financial and technological factors that allow reserves to be added in discovered fields, or conversely, by new field discoveries. Financial volatility and real price of petroleum affect additions to reserves. I will put this discussion in context by describing the inventory concept. Despite financial volatility, an inventory of petroleum can be maintained. I will conclude with a few summary points.

Outline

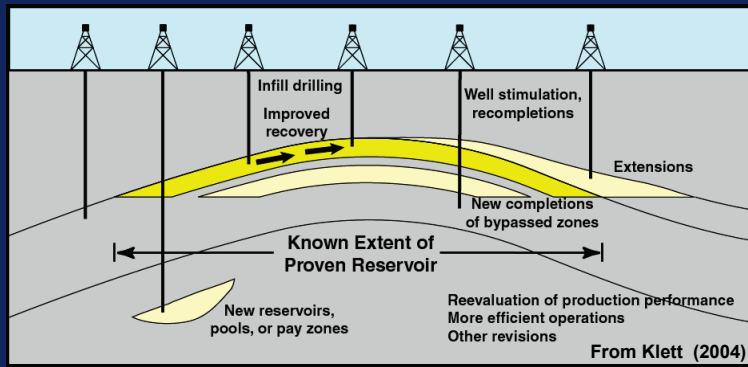
- **Background**
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3. Understanding reserve growth affects abilities of industry, governments, and other interested parties to more fully understand the critical issues of future resource availability.

Reserve Growth: Increases in successive estimates of recoverable quantities of crude oil, natural gas, and natural gas liquids in discovered fields



- Delineation of additional in-place quantities
- Increases in recovery efficiency
- Recalculation of viable reserves in changing economic, operating (technological), and political/regulatory conditions

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4. Commonly, increases in successive estimates of recoverable quantities of crude oil, natural gas, and natural gas liquids are observed in discovered fields. These increases typically are due to additions to reserves, which we call reserve growth. Reserve growth is also called growth-to-known, field growth, or ultimate recovery appreciation. Fields are not well-defined entities in terms of area and stratigraphy. Reserve growth is a result of three main factors: delineation of additional in-place quantities by new pool discoveries, extensions of producing area, and new completions of bypassed zones. Reserves can be added by increases in recovery efficiency by infill drilling, well stimulation, and improved recovery operations. Also, recalculation of viable reserves, for example by reevaluation of production performance and more efficient operations, can add reserves. In most cases additions of in-place recovery quantities and increases in recovery efficiency require investment, with the decisions whether or not to invest depending largely on prevailing economic, operating (or technological), political, and regulatory conditions, all of which result from changes in the financial environment. Financial volatility makes it difficult to predict actual amounts of future reserve growth, but estimates of reserve growth can be determined.

Reserve Growth

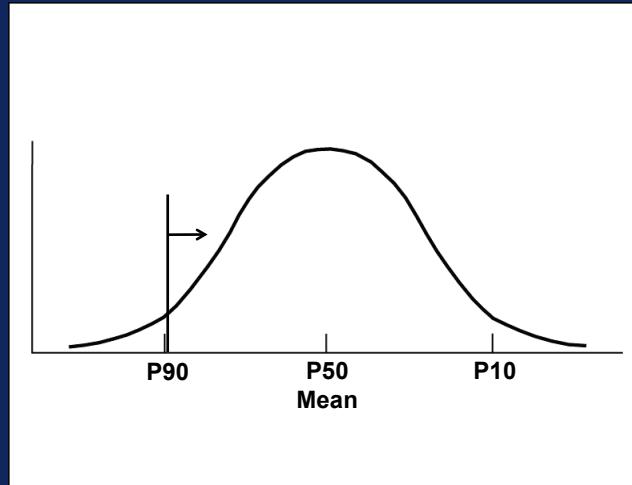
- **Addition of oil and gas quantities to reserves in discovered fields**
- **Fields are commonly identified as conventional and unconventional**



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5. Simply stated, reserve growth is the addition of oil and gas quantities to reported proven or proven-plus-probable reserves in discovered fields. Fields are commonly identified as conventional or unconventional. The USGS calls the unconventional accumulations continuous, and this classification depends on whether or not accumulations rely on buoyancy of petroleum in water. Most of this talk will focus on reserve growth in conventional fields.

As reserves are added, volume increases and proven reserves moves toward central tendency



USGS

From Pike (2008)

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6. This slide shows a normal probability distribution that depicts how reserve growth can change the assignment of petroleum from various reserve classes. Typically, as reserves are added from other reserve classes or resources, the volume increases and the proven reserves move toward some central tendency. Reserve growth in the United States is expected because of the strict requirements for reporting reserves. Only the very well defined proven reserves are reported in the United States. However, reserve growth is observed in fields outside the United States where proven plus probable reserves are commonly reported.

Reserve Growth

- Not all fields show growth in reserves
 - The overall trend is for higher values through time
 - The trend is influenced by volumetrically significant fields
 - Many fields show no growth of reserves and many shrink



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7. Not all fields show growth in reserves, however. The overall trend is for higher values through time, but the trend is influenced by volumetrically significant fields. Many fields show no growth of reserves, and many shrink with continued production.

Reserve Growth

- **Giant fields (>0.5 BBOE) contribute most volumetric reserve growth**
 - Companies may prefer to invest in existing fields
 - Low geologic and production risk
 - Established infrastructure
 - Increase price/cost relation
- **Small-to-medium size fields show higher percentages of reserve growth**
 - Small volumetric contribution

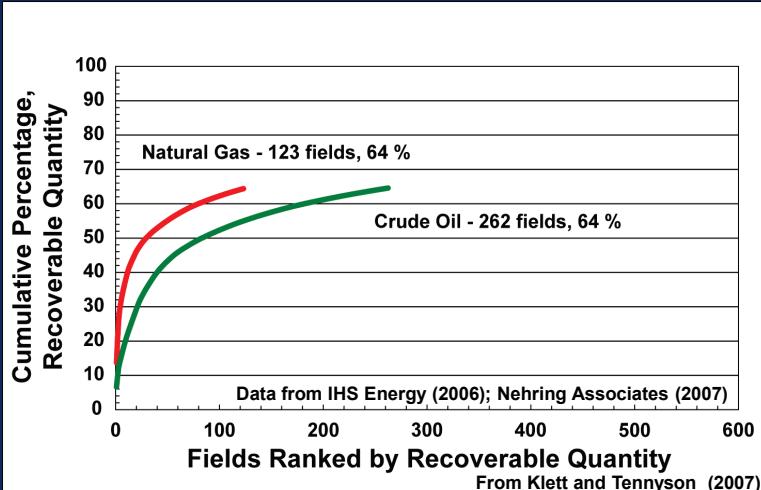


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8. A relatively few giant fields (0.5 billion barrels of oil equivalent, BBOE) contribute most of the volumetric reserve growth, indicating that companies may prefer to invest in existing fields with low geologic and production risk that have an established infrastructure in order to increase their price/cost relation. Small- to medium-size fields might show higher percentages of reserve growth, but reserve growth in these fields contributes only small volumes relative to the large fields.

Greatest quantity of available oil/gas is in largest fields

Fields \geq 1 Billion Barrels of Oil Equivalent

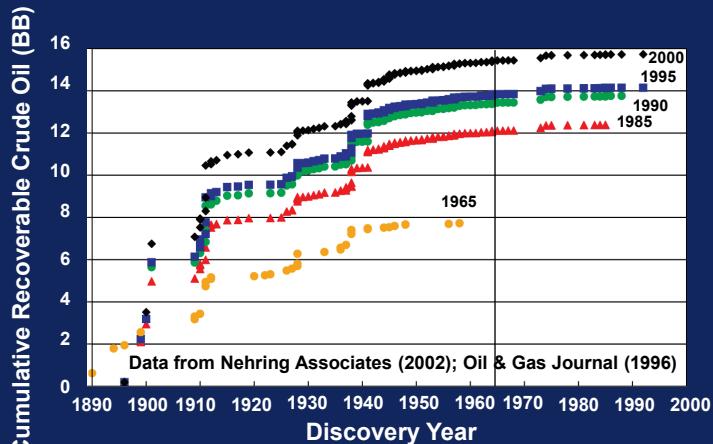


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9. This is an example of the volumetric contribution to the recoverable volumes of oil and gas in the world by a relatively small number of giant fields. The red line represents gas in gas fields and green represents oil in oil fields. Sixty-four percent of the reported recoverable volumes are from 123 giant gas fields and 262 giant oil fields.

Reserve growth fluctuates with prevailing economic and technological conditions

San Joaquin Basin, Crude Oil



USGS

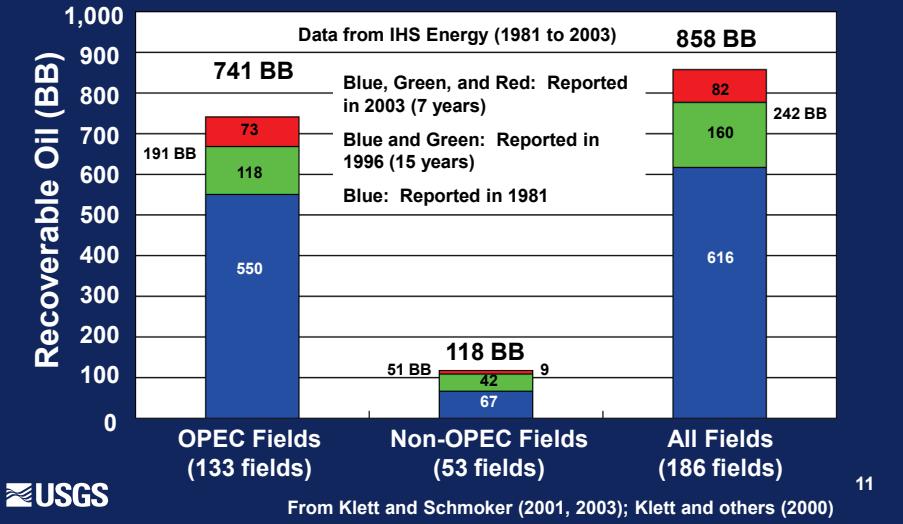
From Klett (2004) after Tennyson (2004)

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10. In many mature basins, greater volumes of petroleum are added to reserves by reserve growth rather than by new-field discoveries. This graph shows a series of creaming curves for the San Joaquin Basin of California. Each curve represents the cumulative recoverable volumes of oil (cumulative field sizes) in fields in the basin reported for a given year. The vertical axis is oil volume in billion barrels, and the horizontal axis is field-discovery year. The orange curve represents the cumulative field sizes as they were reported in 1965. The remaining curves represent 5-year increments in the report years between 1985 and 2000. The same fields are plotted in the same position, by discovery year, in each curve. One thing to note is the significant increases in field sizes through time, shown here by the upward translation of the curves. This is reserve growth. Notice that the amounts of translation among the curves differ. The additions to total recoverable volume are due almost exclusively to reserve growth, not new-field discoveries. The new fields, shown here, are insignificant in terms of field size. Between 1985 and 1990, steam injection greatly increased additions to reserves. Between 1990 and 1995, however, steam injection waned, resulting in smaller additions to reserves. It continued to wane until 1995; despite this, revisions of recoverable estimates made by the California Department of Oil and Gas increased the reserves of Midway-Sunset and South Belridge, as well as several other fields, which resulted in the last jump. Another thing to note is that reserve growth does not occur at a constant rate, but rather in stepwise, inconsistent increases.

Reserve growth is observed in fields outside the United States

Greater percent growth of non-OPEC fields 1981-1996 than OPEC fields, reversed 1996-2003



11. Reserve growth is also observed elsewhere in the world. Field sizes of 186 giant oil fields (0.5 billion barrels (BB) or more of recoverable oil) from around the world were estimated at different times and the totals are shown here. This graph is from a previous study using IHS Energy data. At the time of the study, we did not have data for every year; thus we calculated changes between several-year increments. These giant fields contain about 50 percent of the world's recoverable oil (as of 1996). OPEC and non-OPEC fields were studied together, as well as separately; no U.S. or Canadian fields were included. Russian fields are not fully represented in the non-OPEC dataset. The blue bars on the graph represent the sum of the recoverable oil (field sizes) as reported in 1981. The fields contained a little more than 600 BB of oil. The green bars represent the volumes added between 1981 and 1996, 15 years later. One hundred sixty BB of recoverable oil was added (total of 776 BB). The red bars represent the volumes added between 1996 and 2003, 7 years later. Notice that this time period is about half of the previous time period from which the green segments were derived. Another 82 BB was added for a total of 242 BB of reserve growth since 1981 (overall 858 BB). Notice too that the percent growth between 1981 and 1996 in non-OPEC fields is much greater than in OPEC fields, but the percentage is reversed between 1996 and 2003.

Outline

- **Background**
- **Financial and Technological Factors**
- **Inventory Concept**
- **Conclusions**

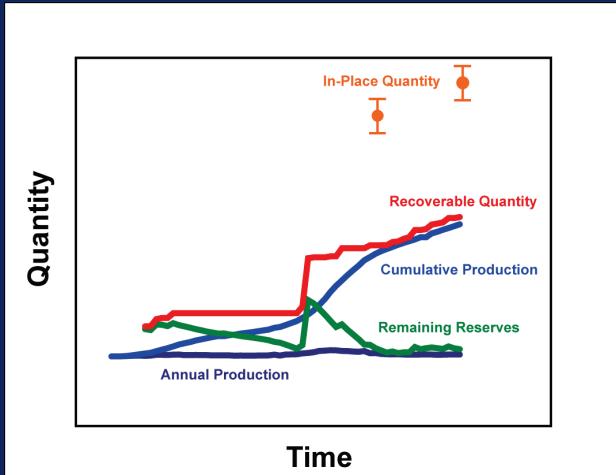


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12. Financial and Technological Factors

Most reserve additions from investment in field operations and development technology

Factors That Affect Reserve Growth



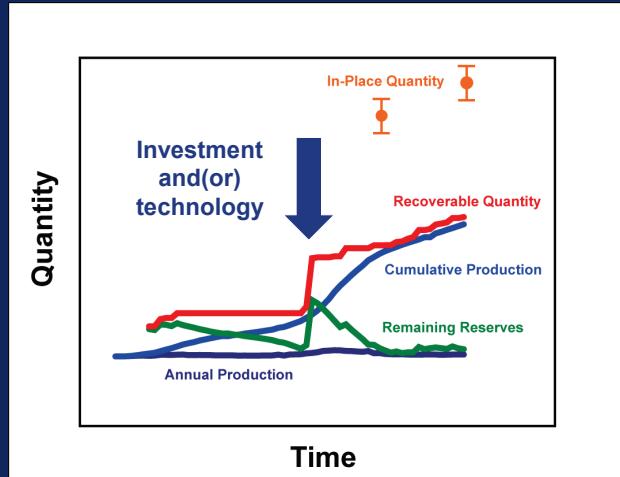
From Klett and Tennyson (2007)

13

13. When reported produced quantities and estimated reserves for a given field are plotted with respect to time, a graph like this can be constructed. Starting at the top, original in-place quantities are shown in orange, recoverable quantities in red, cumulative production in blue, remaining reserves in green, and annual production in blue at the bottom. Recoverable quantities are the sum of cumulative production and remaining reserves. Notice the sharp jump in remaining reserves and recoverable quantity.

Most reserve additions from investment in field operations and development technology

Factors That Affect Reserve Growth



From Klett and Tennyson (2007)

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14. Typically, changes in remaining reserves and recoverable quantities occur in a stepwise fashion resulting from specific investments and (or) technical changes. In this case, it might be due to waterflooding, gas cap injection, carbon dioxide flooding, or even reestimated reserves as was done for some fields in the San Joaquin Basin.

Factors That Affect Reserve Growth

- **Investments justified by**
 - Higher prices
 - Desire to maintain cash flow
 - Greater recovery efficiency



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15. Investments can be justified by higher prices of oil and gas, by the desire to maintain cash flow, and by greater recovery efficiency in well-established fields.

Factors That Affect Reserve Growth

- **Price/cost ratio**
 - Exploration or development
 - Field abandonment
 - Implementation of improved recovery methods

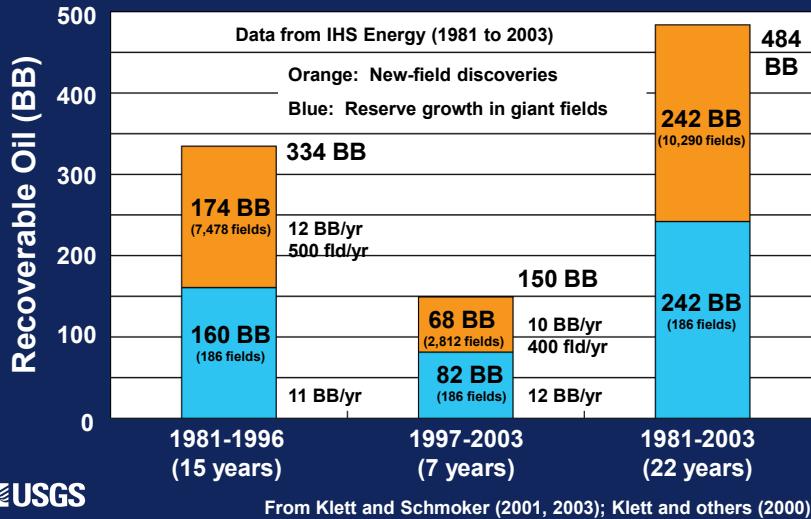


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16. The price/cost ratio affects decisions for field abandonment and (or) implementation of improved recovery methods, and this ratio also affects decisions whether to explore for new fields or develop existing fields.

New-Field Discoveries vs Reserve Growth

Reserve Additions, 1981-2003

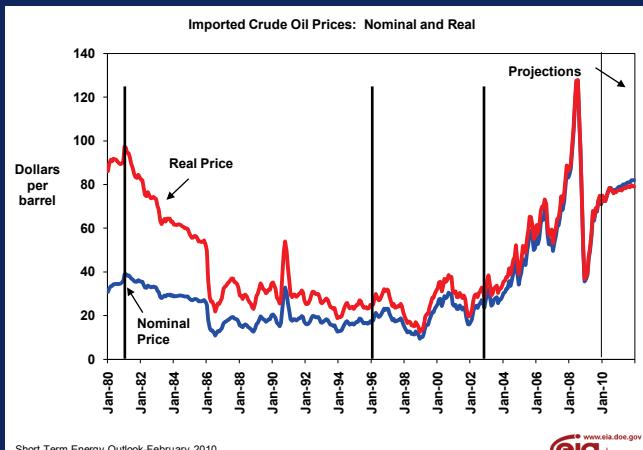


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17. The blue bars on this graph show the amount of reserve growth from the 186 giant fields that I showed earlier from 1981 to 1996 (15 years) and 1997 to 2003 (7 years). As before, the time durations are different, and the center bar represents one-half of the duration as the first bar. The graph also shows additions from new-field discoveries worldwide for the same time periods, by the orange bars. Clearly, the volumes added to reserves from the giant oil fields for the 22-year period are equivalent to those volumes added by all of the new fields discovered around the world. Between 1981 and 1996, the average annual additions to reserves were 11 BB/year from reserve growth and 12 BB/year from new-field discoveries. Since 1997, however, the average annual additions to reserves reversed and were 12 BB/year from reserve growth and 10 BB/year from new-field discoveries. Also, the number of new fields discovered decreased from 500 per year between 1981 and 1996 to 400 per year between 1997 and 2003. Looking at the ratios between new-field additions and reserve growth additions, an issue about forward cost can be raised. These ratios seem to imply that in the years between 1981 and 1996, the forward cost of reserve growth might have been greater than the forward cost of yet-to-find. A greater amount of recoverable oil was added by new discoveries — 174 BB is from 7,478 new fields and 160 BB is from the reserve growth of the 186 giant fields. Further, the ratios imply that at least since 1997, the forward cost of yet-to-find might have been greater than the forward cost of reserve growth, on the average. A smaller amount of recoverable oil was added by new discoveries — 68 BB from 2,812 new fields and 82 BB is from reserve growth of the 186 giant fields. Overall, however, the contributions were coincidentally the same between 1981 and 2003.

Real price of crude oil was higher 1981-1996, lower 1997-2003

Real Price of Crude Oil, 1980-2010



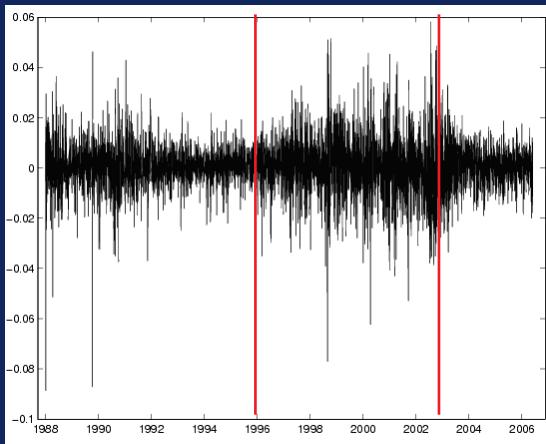
Energy Information Administration (2010)

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18. The question is what caused this shift in the ratios of additions by new-discoveries to reserve growth — was it new technology, reduced exploration opportunities, smaller discoveries, geology, technology, economy, politics? One possibility might be that until recently, the price of oil has been relatively low and rates of exploratory drilling also have been at a very low level. This graph shows the real price of crude oil through time. It indicates that the average real price of crude oil was somewhat higher between 1981 and 1996, when new-field discoveries added more to reserves, and lower between 1997 and 2003, when reserve growth added more, supporting our observations on the previous slide. Exploration requires significant capital and the economic and technological risks could be great. Development is more cost effective than exploration and has lower associated risks, which are desirable when prices are low. The fiscal decisions in the global market to preferentially invest in development of previously discovered fields rather than exploration for new ones might be reflected in these statistics.

**Financial volatility was lower 1981-1996,
higher 1997-2003**

Daily Percent Changes S&P 500, 1988-2007



From University of Amsterdam (2010, M.P. Visser)

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19. This graph depicts financial volatility through time. It shows the daily percent changes of the Standard and Poors (S&P) 500 from 1988 until 2007. An apparent inverse relation between volatility and oil price is observed. Financial volatility was lower between 1981 and 1996 when the real price of oil was higher. Volatility was higher between 1997 and 2003 when the real price of oil was lower.

Factors That Affect Reserve Growth

- **Reserves replacement**
 - Mainly enhanced development of discovered fields rather than new-field exploration
 - Low cost, minimal risk strategy



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20. We will soon see that reserves replacement in the United States has come about mainly through enhanced development of previously discovered oil fields rather than from new-field discoveries. Reserve growth represents a very low cost, minimal risk strategy.

Outline

- Background
- Financial and Technological Factors
- **Inventory Concept**
- Conclusions

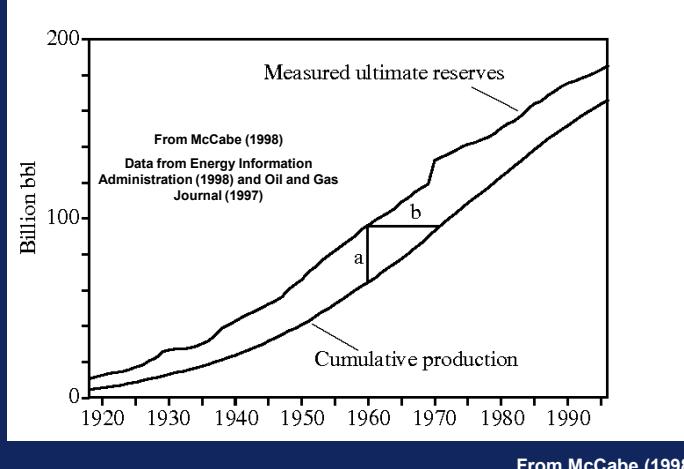


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21. Inventory Concept

Proven reserves sufficient to supply production for following 10-14 years

Inventory of Crude Oil, U.S. Fields

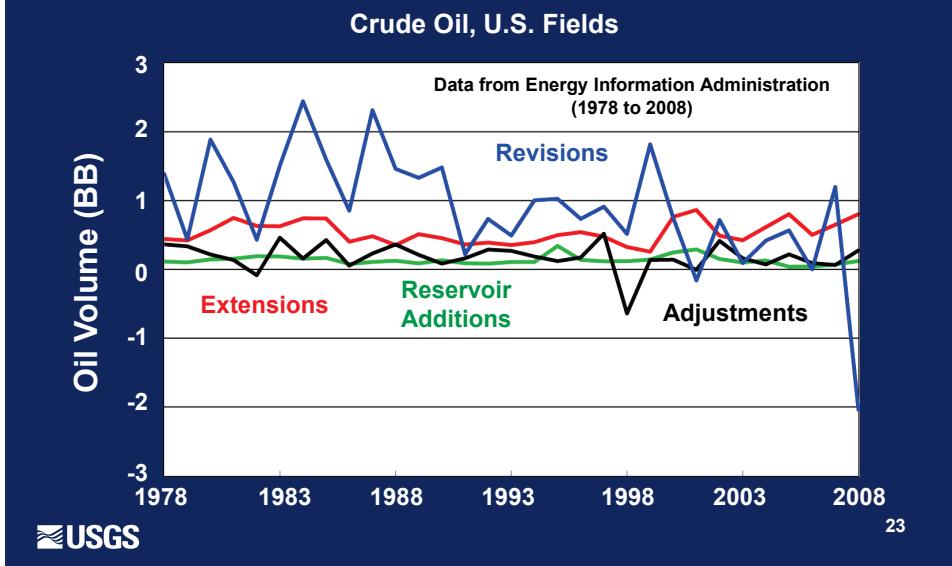


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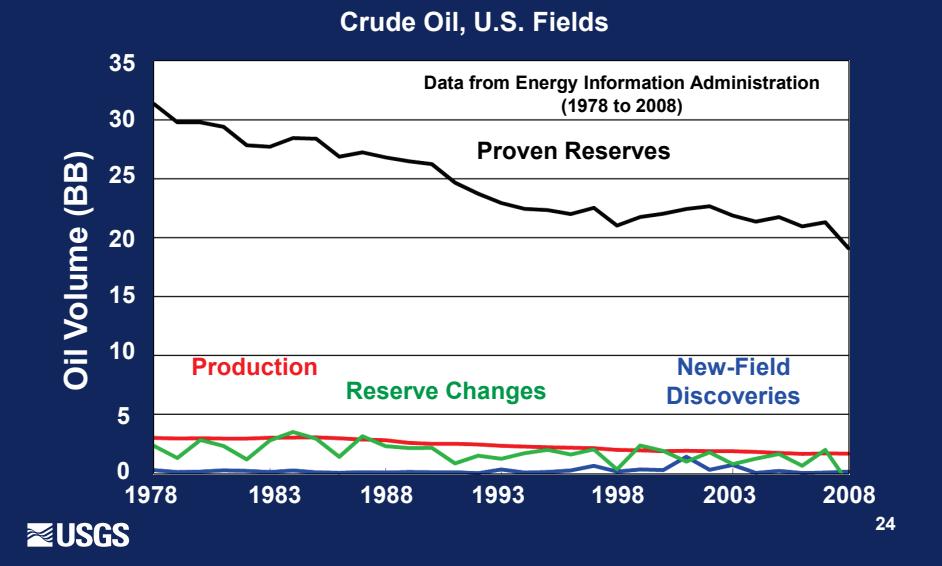
22. This graph represents oil fields in only the United States. The concept is that proven reserves measured in any given year (shown here by line a) have been sufficient to supply the Nation's production for the following 10 to 14 years (shown here by line b). The narrowing of inventory since 1980 is because more rigorous criteria have been used to define U.S. crude oil reserves; that is, the tightening of constraints for reporting only proven reserves. This graph might look significantly different for areas outside the United States because assumptions on what the inventory should be and how long it should last differ among countries and operators. These differences would be a result of reserves reported by Independent Oil Companies compared to those reported by National Oil Companies and differences between reporting proven reserves compared to reporting proven-plus-probable reserves.

Revisions and adjustments more important than reservoir extensions and additions



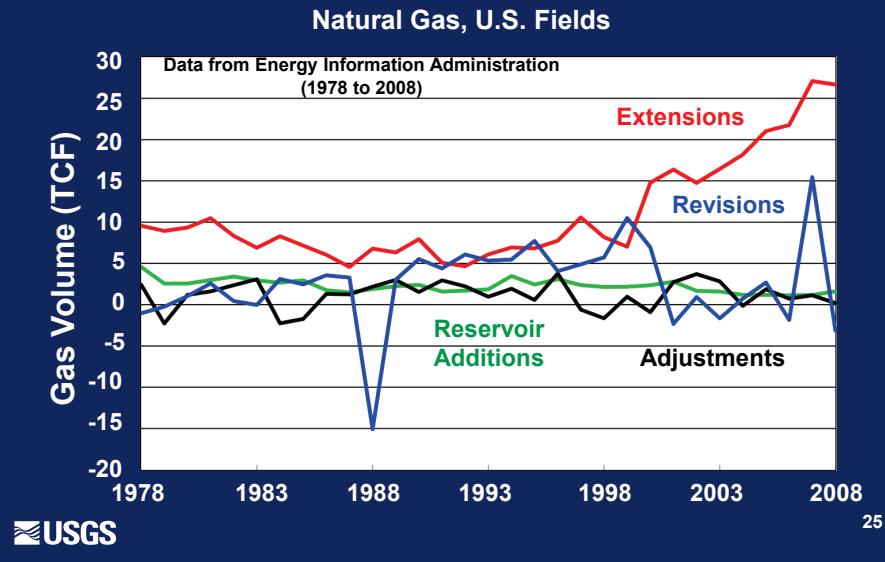
23. This graph shows changes in reserves through time for oil fields in the United States. The graph was constructed using Energy Information Administration (EIA) data and starts with year 1978, about the same time that the previous graph displayed the lowering of inventory. The data include both conventional and unconventional oil onshore and offshore. The lines represent changes in reserves by revisions (blue), reservoir extensions (red), reservoir additions (green), and adjustments (black). Revisions are defined as changes resulting from new information, whereas adjustments are statistical to preserve annual-reserves balance within each State or State subdivision. If the volumes for each line at any point in time were added, it would provide an indication of reserve growth, although the number of fields changes from year to year. Notice that most changes are positive, except for 2008. On this graph, revisions and adjustments are proportionally more important than reservoir extensions and reservoir additions.

Production replaced by additions to reserves from reserve growth



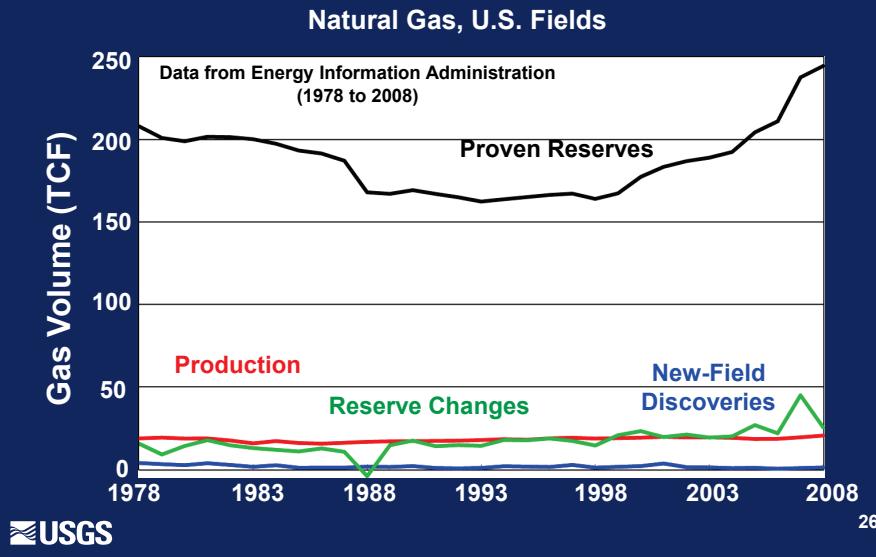
24. This graph was also constructed using EIA data. The lines represent proven reserves (black), annual production (red), new-field discoveries (blue), and changes in reserves (green), the sum of the lines on the previous graph. This graph shows that crude oil production is mostly replaced by additions to reserves from reserve growth. Volumes added to reserves by new-field discoveries are very small.

Continuous gas exploitation makes reservoir extensions most important



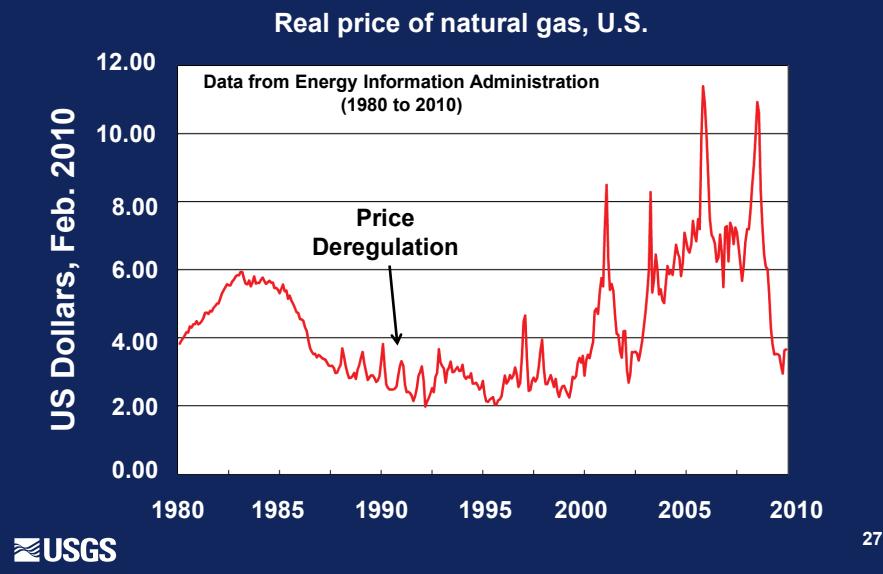
25. This graph shows changes in reserves for gas fields of the United States. Unconventional gas exploitation, from the Barnett Shale (Texas) for example, had recently made reservoir extensions proportionally most important, as shown here by the red line. TCF, trillion cubic feet.

Production replaced by additions to reserves from reserve growth



26. Natural gas production is also almost entirely replaced by additions to reserves from reserve growth.
TCF, trillion cubic feet.

Real price of natural gas has increased since 2000



27. Real price of natural gas has increased in recent years since price deregulation in the early 1990s. Large additions to reserves from unconventional accumulations would be doubtful without the price deregulation and subsequent higher prices.

Outline

- **Background**
- **Financial and Technological Factors**
- **Inventory Concept**
- **Conclusions**



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28. Conclusions

Conclusions

- Future reserve growth affected by fluctuating economic, technological, political/regulatory conditions
- Choice of reserve growth or exploration affected by financial volatility, price
- Despite financial volatility, inventory of petroleum can be maintained
- We speculate that reserve growth will continue to increase in importance



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29. Future reserve growth is expected to be affected by financial volatility and fluctuating economic and technological conditions. Choice between reserve growth and exploration is affected by financial volatility and price. Despite financial volatility, however, an inventory of petroleum can be maintained. We speculate that reserve growth will continue to increase in importance.

**U.S. Geological Survey
Reserve Growth Assessment Project**

Thank You

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