1. Scope and Methodology of the Study

This study was undertaken by the Energy Information Administration (EIA) at the request of the Principal Deputy Assistant Secretary for Fossil Energy, U.S. Department of Energy (DOE). The request followed a letter to Secretary of Energy Bill Richardson from six trade organizations for oil and gas producers: the American Petroleum Institute, Domestic Petroleum Council, Independent Petroleum Association of America, U.S. Oil and Gas Association, National Ocean Industries Association, and Natural Gas Supply Association.

In their letter, the six organizations raised concerns about the effects of depletion on future oil and natural gas supply. Recent interest in the effects of depletion follows reports which suggest that future production may be more difficult than previously thought. Several reports have highlighted the sharp change in the decline rate for wells on the continental shelf in the Gulf of Mexico. While natural gas wells drilled in 1972 declined from their peak at an average rate of 17 percent per year, natural gas wells drilled in 1996 have been declining at an annual rate of 49 percent.[1] At the same time, the ratio of natural gas production to the level of proved reserves—resources that have been identified and are ready to be developed—have increased from 15.7 percent in 1991-1992 to 18.0 percent in 1997-1998. In addition to the effects of depletion, exploratory drilling for oil and gas was also extremely low in 1999 as a result of unusually low prices. In 1999 the average number of rigs drilling for oil and natural gas was only 625, the lowest level in decades. Although the short-term effect of lower drilling activity already is being reversed as a result of higher prices for oil and gas in 2000, accurate future projections must account for the long-term effects of depletion on oil and gas production.

The projections of future oil and gas prices and production presented in EIA's *Annual Energy Outlook 2000* (*AEO2000*) are produced by the National Energy Modeling System (NEMS), which is designed to capture the expected impact of depletion on future production and prices, based on historical trends. Although the *AEO2000* projections incorporated the effects of depletion, this study develops a series of alternate scenarios that project more pronounced effects from depletion than suggested by the long-term historical trend. The scenarios described below show that changing the projected effects of depletion causes changes in projected U.S. oil and natural gas prices and production, as expected.

Background

Definition

Depletion is a natural phenomenon that accompanies the development of all nonrenewable resources. Taken most broadly, depletion is a progressive reduction of the overall stock (or volume in the instance of oil and natural gas) of a resource over time as the resource is produced. In the oil and gas industry, depletion may also more narrowly refer to the decline of production associated with a particular well, reservoir, or field. Typically, production from a given well increases to a peak and then declines over time until some economic limit is reached and the well is shut in.

The economic characteristics of a resource change over time, as depletion leads producers to abandon older fields and develop new ones. The process of developing domestic oil and natural gas resources leads producers to find and develop the larger, more economical fields first. Later fields tend to be less desirable, because they are farther away from existing infrastructure or smaller in size. Thus, as time progresses more effort is required to produce the same level of the resource from the same exploration area.

Depletion and its effects are highly influenced by technology. In the past, technology advances in oil and gas extraction have allowed more accurate drilling and extraction of a higher percentage of oil and gas from each field, extending the economic life of the average well. Advanced technology has also allowed resources to be developed that were not economically viable before, such as deep sea fields, unconventional natural gas, and oil and gas from very deep reservoirs. These trends are expected to continue into the future.

Technology has two contradicting effects on depletion. On one hand, technology offsets the effects of depletion and allows production to grow, even though the resources that are most accessible and inexpensive to produce are used first. On the other hand, technology allows the resource base to be drawn down more quickly, causing existing resources to be depleted more

[1]David Pursell, *Depletion: The Forgotten Factor in the Supply and Demand Equation: Gulf of Mexico Analysis* (Houston, TX: Simmons and Company International, 1998).

rapidly than they otherwise would have been. Although technology can make some domestic oil and gas resources economical to produce that were not before, technology cannot change the underlying size of the resource.

In the past, analysts have drawn a distinction between gross depletion and net depletion of a field.[2] Gross depletion—also referred to as "cashless decline"—is the decline in production from a well or field if no additional investment is made to sustain production. Net depletion is the decline in production after investments have been made (such as recompletions, infill drilling, and secondary and tertiary recovery techniques) to prolong production.

Depletion Fundamentals

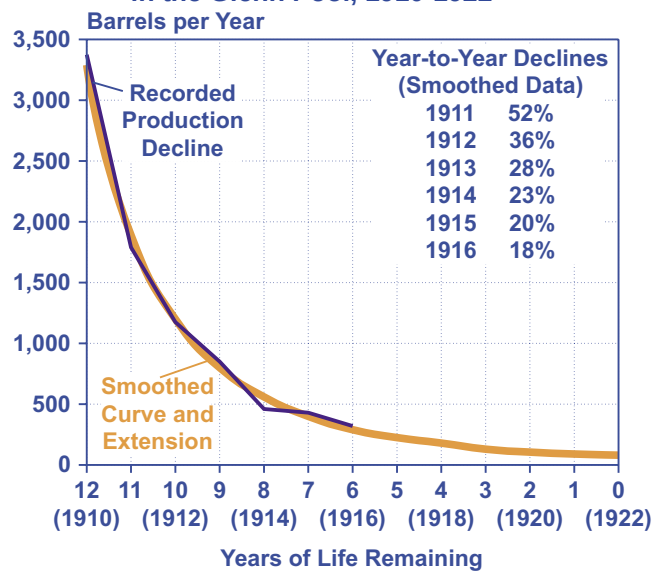
In the 1820s subsurface natural gas was discovered and exploited in the United States, and Colonel Drake drilled his famous rock oil well in 1859. This started the depletion of oil and gas resources in the United States. Since that time, U.S. oil production has matured, peaked, and declined from its highest levels. Natural gas production has yet to reach its ultimate peak. As domestic production has matured, increasingly sophisticated techniques have been developed to measure how much oil and gas is produced and how much remains.

The production decline curve of an individual well in the Oklahoma's Glenn pool illustrates the depletion trajectory of a well in unrestricted production (Figure 1). Although it is taken from a U.S. Department of Interior Bulletin printed in 1924, its message is fundamental and timeless: production rates start high, then decline hyperbolically over time. If all the world's resources were easily accessible and development were not complicated by changes in demand, prices, costs, and technology, the production of the world's resources would resemble this simple decline curve and would be mathematically simple to model. Obviously, depletion is considerably more complicated than this; however, production from oil and gas wells will generally follow a pattern of hyperbolic decline.

Interaction of Depletion and Prices

Regional production is the sum of production from individual wells. Assuming that, within a given region, larger fields with correspondingly higher levels of production are found first, developed, and replaced with smaller fields, then production will tend to decline with time if drilling is roughly constant. However, changes in prices influence drilling. The expectation of higher prices causes more money to be spent to develop wells, whereas the expectation of lower prices causes

Figure 1. Production Decline Curve for Yearly Production from an Individual Well in the Glenn Pool, 1910-1922



Source: U.S. Department of the Interior, *Bulletin 228* (1924).

exploratory activity to decline. Therefore, economics affect regional production paths.

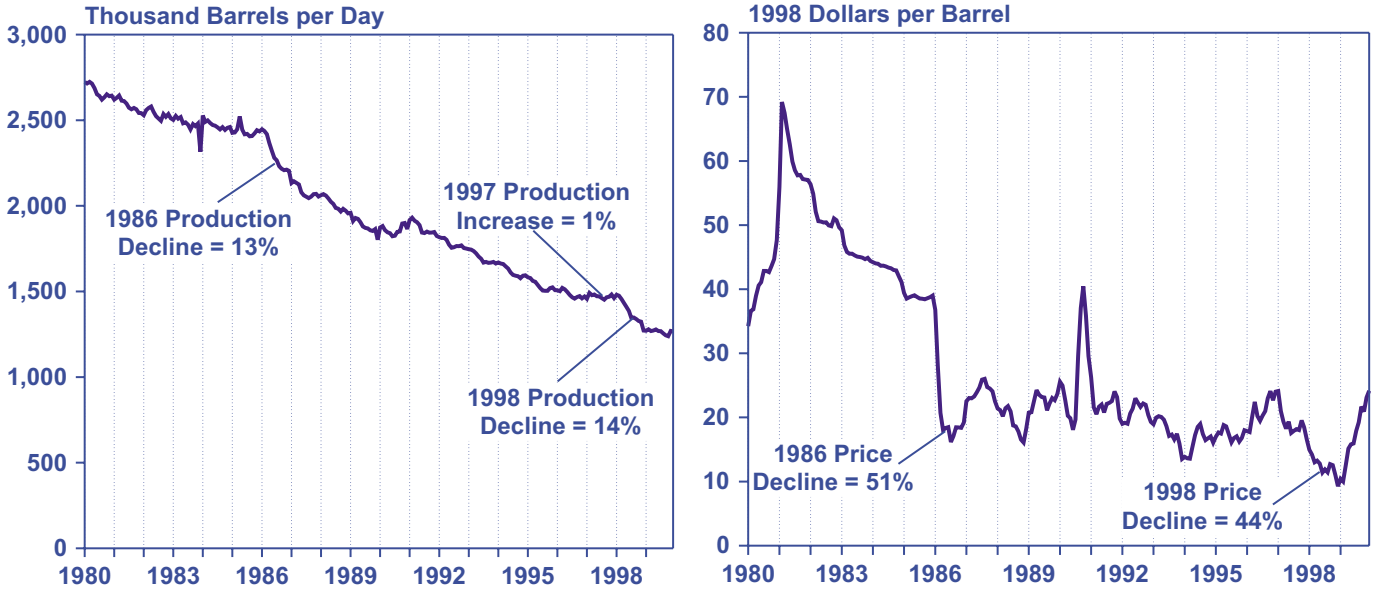
The relationship between prices and regional production can be seen by looking at oil production in Texas from 1980 to 1999 (Figure 2), when Texas fields are considered to have been mature. Production during the period is characterized by the flatter section of a hyperbolic decline curve. In the early 1980s, Texas oil production was declining by a couple of percent per year, even with very high prices and continued drilling. At the end of 1985 production was actually increasing, but during 1986 oil prices fell by 51 percent, and oil production fell by 13 percent.

The 1990-1991 price spike that accompanied the Gulf War led to a modest increase in production; however, there was an overall gradual decline accompanying relatively stable prices from 1986 to 1996, and production from Texas proceeded along the flatter section of the hyperbolic curve described above. In 1997, higher prices led to a 1-percent increase in oil production. Then, in 1998, with a 44-percent drop in prices, Texas oil production fell by 14 percent.

As illustrated in Figure 2, there is not a one-to-one correspondence between changes in prices and changes in production. The relationship is complicated by other factors, such as changes in production costs resulting from changes in the price of inputs (such as labor and materials) and changes in taxes. In addition, production increases may be limited by the availability of drilling rigs and skilled labor in the short run. Thus, although depletion of the resource base may eventually lead to

[2]For example, see R.E. Snyder,"Oil and Gas Prices: What Else is Important?" *World Oil*, Vol. 220, No. 1 (January 1999), p. 31.

Figure 2. Texas Oil and Condensate Production and Texas First Purchase Price, 1980-1999



Source: Energy Information Administration, Office of Oil and Gas, Reserves and Production Division (Dallas, TX).

lower production from a field or region, the rate of decline can be affected or even reversed in the short run by changes in underlying economic factors.

Field Size Distribution

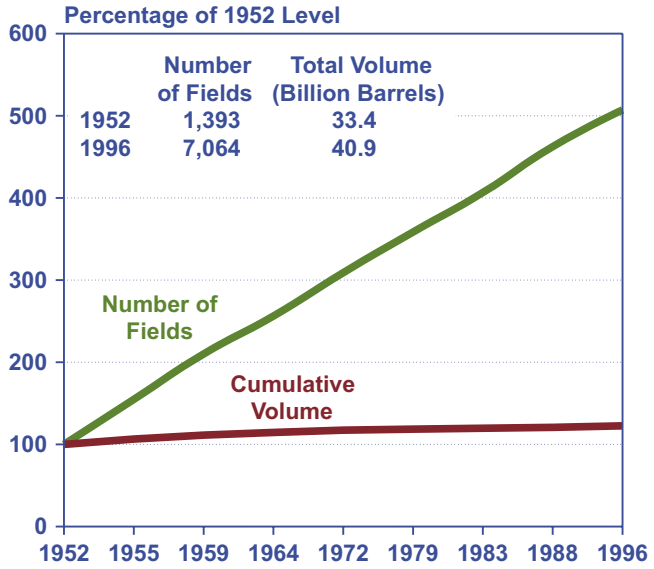
The history of oil and natural gas production in the United States shows that the largest fields are more likely to be discovered first. Large fields will produce for a very long time because of their large supply of resources. As they are exploited exploration continues, and smaller fields typically are discovered and exploited. The smaller fields, individually, do not have the volume of resources that the larger fields do, but there are many more of them.

The effects of adding progressively smaller fields as a region is developed are illustrated by the development history of the Permian Basin, a producing region in West Texas and Eastern New Mexico (Figure 3). By 1952, more than 33 billion barrels of oil had been found in the Permian Basin. Nearly 1,400 fields had been discovered; however, more than 17 billion barrels, or more than one-half of the total volume of oil found, was concentrated in the 20 largest fields. From 1952 to 1996, when the volume of oil discovered in Permian Basin fields grew by just 7.5 billion barrels (to a total of nearly 41 million barrels), the total number of fields discovered was over 7,000, or more than five times the number discovered before 1952.

The experience in the Permian Basin is reflected in domestic oil and gas production as a whole. In 1998, the 20 largest oil fields accounted for about 45 percent of U.S. proved reserves. The 15 largest were discovered before 1990 and were on average 50 years old in 1998. Only 3 of the top 20 fields were discovered after 1990—one in Alaska and two in the offshore Gulf. Of the 20 largest natural gas fields, accounting for about 29 percent of all U.S. proved reserves, only was found after 1990.[3]

Exploration in previously undeveloped regions has historically helped to offset the effects of depletion. For

Figure 3. Trends in Cumulative Volume of Oil and Number of Fields Discovered in the Permian Basin, Selected Years, 1952-1996



Source: Energy Information Administration, Office of Oil and Gas, Reserves and Production Division (Dallas, TX).

[3]Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1998 Annual Report*, DOE/EIA-0216(98) (Washington, DC, December 1999), pp. 58-61.

instance, fields in Alaska and offshore in the deep waters of the Gulf of Mexico are now major sources of production that were not available when oil production was at its peak. Of course, each step of regional development has also served to diminish the existing frontier.

Resource Recovery Rates

The trends of drilling improvements and smaller field size suggest that the initial recovery rates of future wells will be higher than they have been historically. Specifically, the initial recovery rate—the percentage of a well's total ultimate production recovered in the first few years of drilling—is enhanced by better technology but diminished by the incremental deterioration of available resources. Thus far, the positive effects of technological improvements have increased the average recovery rate for new wells at a pace that exceeds the decline in the quality of fields brought into development.

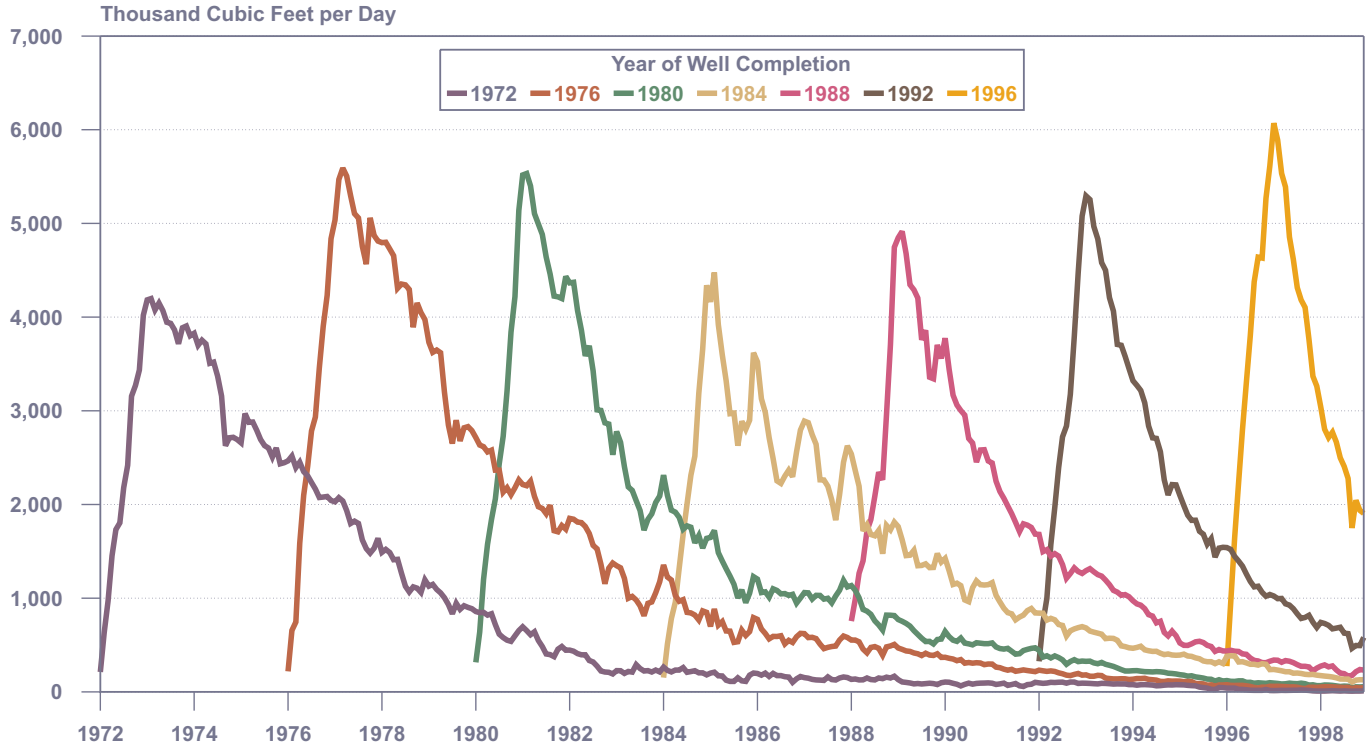
Natural gas production from wells in the Federal waters of the Gulf of Mexico (Figure 4) illustrates how initial flow rates have increased over time. Wells drilled in 1972, on average, reached a peak production level of 4.2 billion cubic feet per day. Wells drilled in 1996 reached an average peak of nearly 6.1 billion cubic feet per day. On the other hand, 2 years after peaking, production from wells drilled in 1972 average 63 percent of their peak level, whereas those drilled in 1996 averaged only 31 percent. The cumulative average volume of production after the first 3 years of production was actually about 10 percent higher for wells drilled in 1996, but the average ultimate recovery (represented by the area under the curve for each year) has varied from year to year without following a specific trend. (See Appendix G for a discussion of how the trends of higher initial flow rates and more rapid declines in production are incorporated in the methodology for this study.)

While the frontier for new resources is diminishing, increased innovation has, thus far, served to offset depletion at least partially, keeping production stronger than it would have been in the absence of the innovations. Technological progress is expected to continue to enhance exploration, reduce costs, and improve production technology. But eventually, as field sizes grow smaller, the ultimate recovery from discovered fields will shrink. Thus, despite technological improvements, ultimate recovery from the average field of the future will be smaller than from the average field today.

Resources and Reserves

EIA annually collects and publishes data on proved reserves in the United States. The distinction between proved reserves and total resources is important for

Figure 4. Average Daily Production from Natural Gas Wells in the Federal Offshore Gulf of Mexico, 1972-1998, by Year of Well Completion



Source: Energy Information Administration, Office of Oil and Gas, Reserves and Production Division (Dallas, TX).

understanding how the NEMS Oil and Gas Supply Module (OGSM) works, as described in the next section.

The total quantity of oil or gas trapped within the boundaries of a reservoir or field makes up its total resources. The amount of total resources in a field—or in the world—is uncertain. Estimates of oil and gas resources by field are routinely based on information from geologists and engineers who measure the porosity and permeability of rock formations, construct geological maps, estimate the extent and thickness of formations suspected or known to contain oil, and compile many other types of data. The estimates are a "best guess" given the available data, and they are revised as more knowledge becomes available. There is no time frame or probability associated with estimates of total resources in place.

In contrast, proved reserves of crude oil and natural gas are the estimated quantities that, on a particular date, are demonstrated with reasonable certainty by geological and engineering data to be recoverable in the future, from known reservoirs under existing economic and operating conditions. Unlike a resource estimate, there is a probability associated with a proved reserves estimate. Generally, there is at least a 90 percent probability that, at a minimum, the estimated volume of proved reserves in the reservoir can be recovered under existing economic and operating conditions.

Each year, production is taken from proved reserves, reducing both proved reserves and the total resource. As the proved reserves are being reduced, exploration and development add to the remaining proved reserves. Technological advances may make it easier to discover resources and reclassify them as proved reserves, but reserve additions—the volume of resource added to proved reserves each year—are fundamentally determined by the amount and success of drilling activity. Although the level of proved reserves may fluctuate because of the conflicting effects of depletion, technological advance base, and the amount of drilling, the total size of the resource remains unchanged.

Historically, the amount of oil and natural gas produced in a given year is related to the level of proved reserves of each (although the relationships have varied from year to year and evolved over time). The relationship between production and proved reserves, quantified as the P/R ratio, is the basis for future production estimates in the OGSM, which calculates each year's production as a fraction of the proved reserves of a given fuel in a given region. Proved reserves are only a subset of the total remaining resources available in a field, and are therefore consistently lower than the best guess in the amount of oil or gas remaining in a field.

Recent events have illustrated that reserves and reserve additions can fluctuate from long-term trends. After the sharp declines in revenues in 1998, reserve additions of oil and natural gas were unusually low. Oil reserve additions, which were 125 percent of production in 1997, were only 24 percent of the total volume of oil produced in 1998; gas reserve additions fell from 104 percent in 1997 to 83 percent in 1998.[4] The larger decline in the rate of oil reserve additions reflects the change in oil prices between 1997 and 1998, which fell faster than natural gas prices.

Although EIA has not released its reserve report for 1999,[5] there is at least one report that indicates that reserve additions in 1999 were higher than in 1998 and returned to the pattern that has prevailed since 1991.[6] The extreme decline in reserve additions during 1998 can be attributed to extremely low prices, as well as the continuing economic restructuring of the industry, characterized by mergers, acquisitions and spinoffs. Restructuring can be a drain on the industry's cash flow and may hinder development. The recent low reserve additions are the result of short-term market conditions, and suggest that future year-to-year drops in reserves will not be as strong.

Impact of Depletion on North American Supply and Demand for Crude Oil

Most of the oil basins in the United States are mature. The fields in U.S. basins require extensive capital investment (such as secondary and tertiary enhanced recovery) to maintain current production rates or, in some cases, merely to minimize rapidly increasing depletion rates. In other words, they are experiencing net depletion after capital investment. One example is Prudhoe Bay, the Nation's largest field, where production is falling by about 10 percent per year despite large investments in enhanced oil recovery technology.[7]

Although depletion limits domestic production, its effect on mature U.S. oil fields has little impact on worldwide oil supply or prices. Because crude oil is relatively easy to transport to distant locations, the market responds to worldwide supply and demand. Therefore, U.S. prices for crude oil are largely determined by the

[4]Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1998 Annual Report*, DOE/EIA-0216(98) (Washington, DC, December 1999), pp.19 and 27.

[5]The report is expected in December 2000.

[6]John S. Herold, Inc., *Herold 33rd Annual Reserve Replacement Cost Analysis—Top 50 U.S. Companies* (Stamford, CT, May 2000).

[7]Energy Information Administration, *Performance Profiles of Major Energy Producers 1998*, DOE/EIA-0206(98) (Washington, DC, January 2000), p. 107.

world market rather than North American supply and demand.

Demand in the United States is met through domestic production and imports, mostly from countries with less mature fields that can produce oil at lower costs. When prices are high, U.S. producers try to expand production, developing new fields and making investments in technology to offset the trend toward declining production in mature fields. When prices are low, such investments are less profitable. Imports are higher when prices are lower, and the effects of depletion on U.S. production increase as investment in technology declines.

Impact of Depletion on North American Supply and Demand for Natural Gas

Because of the regional nature of gas markets, the price of natural gas is much more susceptible to North American field depletion than the price of oil. The decline in oil production from lower 48 onshore fields that accompanies depletion can be offset by increased imports. In contrast, the role of imports in natural gas markets is limited by the difficulty of transporting natural gas from fields outside North America. Although natural gas can be imported from other producing regions of the world in the form of liquefied natural gas, it is expensive and not expected to be a likely major alternative in meeting future gas needs.

There is currently much debate surrounding depletion in the Gulf of Mexico. The debate usually centers not on the overall size of the resource (which appears to be quite large) but on whether there has been sufficient capital investment in the region to allow producers to meet natural gas demand in the future.

In 1998, gas production from offshore fields in the Gulf of Mexico averaged 15.1 billion cubic feet per day, or 28 percent of total U.S. production.[8] There is evidence that the average decline in production from existing wells from year to year in the absence of additional drilling has been increasing over time, from slightly less than 16 percent in 1991-1992 to more than 18 percent in 1997-1998. When only producing proved reserves are considered, the corresponding increase is about 27 percent in 1991-1992 to more than 32 percent in 1997-1998.[9]

According to one estimate, in the absence of additional wells, production in 1999 from the shelf portion of the Gulf of Mexico is expected to show a decrease of about 29 percent, or 4.1 billion cubic feet per day, from 1998 production. The same estimate projects that maintaining production on the shelf area would require roughly 1000 additional wells, each producing on average 6.0 million cubic feet per day.[10] When the annual depletion-related decline in production from traditional areas can no longer be replaced, it will have to be replaced by production from deep water Gulf of Mexico or sub-salt shallow water natural gas sources. This will require continued capital investment in new field development, pipeline infrastructure, and drilling technology.

Access Limitations

Access to Federal lands is a critical factor in any evaluation of the effects of resource depletion on the future supply and prices of natural gas. A significant portion of the Nation's resource base is found on Federal lands or in Federal waters where development is restricted or prohibited by statute or environmental regulations. The Rocky Mountains and the Nation's offshore regions, areas of high potential for future gas production, have significant access restrictions. This analysis assumes that 45 percent of the potential gas resource in the Rocky Mountain region (approximately 108 trillion cubic feet) is located beneath Federal land that is either closed to exploration or under restrictive provisions. According to a recent report released by the National Petroleum Council (NPC), an additional 31 trillion cubic feet of natural gas is inaccessible as the result of a moratorium passed by Congress, which closed the East Coast of the United States to oil and gas development.[11] The West Coast and the Eastern Gulf of Mexico have also been constrained with similar developmental restrictions, affecting another potential 46 trillion cubic feet of natural gas. Simply put, access issues limit the industry's ability to exploit known resources. Increased access to restricted Federal land and waters could provide new fields to replace older fields and serve as a potential countermeasure to the effects of depletion on total U.S. production.

Role of Technology

Industry observers have recognized the effect of technology on oil and gas resource depletion. Some argue that advances in technology have accelerated depletion; others contend that they have helped to counter accelerating depletion. Innovative production techniques to prolong production, such as well recompletions, secondary and tertiary enhanced recovery techniques, and expanded production of unconventional resources,

[8] Energy Information Administration, *Natural Gas Annual 1998*, DOE/EIA-0131(98) (Washington, DC, October 1999), Table 3, p.12. The daily figure is calculated by adding yearly State and Federal offshore figures for Texas, Louisiana, and Alabama and dividing by 366.

[9] Advanced Resources International, internal memorandum, 1999.

[10] R.E. Snyder, "Oil and Gas Prices: What Else is Important?" *World Oil*, Vol. 220, No. 1 (January 1999), p. 31.

[11] National Petroleum Council, *Meeting the Challenges of the Nation's Growing Natural Gas Demand*, Vol. I (Summary Report) (Washington, DC, December 1999), p. 13.

have reduced net depletion rates at the well and field levels.

Advanced exploration and drilling techniques, such as 3-D seismic imaging, directional drilling, and multiple wells from single boreholes,[12] have had a major impact on depletion. These technologies reduce the cost of finding new pools, reduce the risk of dry holes and dry hole costs, and allow new pools to be developed and produced more quickly. One analyst estimated that in the early to mid-1990s technological development reduced the finding costs of crude oil by about 15 percent per year.[13]

Lower exploration, drilling, and dry hole costs increase the return on capital by lowering costs. More rapid production of resources from a field increases the return on capital because earnings are realized sooner in the project's life, and therefore, discounted less. The reduction of risk and increased returns on capital have two effects. First, higher returns on capital attract and stimulate drilling activity. Second, higher returns make some fields that are too expensive to develop under "normal" circumstances economically feasible, because reduced costs may allow firms to make profits where they could not before.

On the other hand, some analysts have countered these assertions by stating that more rapid development and production of a field by definition increases the rate of depletion. If an operator produces a field more quickly, the argument goes, the rate of depletion must rise. While the rate of depletion increases with technological progress, the adverse effects of depletion are diminished, and higher levels of production can be maintained for longer periods of times. This analysis examines the ameliorating effects of technological development on depletion.

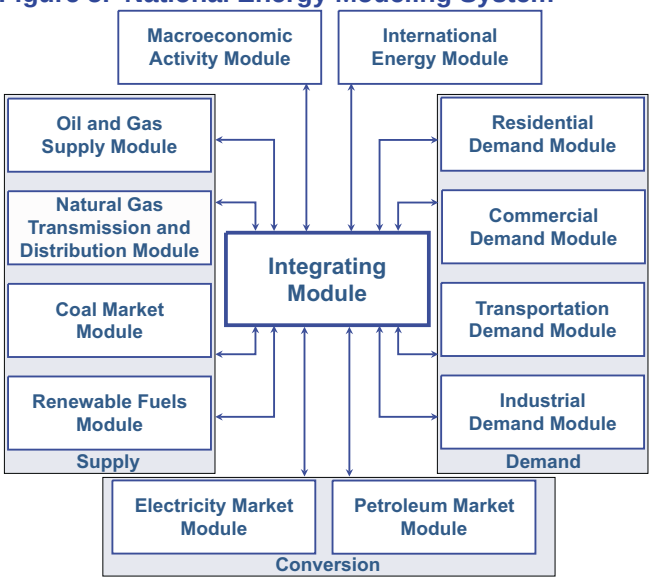
Overview of the National Energy Modeling System/Oil and Gas Supply Module

The analysis of the accelerated depletion cases was conducted by EIA using NEMS.[14] NEMS is an integrated model that balances supply and demand for each fuel and consuming sector on an annual basis. It is organized and implemented as a modular system, including four supply modules, four demand modules, a macroeconomic activity module and an international energy module (Figure 5). The time horizon for NEMS projections is roughly 20 years—currently through 2020. NEMS is used to produce the forecasts for EIA's *Annual Energy Outlook* and for other appropriate projects, such as the 1999 *Analysis of the Impacts of an Early Start for Compliance with the Kyoto Protocol*.[15]

The interrelationships among depletion, technological improvements, and domestic oil and natural gas production are modeled in NEMS in the OGSM. The OGSM represents domestic supply of crude oil and natural gas from conventional and unconventional sources at a regional level. Oil and natural gas exploration and development projections are based on the expected profitability of projects, subject to anticipated future prices, costs, and technological change.

The finite nature of oil and natural gas resources is modeled in the OGSM. In the *Annual Energy Outlook 2000* (*AEO2000*),[16] the technically recoverable oil resource

Figure 5. National Energy Modeling System



Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

[12]3D seismic imaging is a technique that uses sound waves and advanced computing technology to model the three dimensional shape of underground reservoirs, and horizontal drilling is a development process that extracts oil and gas by drilling through a reservoir horizontally, to maximize the number of feet of resource that is drilled through from a single well, thereby improving production. For more information about these techniques and other technologies that have aided oil and natural gas production see US Department of Energy, *Environmental Benefits of Advanced Oil and Gas Exploration and Production Technology*, DOE/FE-0385 (Washington, DC, October 1999).

[13]M.N. Fagan, "Resource Depletion and Technical Change: Effects of U.S. Crude Oil Finding Costs from 1977 to 1994," *The Energy Journal*, Vol. 18, No. 4 (1997), p. 101.

[14]A synopsis of NEMS, the model components, and the interrelationships between the components is available in Energy Information Administration, *The National Energy Modeling System: An Overview*, DOE/EIA-0581(2000) (Washington, DC, March 2000).

[15]Energy Information Administration, *Analysis of the Impacts of an Early Start for Compliance with the Kyoto Protocol*, SR/OIAF/99-02 (Washington, DC, July 1999).

[16]Energy Information Administration, *Annual Energy Outlook 2000*, DOE/EIA-0383(2000) (Washington, DC, December 1999).

base for the United States was estimated at 140 billion barrels, of which 24 billion barrels were considered proved reserves ready for production. Proved reserves of natural gas were estimated at 167 trillion cubic feet, out of a technically recoverable resource base of 1,259 trillion cubic feet. The OGSM resource estimates are based on estimates of technically recoverable resources from the U.S. Geological Survey (USGS) and the Minerals Management Service (MMS) of the Department of the Interior. Supplemental adjustments to the USGS nonconventional resources were made by Advanced Resources International (ARI), an independent consulting firm, and adjustments to the MMS offshore Gulf of Mexico resources were based on estimates from the National Petroleum Council.

The impacts of depletion are explicitly incorporated into the OGSM framework through three key elements: production-to-reserves (P/R) ratios, reserve additions per well (finding rates), and expected return on investment in drilling projects. In the OGSM, production is estimated each year as a fraction of proved reserves—the P/R ratio. The P/R ratio generally increases over time, reflecting the higher extraction rate for new wells. The projected change in the P/R ratio used in the *AEO* reference case is based on historical trends. Finding rates are assumed to decline as drilling progresses and remaining undiscovered and undeveloped resources decline. The decline can be partially offset by improvements in technology, but eventually the impacts of depletion will outweigh the technology improvements.

The OGSM determines expected drilling returns on the basis of a discounted cash flow algorithm, which is based on representative well production profiles. Each profile represents a schedule of the average projected production from a well over its economic lifetime, which is assumed to be 20 years. Production from a well is greatest in the first full year of the production life then declines, reflecting both depletion and the desire to produce as much as possible early in order to maximize the return on investment. Initial flows also decrease over time as a result of the natural progression of the discovery process from larger, more profitable fields to smaller, less economical ones. Although representative well profiles are used to determine the expected return on drilling projects, the number of producing wells and their vintage are not tracked in the OGSM.

Accelerated Depletion Cases

For this analysis, NEMS was used to generate a series of projections based on different assumptions about the effects of depletion on future production and prices. Sensitivity cases were developed to evaluate the effects on changes resulting from accelerated depletion of U.S. oil and gas resources that might result from higher imports of natural gas, higher or lower world oil prices, different rates of improvement in technology, and increased access to unconventional natural gas resources in the Rocky Mountains. A total of 12 cases were examined. The assumptions used to define the Reference Case, the Accelerated Depletion Case, and all but one of the sensitivity cases were provided by the Office of Fossil Energy, in consultation with representatives of the six trade groups requesting the study. Appendix A includes a description of the cases provided by industry representatives and the Office of Fossil Energy.

- **Reference Case.** The Reference Case, depicting business as usual, is similar to the Reference Case for the *Annual Energy Outlook 2000* (*AEO2000*), with some minor changes in the assumed conventional natural gas resource base in the Rocky Mountain region and the technology assumptions for unconventional gas production. The world oil price and natural gas wellhead prices in 1999 and 2000 were also with revised short-term projections from EIA's April 2000 *Short-Term Energy Outlook*[17] (see Appendix E for more detail).
- **Accelerated Depletion.** The Accelerated Depletion Case, reflecting the issues raised by the six trade groups, shows a faster decline in production than the Reference Case. Future oil and gas discoveries are assumed to be one-third smaller and new fields are projected to produce more rapidly than in the Reference Case. Assumptions about the rate of technological change and accessible oil and gas resources are the same as in the Reference Case. The Accelerated Depletion Case is a hypothetical case designed to highlight the potential impacts of lower reserve additions and faster depletion rates on natural gas and oil prices, production, imports, and consumption.
- **Accelerated Depletion with High and Low World Oil Prices**. These two cases show how domestic production and prices with accelerated depletion are affected by different world oil price paths. The high and low oil price cases are the same as those used in *AEO2000*. The High World Oil Price Case assumes that the world oil price rises to $28.04 per barrel in 2020, compared with $22.90 in the Reference Case and $14.90 in the Low World Oil Price Case (all prices in 1998 dollars).
- **Accelerated Depletion with Rapid and Slow Technology Growth.** These two cases show the interaction of accelerated depletion with changes in the expected rate of technological development. The

[17]Energy Information Administration, *Short-Term Energy Outlook*, DOE/EIA-0202(00/2Q) (Washington, DC, April 2000), www.eia.doe.gov/pub/forecasting/steo/oldsteos/apr00.pdf.

rate of technological improvement is captured by changes in future costs, drilling accuracy, and the amount of oil and gas added to proved reserves with each well drilled. For conventional oil and natural gas, NEMS uses a composite rate of technology growth and does not project the introduction of specific technologies. The rate of technological growth used in the Reference Case is based on past trends. In the Rapid Technology Growth Case, technology advances are assumed to increase the rates of improvement in costs, accuracy, and reserve additions per well by 50 percent over those in the Reference Case; in the Slow Technology Growth Case, the improvement rates are assumed to be 50 percent slower.[18] While the fields found in the Accelerated Depletion Cases are smaller than those found in the Reference Case, changing the technology influences how quickly and thoroughly these fields are developed. Rapid technology growth causes the projected volume of reserve additions per well to be higher than the Accelerated Depletion Case over time and closer to the path set in the Reference Case; in other words, faster technology growth can partially offset depletion effects. Slower than expected technology growth causes projected volumes of reserve additions to be lower than the Accelerated Depletion Case, or make depletion effects worse. All other parameter values are the same as in the Reference Case, including the technology parameters for other modules, parameters affecting foreign oil supply, and assumptions about imports and exports of liquefied natural gas and natural gas trade with Canada and Mexico. The path of the world oil price is the same as in the Reference Case.

- **Accelerated Depletion with Improved and Reduced Productivity Technology.** In these two cases, the effect of technology improvement is captured only for changes in reserve additions per well drilled, without changing assumptions about future costs or drilling accuracy. Therefore, the projections from the Improved and Reduced Productivity Technology Cases vary less from the Reference Case projections than do those from the Rapid and Slow Technology Cases. In the Improved and Reduced Productivity Technology Cases, the rate of growth in the amount of oil and natural gas added to proved reserves per well is adjusted by plus or minus 50 percent. Other rates of technological change are the same as in the Reference Case. The path of the world oil price is also the same as in the Reference Case.

- **Accelerated Depletion with High Rocky Mountain Access.** This case illustrates the effects of increasing the amount of natural gas available for development in the Rocky Mountain States by assuming the elimination of environmental and other constraints on production in the region. The question of access is limited to the Rocky Mountain region, where resources are sizable. In the Reference Case,97 trillion cubic feet out of a total of 251 trillion cubic feet of unconventional gas resources is assumed not to be accessible to development before 2020. In the High Rocky Mountain Access Case, the inaccessible portion is assumed to be only 18 trillion cubic feet. The world oil price path is the same as in the reference case.

- **Accelerated Depletion with High Rocky Mountain Access and Improved Productivity Technology.** This case combines the assumptions of the two previous cases to show how increased Rocky Mountain access and improved productivity technology could ameliorate the effects of accelerated depletion.

- **Accelerated Depletion with High Rocky Mountain Access and Rapid Technology Growth.** This case combines the assumptions of the Rapid Technology Growth and High Rocky Mountain Access Cases to show how increased access and faster technology growth could offset some of the effects of declining production due to accelerated depletion.

In addition to the 11 cases provided by the Office of Fossil Energy, one other case was developed to address the uncertainty regarding the potential for additional imports of natural gas, primarily from Canada and Mexico:

- **Accelerated Depletion with High Natural Gas Imports.** This case combines the assumptions of the Accelerated Depletion Case with an assumed increase in the volume of natural gas imported from other countries. In the Accelerated Depletion Case, despite higher price projections, pipeline imports of natural gas from Canada are limited by constraints on pipeline capacity, and imports of liquefied natural gas (LNG) are limited by constraints on gasification plant capacity. In this case, more natural gas imports and a more rapid increase in imports are allowed in response to the higher domestic prices that result from accelerated depletion than are allowed in the Reference and Accelerated Depletion Cases. Other assumptions about world oil prices, technology growth, and access to Rocky Mountain resources are the same as in the Reference Case.

[18] Although the Rapid and Slow Technology Growth Cases are designed to highlight the uncertainty associated with the effects of technological development, they do not provide a formal confidence interval. In *AEO2000*, the rates of technological growth for the technological sensitivity cases were adjusted by 33 percent, rather than the 50 percent used for this analysi s in order to acknowledge th ebroad range of uncertainty around future technological change.