3. Oil Supply: U.S. Perspective on a Global Market

The U.S. is heavily reliant on the world crude oil market, which has been subject to huge inter-annual volatility since 1973. Neither of these facts is likely to change. Domestic crude oil production declined over the past decade, while domestic crude oil demand increased. The difference was satisfied by increased crude oil imports. The United States' proved crude oil reserves declined more than 21 percent from 1985 to 1995. Its technically recoverable crude oil resources beyond proved reserves are estimated to be about 6 times more than the year-end 1995 proved reserves. However, excepting the Gulf of Mexico and the Alaskan offshore, many of the most promising oil-prone regions of the country are presently off-limits to exploration. Over the long term — beyond 2020 or so — the United States will be increasingly unable to satisfy its crude oil requirements from domestic sources. Imported volumes and world oil prices can both be expected to rise over time, and much of the new imports will have to be obtained from the Persian Gulf region.

The market for crude oil is global. To varying degrees, every continent on Earth except Antarctica is both a producer and a consumer of crude oil. For a host of reasons having to do with factors such as how supply and demand evolved over time relative to the location and discovery sequence of commercially exploitable conventionally reservoired deposits, as well as rates of progress in the geosciences and petroleum engineering, the price of crude oil remained remarkably stable from the early 1900's through 1973 at less than $15 per barrel in constant 1992 U.S. dollars (Figure 35). For much of the time prior to 1959 the real (inflation adjusted) price was substantially less.

After 1973 the coupling of significant concentrations of supply-side market power with short-term inelasticity of demand and regional conflicts rendered the world crude oil market subject to huge inter-annual volatility. The resulting post-1970 world crude oil price path, represented by the nominal U.S. refiner acquisition cost of imported crude oil, is shown in Figure 36. It is annotated with significant events that affected the market, the U.S. actions taken in response to them, and the domestic environmental and energy conservation measures referred to or discussed in the other chapters. In keeping with the other chapters' short-term horizon, the following sections of this chapter primarily address the past decade, which began with the crude oil price collapse of 1986.

Oil Production

Domestic Production Is Declining While Demand Is Increasing

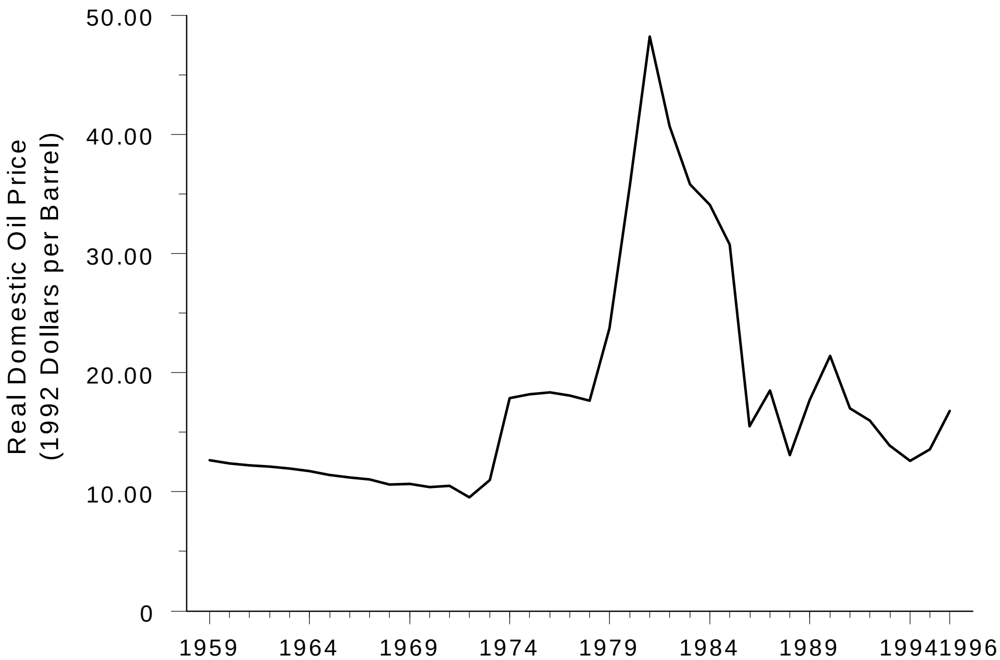
Domestic crude oil production declined over the past decade from a level of 10.2 billion barrels in 1986 to 8.6 billion barrels in 1996 (Figure 37). Domestic demand continued to rise, however, from 16.3 billion barrels in 1986 to 18.2 billion barrels in 1996. The difference was satisfied by increased imports, which have exceeded domestic production since 1994.

The U.S. is the most intensely explored and developed oil-productive nation on Earth. In 1986 there were 623,000 producing oil wells with an average daily production rate of 13.9 barrels of oil. By 1995, both the number of producing wells and their quality had declined. Eight percent fewer wells (574,000) were producing at an average daily rate of 11.3 barrels of oil (down almost 19 percent). The petroleum products that can be refined from this crude oil are summarized in the box on p. 51.

Regionally, while relative levels of production for the lower 48 States and Alaska remained about the same, total production fell 26 percent in the former and 21 percent in the latter over the 1985-1996 period. Onshore production fell 30 percent over the period and its share of total production also fell by 6 percent, while offshore production increased by almost 8 percent (Figure 38).

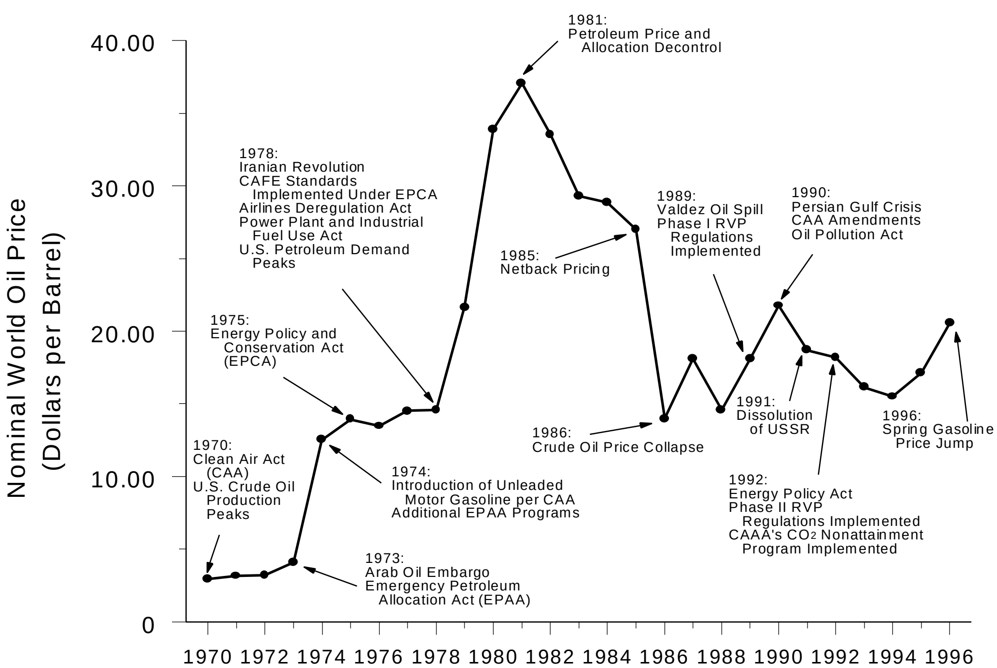
The above statistics in part reflect continuing depletion of the Nation's crude oil resource endowment, but other factors are influencing this trend. The size of new field discoveries is economically important because lifting costs per unit of production fall in response to increasing field size. In general, the largest fields in a new exploration area are among the first to be discovered. Therefore, since the onshore lower 48 States are the most intensively explored area on Earth, the remaining undiscovered oil resources occur in mostly small- to medium-size fields. During the 1985-1995 period oil exploration was prohibited or restricted in most of the few remaining domestic areas where large fields remain to be found, such as the 1002 Area within the Arctic National Wildlife Refuge (ANWR) and the southern California offshore. These restrictions resulted in an inability

Figure 35. Real Domestic Oil Price, 1959-1996



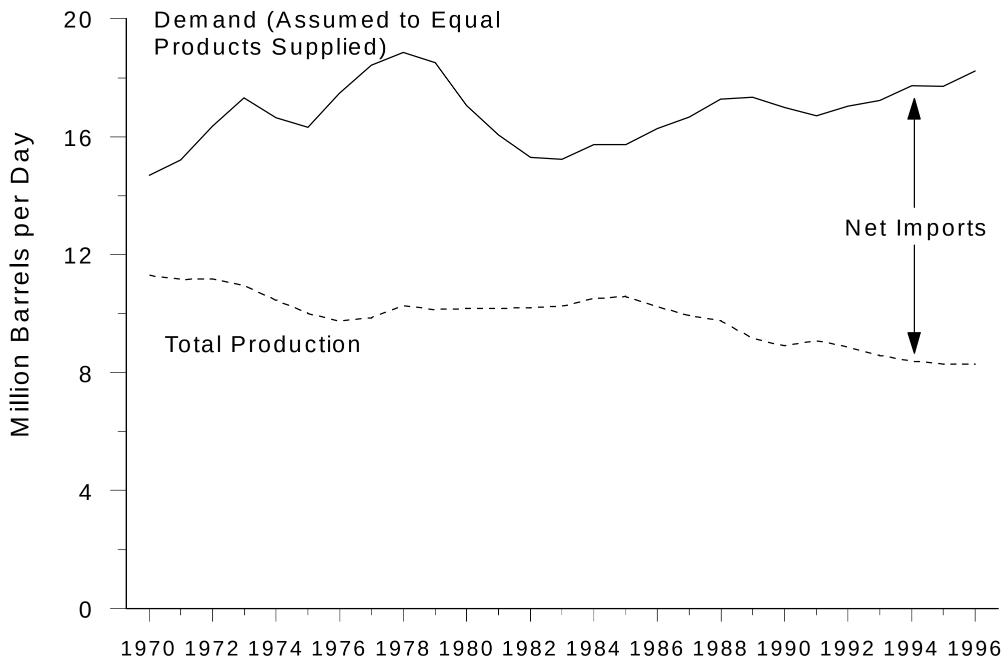
Note: Price taken to be the crude oil domestic first purchase price.
Sources: Energy Information Administration (EIA), *Annual Energy Review, 1995*; and EIA, *Monthly Energy Review* (March 1997).

Figure 36. World Oil Price and Related Events, 1970-1996



Note: World oil price taken to be the U.S. refiner acquisition cost of imported oil.
Source: Energy Information Administration, *Annual Energy Review, 1995*; and *Monthly Energy Review* (March 1997). Adapted from *The U.S. Petroleum Industry: Past as Prologue, 1970-1992*.

Figure 37. U.S. Petroleum Supply and Demand, 1970-1996



Source: Energy Information Administration, *Annual Energy Review, 1995*.

The Average 1995 U.S. Oil Well Gave Us:

Production of 11.3 barrels per day, which a refinery converted into:

6	barrels per day of motor gasoline
1.1	barrels per day of jet fuel
2.5	barrels per day of distillate fuel oil
0.6	barrels per day of residual fuel oil
2	barrels per day of heavier refined products (lubes, waxes, asphalt, road oil, etc.)

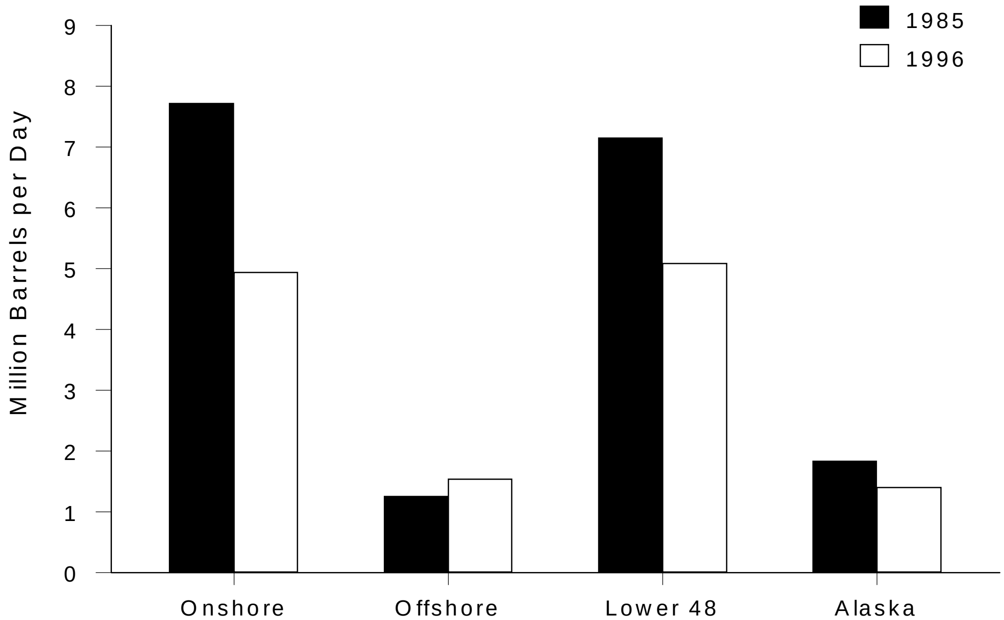
Simultaneous use of these refined products could have provided:

5,292	miles of highway travel in the average U.S. automobile. (Equivalent to the shortest round trip between Miami and San Francisco plus 56 in-town miles, or to 2000 2.6 mile utility trips.)
24	miles of air travel in a B737-700 passenger jet
62	average oil-heated homes kept comfortable on an average day
78	kilowatt hours of electricity generated with steam produced by a residual fuel oil fired boiler. (Enough electricity to power 269 light bulbs of 75 watts through one four-hour evening.)
	Minimal amounts of some of the thousands of useful things made from the heavier refined petroleum products listed above

The Bottom Line Is:

A day's production from the average U.S. oil well provides many useful products, but it does not provide much of them. Due to its very large number of low yield wells, the United States nevertheless ranked second in the world in 1995 oil production. In Saudi Arabia, the number one oil producing nation in 1995, the average oil well produced 5,800 barrels per day, or 516 times more than the average U.S. well.

Figure 38. U.S. Crude Oil Production by Site, 1985 and 1996



Sources: **1985:** Energy Information Administration, *Annual Energy Review, 1995.* **1996:** *Monthly Energy Review* (March 1997).

to maintain domestic lifting costs associated with new fields at a worldwide competitive level from 1983 to 1991. The largest U.S. exploration and production firms — and many smaller ones — therefore increasingly focused their exploration and development effort and budgets on more economically promising prospects located abroad. Trends in lifting costs, exploration, and development expenditures are portrayed by the Energy Information Administration's Financial Reporting System, an annual survey of major U.S. energy-producing companies (see Figures 39, 40, and 41).

The majors' shift away from the United States is also mirrored in Figure 42, which shows the quantities and location of production for majors and non-majors in the U.S. The majors' share of domestic onshore production has fallen steadily since 1985, by about 25 percent or 300 million barrels per year overall. Some of that production was taken over by smaller operating firms that had lower overheads. The majors invested the proceeds from the sale of some of their onshore U.S. properties primarily in frontier exploration and development projects located abroad and in the deep water Gulf of Mexico.

OPEC Leads Increase in International Production

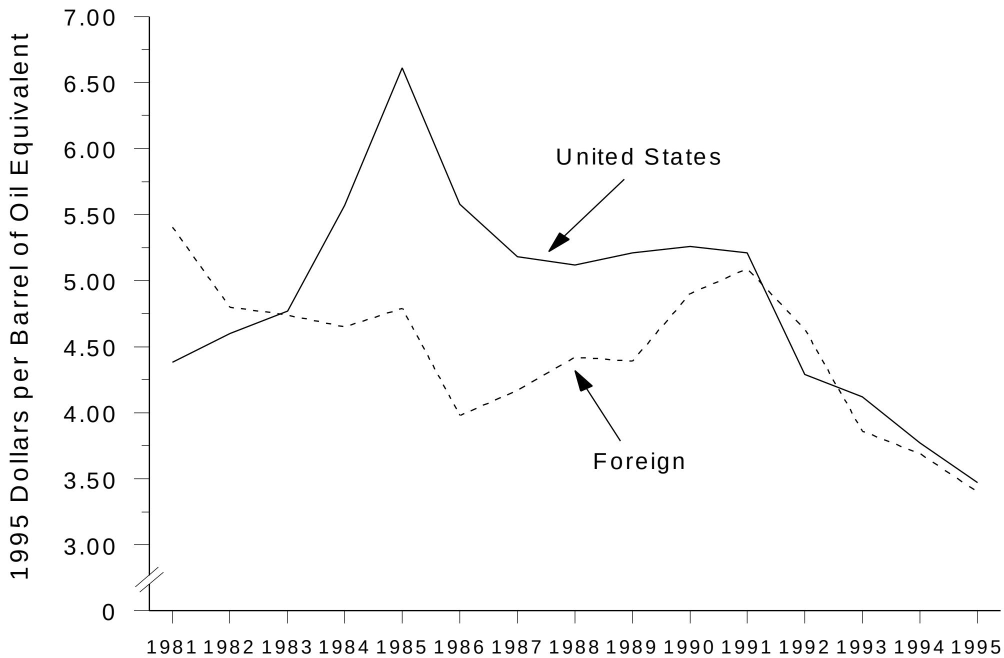
Over the past decade world crude oil production increased almost 14 percent to 64 million barrels per day in 1996. This increase is largely attributable to the member states of the Organization of Petroleum Exporting Countries (OPEC), where production increased 46.5 percent. The production of the Persian Gulf members of OPEC, which accounted for 65 percent of 1996 OPEC production, increased by 48.5 percent in the same period. There was a slight decline in non-OPEC production because increased output from such areas as the North Sea and the Pacific Rim was more than offset by declining production in mature producing areas such as the former Soviet Union and the United States (Figure 43).

Figure 44 shows the recent production trends of the four largest oil producing countries. Saudi Arabia's production more than doubled during the first part of the past decade, while the Soviet Union/former Soviet Union's production decreased by half. Table 2 shows the worldwide production of the 20 leading companies in 1972 and 1995, when they respectively accounted for 74.6 and 63.1 percent of world production. The change in the names and rankings of the top 20 firms reflects the spate of nationalizations or expropriations that took place in the mid-1970s.

Oil Reserves

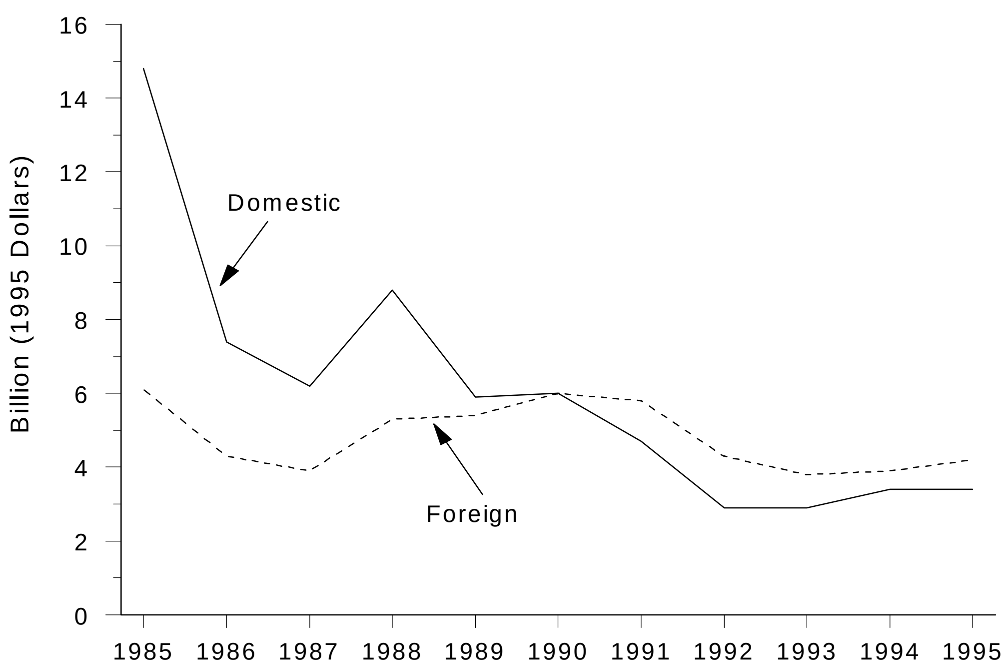
Proved reserves are those volumes of oil that geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from know reservoirs under existing economic and operating conditions.

Figure 39. Direct Oil and Gas Lifting Costs for FRS Companies, 1981-1995



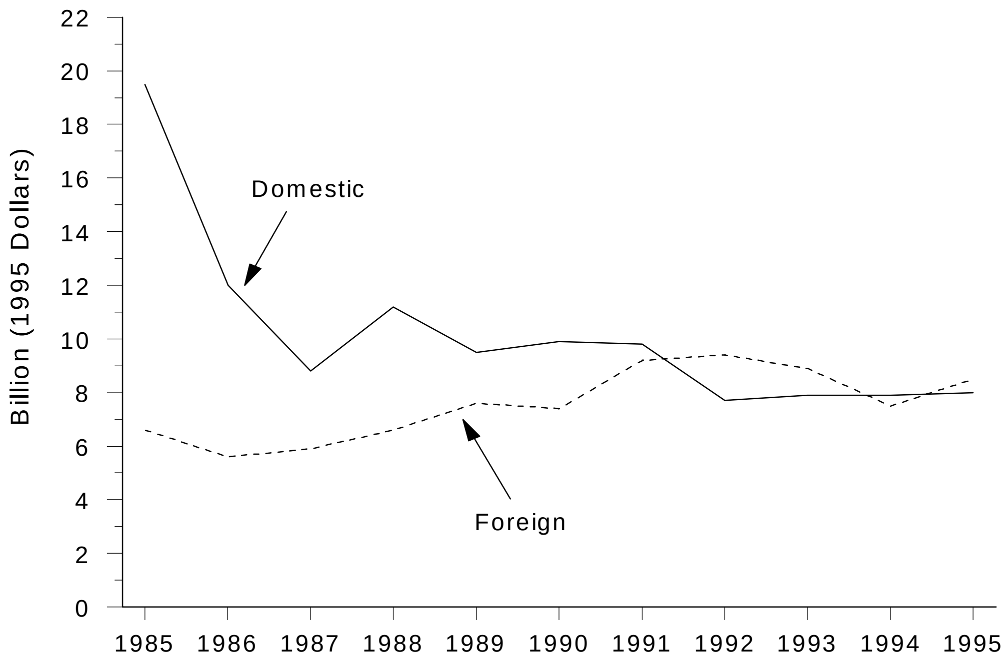
Source: Energy Information Administration, Financial Reporting System (FRS), *Performance Profiles of Major Energy Producers 1995.*

Figure 40. Exploration Expenditures by FRS Firms, 1985-1995



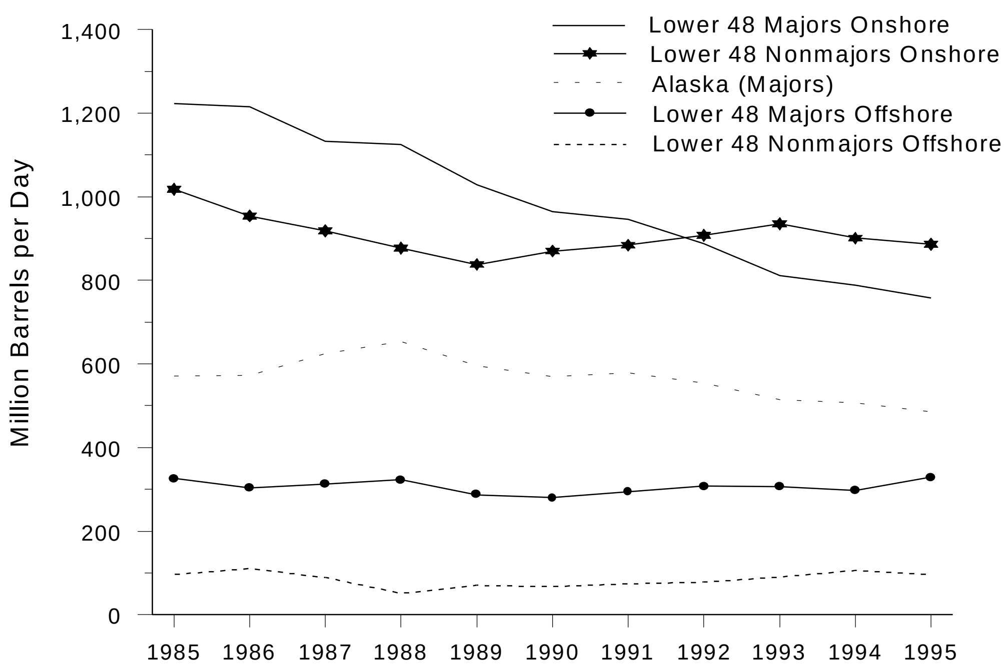
Note: Includes expenditures for unproved acreage.
Source: Energy Information Administration, Financial Reporting System (FRS), Form EIA-28.

Figure 41. Development Expenditures by FRS Firms, 1985-1995



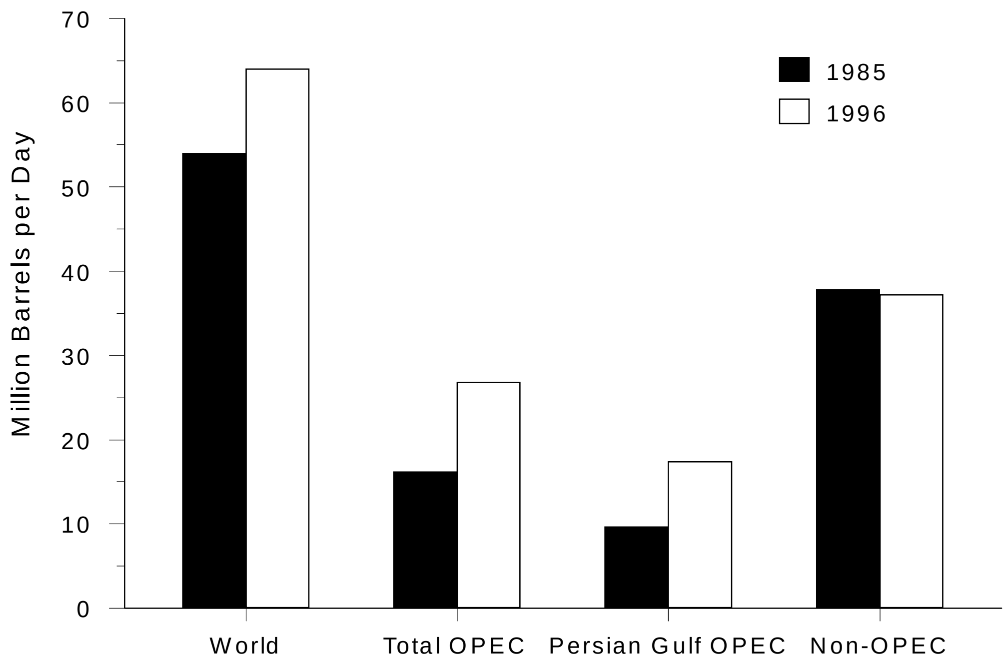
Note: Includes expenditures for proved acreage.
Source: Energy Information Administration, Financial Reporting System (FRS), Form EIA-28.

Figure 42. Majors and Nonmajors, U.S. Oil Production by Region, 1985-1995



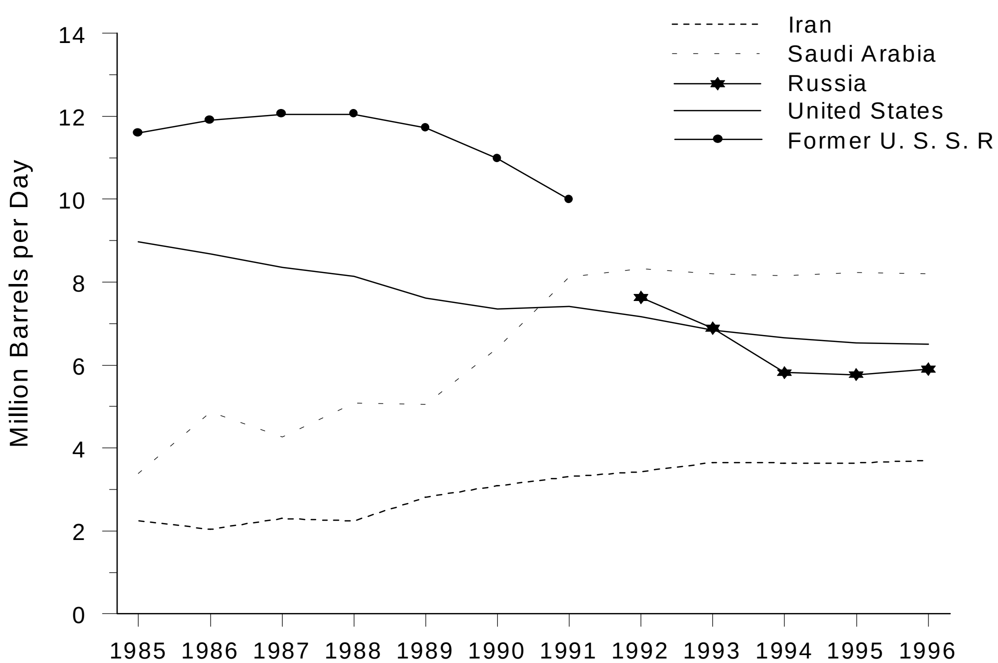
Source: Energy Information Administration, *Oil and Gas Development in the United States in the Early 1990's* (October 1995), and Financial Reporting System.

Figure 43. World, OPEC, and Persian Gulf Oil Production, 1985 and 1996



Source: Energy Information Administration, *Monthly Energy Review* (March 1997).

Figure 44. Leading World Oil Producers, 1985-1996



Source: Energy Information Administration, *Monthly Energy Review* (March 1997).

Table 2. Worldwide Crude Oil Production of 20 Leading Companies, 1972 and 1995
(Thousand Barrels per Day)

1972			1995		
Company	Production	Percent of Worldwide Total	Company	Production	Percent of Worldwide Total
Exxon Corp.	4,968	10.8	Saudi Arabian Oil	8,585	13.8
British Petroleum	4,664	10.1	National Iranian Oil Co.	3,720	6.0
Royal Dutch/Shell	4,169	9.0	Petroleos de Venezuela	2,885	4.6
Texaco Inc.	3,777	8.2	China National Petroleum	2,796	4.5
Chevron Corp.	3,232	7.0	Petroleos Mexicanos	2,722	4.4
Gulf Oil	3,214	7.0	Royal Dutch/Shell	2,254	3.6
Mobil Corp.	2,316	5.0	Kuwait Petroleum Corp.	2,070	3.3
Communist Bloc[a]	1,301	2.8	Exxon Corp.	1,726	2.8
CFP (Total - France)	977	2.1	Libya National Oil Company	1,345	2.2
Sonatrach (Algeria)	925	2.0	Abu Dhabi National Oil Co.	1,300	2.1
Amoco Corp.	815	1.8	Sonatrach (Algeria)	1,283	2.1
ARCO	652	1.4	British Petroleum	1,283	2.1
DuPont (Conoco)	594	1.3	Nigerian National Petroleum	1,200	1.9
USX Corp. (Marathon)	453	1.0	LUKoil (Russia)	1,116	1.8
Petroleos Mexicanos	440	1.0	Pertamina (Indonesia)	1,065	1.7
Occidental Petroleum	443	0.9	Chevron Corp.	1,001	1.6
Getty Oil	443	0.9	Mobil Corp.	810	1.3
Sun Co.	369	0.8	Elf Aquitaine (France)	764	1.2
Unocal Corp.	365	0.8	Texaco Inc.	762	1.2
Phillips Petroleum Co.	337	0.7	Yokos (Russia)	722	1.2
Top 20 Total	**34,434**	**74.6**	**Top 20 Total**	**39,409**	**63.1**
Worldwide Total[a]	**46,170**	**100.0**	**Worldwide Total**	**62,446**	**100.00**

[a]For 1972, only non-communist world oil production and communist bloc (including China) exports to the non-communist world are included, while 1995 includes total world production. Sum of components may not equal totals due to independent rounding. Shares were calculated based on unrounded data.

Sources: Energy Information Administration (EIA). **1972:** EIA, *Performance Profiles of Major Energy Producers 1993*. **1995:** EIA, Financial Reporting System.

Domestic Reserves Declined Over the Past Decade

In the past decade, the United States' proved reserves of crude oil have fallen gradually, declining over 21 percent from 28.4 billion barrels in 1985 to 22.3 billion barrels in 1995 (Figure 45). The last inter-annual increase, amounting to about 400 million barrels, occurred between 1986 and 1987. As Figure 46 indicates, proved reserves of crude oil increased only in the offshore Gulf of Mexico during the decade.

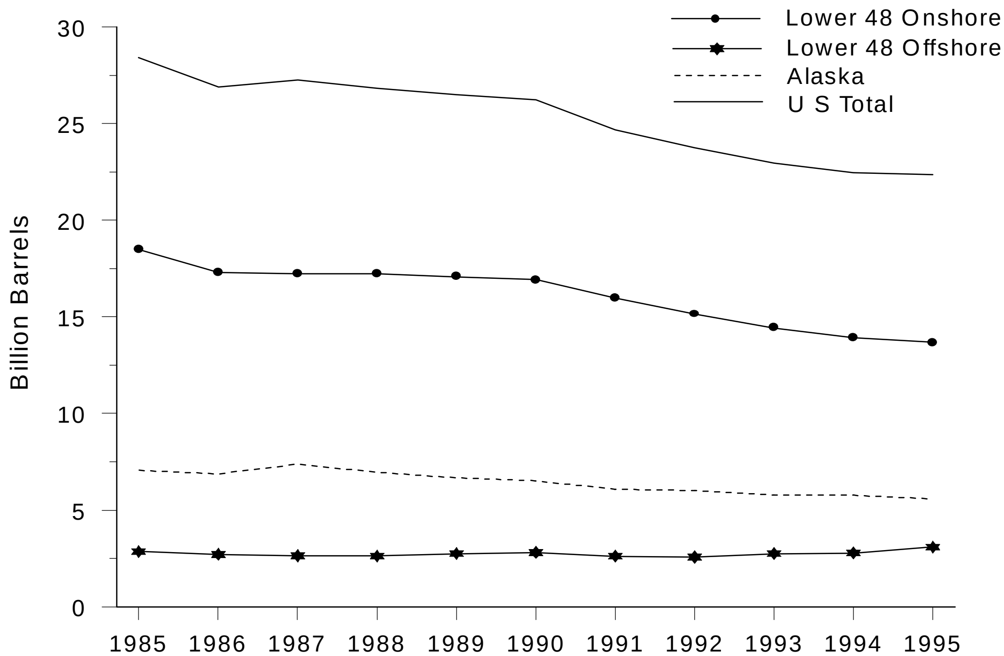
This reserves record is primarily attributable to the sharp decrease in drilling caused by the 1986 collapse of crude oil prices, which declined 49 percent worldwide and 51 percent in the domestic market (Figure 47).[14] Domestic crude oil well completions dropped 47 percent in 1986 alone, from 35,021 in 1985 to 18,701, while exploratory oil well completions similarly declined from 1,879 in 1985 to 988 (Figure 48). A secondary factor was the shift toward gas drilling that took place during the period. After 1992 natural gas rather than crude oil became the dominant domestic drilling target.

Restrictions on oil exploration in many of the most prospective oil-prone places left in the United States, due to environmental considerations, also contributed to the decline of domestic proved crude oil reserves. Alaska on- and offshore, the Gulf of Mexico, and the far western United States[15] are the only regions of the country in which undiscovered conventional oil and gas resources sufficiently large to be of long term national supply significance remain to be found and converted to supply at low levels of unit cost relative to other current and foreseeable oil and gas supply alternatives. This is consistently shown by:

[14]Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*, Annual Report 1995, DOE/EIA-0216(95), Table 3, p. 10.

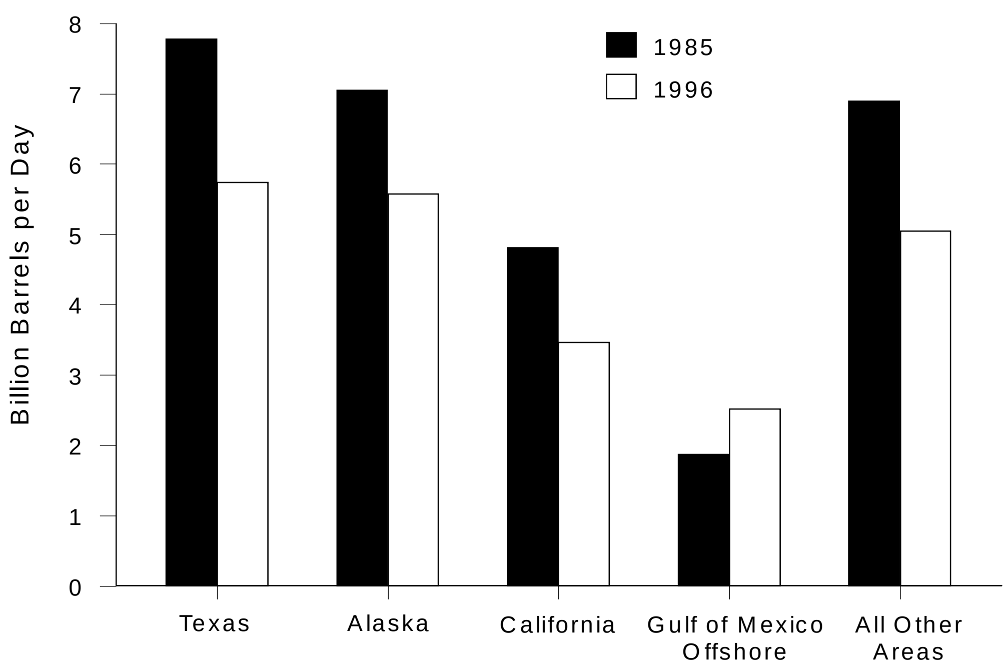
[15]On- and offshore Washington, on- and offshore Oregon, on- and offshore California, Idaho, Nevada, and parts of Utah and New Mexico.

Figure 45. Domestic Crude Oil Proved Reserves, 1985-1995



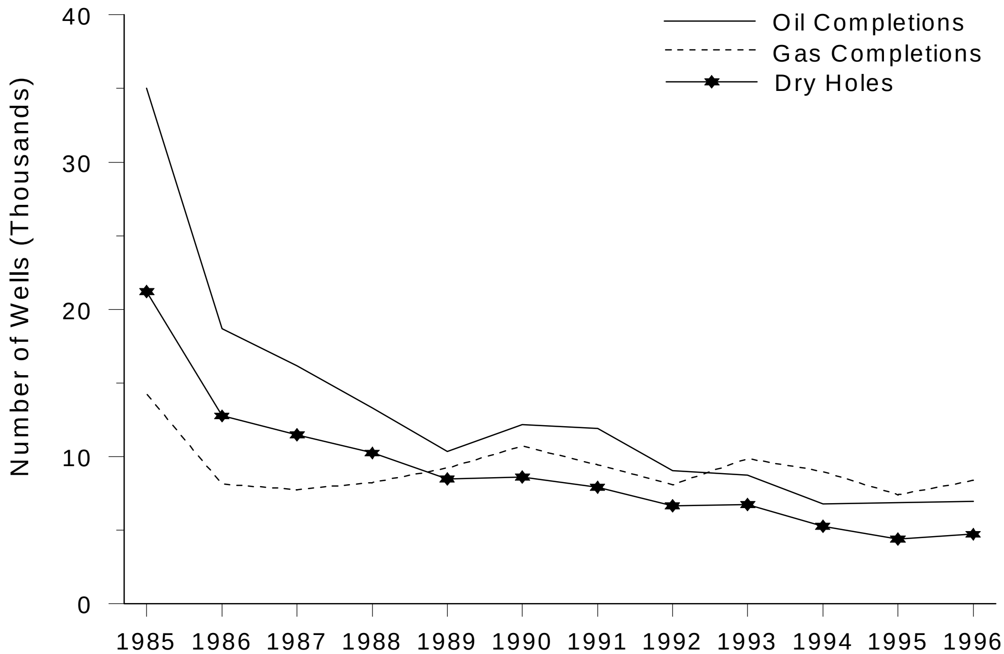
Source: Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1995*.

Figure 46. Crude Oil Proved Reserves by Area, 1985 and 1996



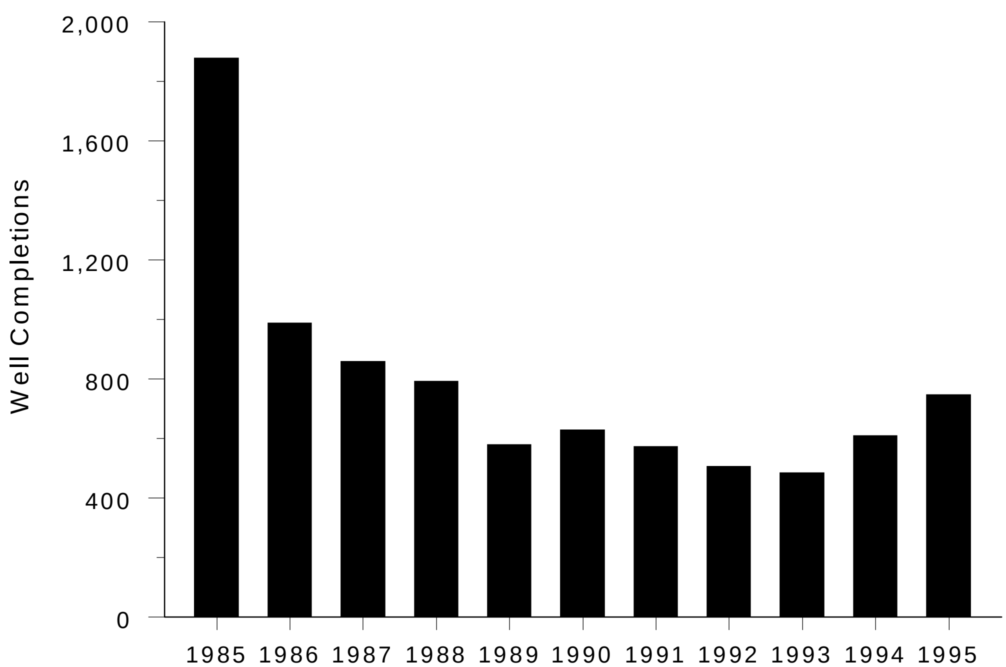
Source: Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves 1995*.

Figure 47. Domestic Oil and Gas Well Completions, 1985-1996



Source: Energy Information Administration, *Monthly Energy Review* (March 1997).

Figure 48. Domestic Exploratory Oil Well Completions, 1985-1995



Source: Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1995.*

- periodic estimates of domestic undiscovered oil and gas resources produced by the United States Geological Survey and the Minerals Management Service;[16]

- biennial estimates of natural gas resources prepared by the industry-based Potential Gas Committee;[17]

and is demonstrated in the EIA publication *Geologic Distributions of U.S. Oil and Gas*.[18] However, the most oil-prospective areas of onshore Alaska and offshore California have for years been administratively or legislatively declared off-limits to oil and gas exploration.

A factor that prevented the Nation's 1995 crude oil reserves situation from being worse was that discoveries per exploratory well completion generally increased over the decade (Figure 49). This occurred in part because the lower overall level of drilling permitted "high grading" of the portfolio of prospects available to the industry, and in part was due to the introduction of several new technologies that increased the drilling success rate or otherwise reduced either the risk or cost of upstream operations (see box, p. 61).

International Reserves Are Much Larger Than U.S. Reserves

Crude oil resources and the reserves derived from them are unevenly distributed over the globe. Based on country-by-country estimates of crude oil reserves and production compiled from multiple sources by DeGolyer and MacNaughton[19], the world's reserves of crude oil were 1,114.7 billion barrels at year-end 1994 while 1994 world production was 22.632 billion barrels. The distribution of these quantities is shown in Table 3 for the continents and the Middle East region. The 1994 worldwide ratio of year-end reserves to annual production (R/P) was 49.2. This statistic, often inaccurately and misleadingly termed a "reserve life index," *does NOT imply* that the world's year-end 1994 reserves will be exhausted in 49.2 years. The 1994 reserves base will instead produce at generally decreasing levels to well beyond 2050. The R/P statistic is more useful for comparative purposes. Table 3 indicates the general worldwide 1994 distribution of crude oil reserves and production and provides some location-specific R/P ratios. The United States' R/P of 9.3 was the lowest of any major oil- producing country or area. This reflects the fact that the United States is the most intensively explored country in the world, having been the first to achieve an annual production rate of a billion barrels per year.

Oil Resources

Estimates of recoverable oil resources are subject to a greater degree of uncertainty than are estimates of proved reserves. They include, in addition to proved reserves, oil that is yet to be discovered and other classes of reserves that are generally less precisely quantifiable than proved reserves. Their eventual recovery is less assured.

Domestic

Based on year-end 1993 data for onshore and state jurisdiction offshore areas and year-end 1994 data for Federal jurisdiction offshore areas, the Department of the Interior's 1995 mean (expected value) estimate of undiscovered recoverable plus inferred resources of domestic crude oil was 132 billion barrels.[20] This volume includes both anticipated new field discoveries and the expected appreciation of the ultimate recovery estimates of existing fields for both conventional and unconventional types of deposits. It is about 6 times larger than year-end 1995 proved reserves.

International

The Federal government's estimates of world oil and gas resources are produced by the United States Geological Survey's (USGS's) World Energy Resources Program (WERP). The latest estimate, dated January 1, 1993, is that a mean (expected value) of 547 billion barrels of technically

[16]United States Geological Survey, *Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States*, Circular 725 (Washington, DC, 1975); United States Geological Survey, *Estimates of Undiscovered Recoverable Conventional Oil and Gas Resources in the United States*, Circular 860 (Washington, DC, 1981); United States Department of the Interior, U.S. Geological Survey, and Minerals Management Service, *Estimates of Undiscovered Conventional Oil and Gas Resources in the United States -- A Part of the Nation's Energy Endowment* (Washington, DC, 1989); United States Geological Survey, *1995 National Assessment of United States Oil and Gas Resources*, Circular 1118 (Washington, DC, 1995); Minerals Management Service, *An Assessment of the Undiscovered Hydrocarbon Potential of the Nation's Outer Continental Shelf*, OCS Report MMS 96-0034 (Washington, DC, 1996).

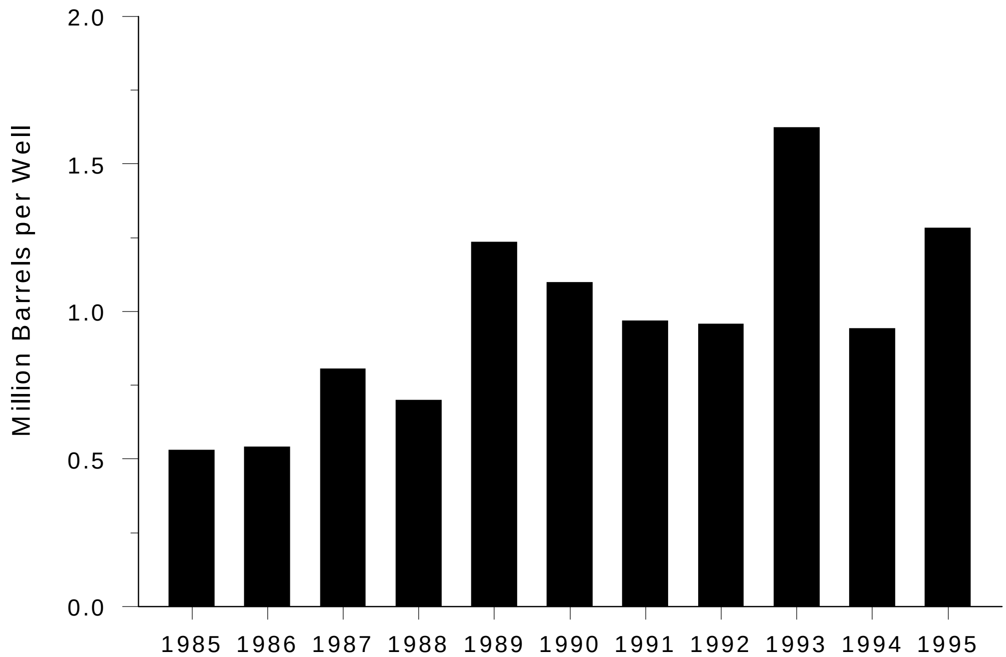
[17]Potential Gas Committee, *Potential Supply of Natural Gas in the United States*, biennial series through 1996, (Golden, CO).

[18]Energy Information Administration, *Geologic Distributions of U.S. Oil and Gas*, DOE/EIA-0557 (Washington, DC, July 1992).

[19]DeGolyer and MacNaughton, "Estimates of Petroleum Reserves in Principal Producing Countries and Crude Oil Production in 1994," *Twentieth Century Petroleum Statistics*, (Dallas, TX, 1995), p. 1.

[20]United States Geological Survey, *1995 National Assessment of United States Oil and Gas Resources*, Circular 1118, (Washington, DC, 1995); Minerals Management Service, *An Assessment of the Undiscovered Hydrocarbon Potential of the Nation's Outer Continental Shelf*, OCS Report MMS 96-0034 (Washington, DC, 1996).

Figure 49. Domestic Crude Oil Discoveries per Exploratory Oil Well Completion, 1985-1995



Source: Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1995*.

recoverable crude oil remains to be discovered worldwide (Table 4). There is a 19 in 20 chance that at least 43 billion barrels remain to be discovered, and a 1 in 20 chance that at least 945 billion barrels remain to be discovered.[21]

The geographic distribution of the mean estimate is as follows: 30.1 percent is expected to be located in the Americas, 22.3 percent in the Middle East, 18.5 percent in the former Soviet Union, 14.8 percent in Asia-Oceania, 8.8 percent in Africa *ex* the Middle East, and just 5.5 percent in Europe, Western, and Eastern.

It should also be noted that those places with the highest current R/P ratios, as shown in Table 3, also usually have the highest estimated volumes of undiscovered oil resources. This reflects two facts about these places: they are *very* oil-rich; and, in most instances, exploration and development began much later in them than in the United States.

Future Implications

The United States' proved crude oil reserves could exhibit a modest increase commencing this year or next given recent developments in the Gulf of Mexico where:

- 3-D seismic surveying technology has within the past decade made it possible to accurately image reservoirs located in the deep Gulf (i.e., in more than 1000 feet of water) and beneath the extensive salt sheets that occur in the shallower portions of the Gulf;

- the development of new production technologies applicable to deep water, such as tethered floating drilling and production platforms (tension leg platforms), spar buoy-shaped production facilities, and sub-sea well completion and production systems, has made it profitable to develop large deep water fields.

Also contributing to the possibility of a modest near-term increase in domestic oil reserves are the efforts now underway to find and/or develop the so-called "smaller" oil reservoirs and fields peripheral to the existing giant producing fields on the North Slope of Alaska, each of which is a big field by lower 48 States-standards. However, in view of the remaining undiscovered resource situation, the continued restrictions on oil exploration in many highly prospective oil-prone areas, and the inexorable if slow growth of demand, this increase can only be temporary, lasting a few years at most.

The industry is also engaged in a large effort to increase its proved crude oil reserves in South America, which has short-haul access to the United States market. Over the mid-term

[21]C.D. Masters, D.H. Root and E.D. Attanasi, *Resource Constraints in Petroleum Production Potential*, Science, v. 253 (12 July 1991).

New Upstream Technologies: What They Deliver

Three-Dimensional Seismic Surveying

Three-dimensional seismic surveying (3-D), made possible by the computer revolution, improves the precision and content of geological interpretations of the earth's subsurface far beyond what the traditional two dimensional (2-D) seismic surveying methods provided. Widespread implementation of 3-D in the past decade has led to a much higher ratio of successful wells to dry holes, particularly for exploratory wells.

Horizontal Drilling, Measurement-While-Drilling, and Logging-While-Drilling

Horizontally-oriented wells typically produce at 3 to 5 times the rates achieved by conventional vertical wells drilled into the same reservoir. While they are more difficult and expensive to drill, using them tends to approximately halve the average unit cost of development. They, along with other kinds of directional drilling, also allow the industry to have a much smaller surface "footprint" because areas up to several square miles can be tapped from a single drilling site. This characteristic of horizontal drilling is particularly important in frontier areas such as the Arctic and the deep offshore, and in environmentally sensitive areas.

New downhole technologies which enabled the drilling of horizontal holes that stay within the target formation include measurement-while-drilling (MWD) and logging-while-drilling (LWD) systems. MWD systems allow real-time acquisition of previously unavailable data related to the drilling operation itself such as weight-on-bit, mud pressure, torque, vibration, and hole caliper, angle and direction. LWD systems allow real-time acquisition of downhole resistivity and sonic and gamma ray measurements that rival those attainable via traditional progress-interrupting wireline logging. These geophysical measurements can be simultaneously interpreted to determine rock type (sandstone versus shale versus carbonates) and pore content (water versus hydrocarbons). Having this knowledge in real time allows path correction commands to be sent back down the hole to a steerable motor located just behind the drill bit and just in front of the MWD and LWD tools. Thus, the position of the bit can now often be controlled to within 2 feet of the intended (design) position.

Slim Hole Drilling

Slim hole drilling, the drilling of wells with smaller diameter bores than those drilled over the past several decades, is rapidly increasing. Major technological strides have been made in downsizing the traditional suite of downhole instruments and tools without loss of effectiveness during the last few years. The principal advantage of slim hole drilling is reduced cost. For example, steel is priced by the ton and 1,000 feet of conventional 12.25 inch hole casing weighs 59 tons, while the equivalent length of 8.5 inch casing weighs only 29 tons. Similarly, lower costs are associated with drill pipe, drill bits, fuel costs, mud chemicals, cement, cuttings cleaning and disposal, and elapsed drilling time to total depth.

Drilling With Coiled Tubing

Standard drill pipe comes in 30 foot lengths with threaded connections at the ends. It is typically stored on a drilling rig's pipe rack in 90 foot stands made up of 3 joints, which must be sequentially added to the drill string while drilling. Similarly the stands must be sequentially decoupled to change the downhole tools and drill bit. "Tripping" to do so is a laborious, time consuming, expensive way to drill. Thanks to recent developments in the material sciences standard drill pipe is being replaced in many drilling applications with coiled tubing. This is a continuous length of pipe which is stored wrapped around a large reel. It is straightened off the reel over a curved guide to and through a motorized injector head mounted atop the well control stack, and thence down the well. Coiled tubing wall thickness ranges from 0.2 to 0.5 inches depending on the tubing's diameter and the required load-bearing characteristics. Several thousand feet of coiled tubing can be run down or withdrawn from a hole in tens of minutes rather than the many hours required to "trip" with standard drill pipe, providing substantial cost savings. Another advantage over standard drilling technique is that fluid circulation in the hole can be maintained at all times, which helps to avoid a number of well control, drilling, and well completion problems.

Nuclear Magnetic Resonance Borehole Imaging

Downhole tools have recently been developed that perform nuclear magnetic resonance (NMR) analysis of the hydrogen-containing fluids located in near-borehole rock. NMR can quantitatively differentiate between (1) hydrogen atoms bound to clays, (2) hydrogen atoms included in water molecules, and (3) hydrogen atoms included in hydrocarbon molecules. This knowledge enables both better well completion design and the completion of thinner productive zones than before.

Integrated Teams and Petroleum System Modeling

Prior to the 1980s, most oil and gas firms were structured in such a way that their exploration geologists and their geophysicists had minimal contact with each other and neither group talked to the development geologists and production staff. Each had separate sets of data and there was little communication. This situation has radically changed, in most firms, for the better. Exploration and development teams consisting of all disciplines operate off the same computer-housed data base, thereby avoiding disconnects and bringing the best thinking of all involved in finding, developing and producing a field or reservoir to bear at the same time. Adjunct to this approach is the developing area of petroleum systems modeling, which has been made possible by the advent of fast computers capable of massive processing tasks. A petroleum system consists of the source rocks, migration pathways, traps, and seals required to generate, accumulate, and preserve oil or gas in the subsurface. These elements of a petroleum system have to have occurred in an appropriate time relationship for a commercially exploitable oil or gas reservoir to be present. It has now become possible to model the generation of oil and/or gas from the kerogen present in the source rocks, the formation of overlying traps and their seals, the expulsion of oil or gas from the source rocks, and migration to the traps. While such models are as yet fairly rudimentary, and much more data and therefore even faster computers are needed to improve them, only individual components had been modeled before. Integrated petroleum system modeling is a major improvement that helps to avoid technical disconnects in the analysis of the system. In several instances it has demonstrably reduced the required exploration expenditures and speeded the exploration process by accurately indicating what traps within the target system were likely to be commercially productive.

Table 3. Distribution of Crude Oil Reserves and Production with Corresponding Local R/P Ratios, 1994

Area/Country	Percent of World Reserves	Percent of World Production	R/P Ratio
North America	7.28	18.11	20.0
United States	2.01	10.74	9.3
South America	7.33	8.20	43.1
Venezuela	5.82	4.17	68.5
Europe	3.28	9.38	17.2
United Kingdom and Norway	2.91	8.1	17.6
Former Soviet Union	17.15	11.84	71.6
Africa	6.53	10.73	30.2
Nigeria	1.54	3.06	25.0
Middle East	53.69	30.69	86.0
Saudi Arabia	23.32	12.86	89.3
Asia-Oceania	4.75	11.04	21.0

Note: R/P = Year-end reserves divided by annual production.

Source: Derived from DeGolyer and MacNaughton, "Estimates of Petroleum Reserves in Principal Producing Countries and Crude Oil Production in 1994," *Twentieth Century Petroleum Statistics* (Dallas, TX, 1995), p.1.

this source of crude oil supply, particularly from Venezuela, will be significant for the United States. However, South America is estimated to have only about 7 percent of the world's undiscovered conventional crude oil resources. It is not therefore expected to be a major source of long-term supply unless and until means can be developed to economically tap its large known resources of heavy oil.

Regardless of what transpires in relation to exploitation of the United States' remaining domestic crude oil resources, it is clear that the upstream sector of the petroleum industry has increasingly focused on foreign opportunities over the past decade. As noted earlier and shown in Figure 39, the direct lifting costs of EIA's Financial Reporting System (FRS) companies, which include all of the domestic majors, were lower abroad than they were in the United States from 1983 to 1991. Since 1991 there has been no important distinction between foreign and domestic lifting costs, but there has been no change in the emphasis on foreign operations. And, as shown in Figures 40 and 41, expenditures by the majors on foreign operations increased for both exploration and development from 1987 through 1990-1991, flattened out or declined slightly for two to three years, and then began to increase again slightly. The majors are simply following the available resource base on a world scale, enabled by the liberalization/rationalization of ownership, leasing, and tax policies that was initiated by many oil-prospective countries during the past decade.

Over the long term — beyond 2020 or so — the United States will be increasingly unable to satisfy from domestic sources its requirements for crude oil. Considering the limited long-term domestic capability to produce crude oil and increasing demand, the United States will become increasingly reliant on imported crude oil.[22]

There continues to be a lack of economical substitutes for the the products derived from crude oil, most particularly motor gasoline. This, in concert with the anticipated rapid growth of petroleum product demand in developing countries, will lead to increasing international competition for crude oil.[23] Future crude oil imports will therefore likely be obtained at increasing prices until such time as a cap is placed on world crude oil prices by one or more of the emerging natural gas-to-liquids, coal-to-liquids, or heavy oil recovery technologies.

As a consequence of the natural distribution of petroleum resources, much of the United States' out year-supply will have to be imported from the Persian Gulf region, which has a history of supply disruptions induced by political events.

[22]Comparison of crude runs to domestic stills with domestic crude oil production indicates that the U.S. has not come within 10 percent of being crude oil self-sufficient since 1957, and that there has been a pronounced reduction of self-sufficiency since 1982, to the point that 53 percent of 1995's crude runs were of a foreign origin. While it is highly improbable that the U.S. can attain crude oil self-sufficiency again, it remains possible to assert some control over the magnitude and timing of future insufficiencies.

[23]Energy Information Administration, *International Energy Outlook 1997*, DOE/EIA-0484(97), (Washington, DC, April 1997).

Table 4. Estimates of Worldwide Cumulative Production, Identified Reserves, and Undiscovered Technically Recoverable Resources of Conventional Crude Oil
(Billion Barrels)

Area	Cumulative Production 1/1/93	Identified Reserves 1/1/93	Mean Undiscovered Resources
North America	182.8	83.0	121
Canada	14.3	7.0	33
Mexico	15.7	27.4	37
United States	152.7	48.5	49
Other	0.1	0.1	1
South America	57.9	43.8	44
Argentina	4.9	2.3	2
Brazil	2.5	2.8	9
Venezuela-Trinidad	43.9	34.4	20
Other	6.7	4.3	14
Europe	22.5	28.9	30
Netherlands	0.5	0.2	0
Norway	3.1	11.0	13
United Kingdom	8.6	13.5	11
Other Western Europe	3.5	2.2	4
Eastern Europe	6.8	2.0	2
Former Soviet Union	103.6	80.0	101
Africa	46.4	58.7	48
Algeria	9.1	8.4	2
Angola	1.3	2.0	2
Egypt	4.4	4.6	5
Libya	15.9	22.4	8
Nigeria	12.4	16.0	9
Other	3.2	5.3	21
Middle East	160.2	584.8	122
Iran	36.1	63.0	22
Iraq	19.9	99.0	45
Kuwait	23.3	96.0	3
Saudi Arabia	55.8	255.0	41
United Arab Emirates	11.0	56.2	27
Other	14.2	15.6	4
Asia-Oceania	36.8	42.8	81
Australia-New Zealand	3.0	2.4	5
China	13.0	22.0	48
India	2.6	4.5	3
Indonesia	13.3	8.4	10
Malaysia-Brunei	3.9	4.6	6
Other	0.9	1.0	8
World	610.2	922.1	547

Source: From Masters, C.D., Root, D.H., and Attanasi, E.D., *Resource Constraints in Petroleum Production Potential,* Science, v. 253 (12 July 1991), p. 147.