Chapter 2
ENERGY SUPPLY

Abstract

World energy resources are plentiful, but accumulating risks threaten continued expansion of oil and natural gas production from conventional sources relied on historically. To mitigate these risks, expansion of all economic energy sources will be required, including coal, nuclear, renewables, and unconventional oil and natural gas. Each energy source faces significant challenges, including technical, environmental, political, or economic hurdles, and each imposes infrastructure requirements for development and delivery.

This chapter examines endowment, resource, and production dynamics; describes the historical and projected energy mix; analyzes diverse public and aggregated proprietary data sources; and considers options for energy infrastructure and delivery.

The outline of the Energy Supply chapter is as follows:

- Supply Summary
- Prospects for Energy Supply
- Analysis of Energy Outlooks
  - Oil and Other Liquids
  - Natural Gas
  - Coal
  - Biomass
  - Non-Bio Alternative Energy Sources
  - Energy Conversion and Delivery Infrastructure
- Access to Resources.

A set of detailed studies on specific supply-related topics supports the analysis in this chapter. These topic papers are included on the CD distributed with this report (a list of all the topic papers can be found in Appendix E). The data used for analyzing energy outlooks are included in the Data Warehouse section of the CD.

SUPPLY SUMMARY

The question of future energy supplies is significant, controversial, and extends beyond oil and gas. Energy supply is a complex system that includes several basic components: (1) the natural endowment or physical store of a particular resource; (2) production or conversion of the resource to usable form; and (3) delivery of products to consumers. The components function within a larger and changing economic, geopolitical, and technical context. The study takes a comprehensive view that includes each of these elements for fossil hydrocarbons and other energy sources such as biomass, nuclear, and non-bio renewables.

Data Sources

The study considered a diverse set of data that represents the range of opinion about energy supply. These data were collected in the NPC Survey of Global Energy Supply/Demand Outlooks ("NPC Survey of Outlooks"). Figure 2-1 shows the sources of supply forecasts and

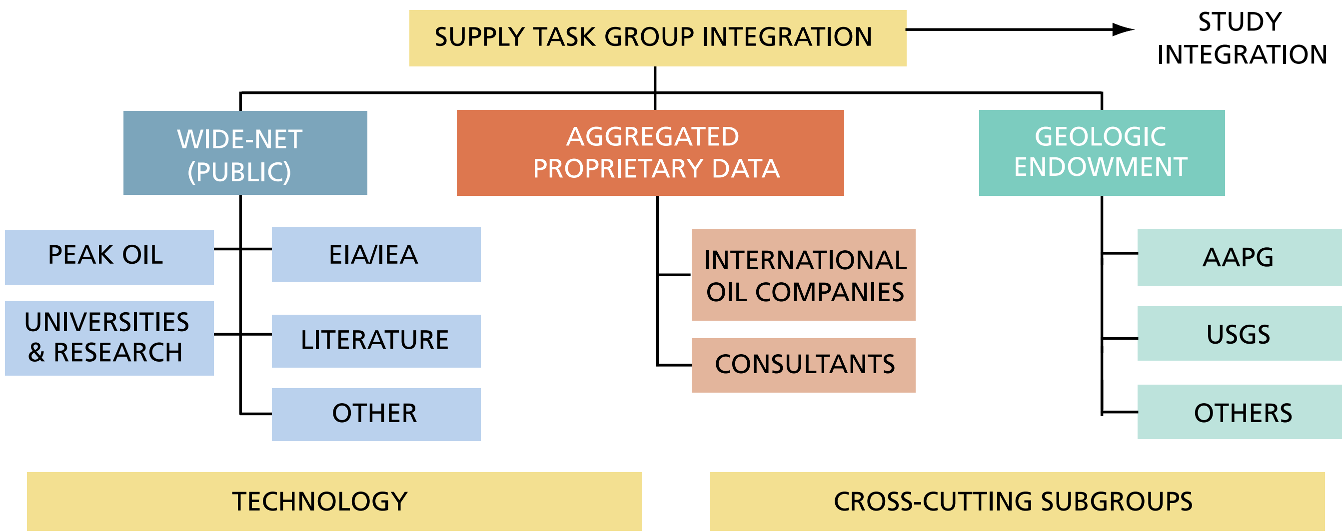


FIGURE 2-1. *Supply Data Sources*

data about the underlying resource base. The comprehensiveness of the data is unique to this study and established an objective basis for the findings.

The data were classified into categories that included quantitative forecasts as well as reports and opinion papers:

- *Public data* are freely available from agencies such as the U.S. Energy Information Administration (EIA) and the International Energy Agency (IEA); academic and research institutions; interest groups; open literature; and foreign governments.
- *Proprietary data* were made available to the study, anonymously and with strict safeguards, by private businesses such as energy companies and industry consultancies.
- *Endowment data* represent expert technical opinion about the physical resource base for hydrocarbons and other sources of energy.

Source data ranged from integrated supply-demand projections through studies of specific elements of the energy system such as biomass and transportation infrastructure. See the Methodology chapter of this report for full details about the techniques used in data collection and analysis.

Resource Endowment

Endowment and recoverable resources are fundamental concepts in any discussion of energy supply. *Endowment* refers to the earth's physical store of potential energy sources: tons of coal, cubic feet of natural gas, barrels of oil, etc. The endowment of fossil hydrocarbons is fixed: it can be depleted but not replenished. *Recoverable resources* are a subset of the hydrocarbon endowment—the portion that can be viably produced and converted to fuel and power.

The natural endowment is the foundation of all supply projections. Although there are many estimates for future producible reserves and production, these are often based on the same resource estimates, principally data compiled by the United States Geological Survey (USGS). Other estimates are made by energy companies and non-U.S. governmental agencies. However, public and proprietary assessments are not integrated with each other and may use different methodologies. The wide range of assessments creates uncertainty for policy makers.

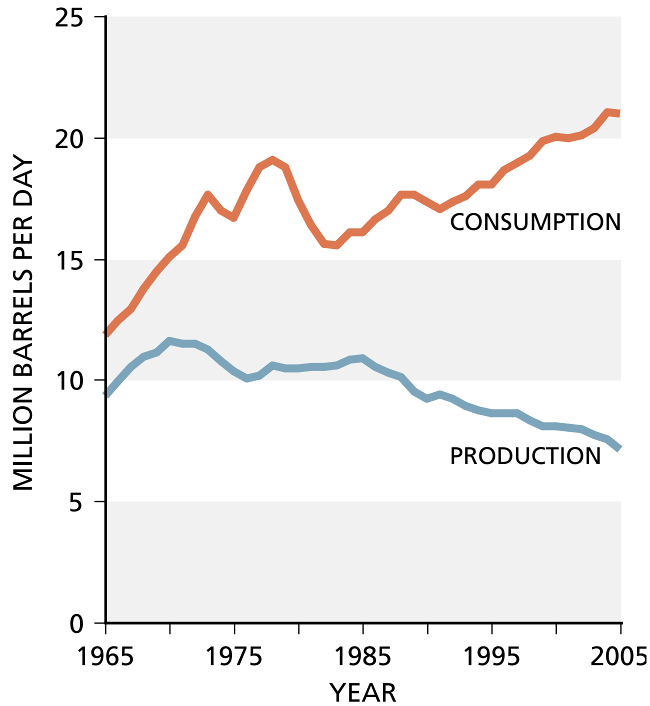
Current endowment and resource assessments for oil, gas, and coal indicate very large in-place volumes and resource potential, several times the cumulative produced volumes and current reserve estimates. Renewable resources such as biomass, wind, and solar power add additional potential. However, physical, technical, commercial and other constraints make only a fraction of any endowment available for extraction. The key consideration for all energy sources is converting the resource endowment to economically and environmentally viable production and delivery.

Resources to Production

The United States is the world's largest cumulative oil producer and remains the third-largest daily producer after Saudi Arabia and Russia. However, Figure 2-2 shows that U.S. oil production has declined steadily over the past 40 years. Demand for oil (and natural gas) has grown at the same time, creating a gap with domestic production that is filled by imports. Any continuing production decline for domestic oil will widen the projected gap between supply and consumption over the next 25 years and beyond. Accumulating geological, geopolitical, investment, and infrastructure risks to global oil and natural gas supply may compound the gap.

Supply forecasts are wide ranging and reflect uncertainty at least partly based on recent difficulty in increasing oil production. Forecast worldwide liquids production in 2030 ranges from less than 80 million to 120 million barrels per day, compared with current daily production of approximately 84 million barrels. The capacity of the oil resource base to sustain growing production rates is uncertain. Several outlooks indicate that increasing oil production may become a significant challenge as early as 2015. The uncertainty is based on (1) the rate and timing at which significant quantities of unconventional oil enter the supply mix; (2) industry's ability to overcome increasing risks to supply. Figure 2-3 illustrates potential sources of total liquids supply as depicted in the IEA *World Energy Outlook 2004* (WEO 2004). This figure is an illustrative example of the various components that make up total liquids supply, although the timing and combination of the components may vary.

Public and proprietary supply projections are based on assumptions about underlying factors such as economic growth, energy prices, and resulting demand; carbon constraints; technology; and maximum production volumes and timing. The EIA's low economic growth case, for example, forecasts 50 percent growth in total global energy supply by 2030, while its high economic growth case forecasts 90 percent growth. The EIA, IEA, and consultant reference and high-demand cases result in the highest projected global oil production levels. In contrast, the production maximum (or peak oil) and carbon-constrained cases project the lowest estimates of global oil production. International oil company (IOC) outlooks are considerably higher than the lowest supply cases, but lower than the EIA



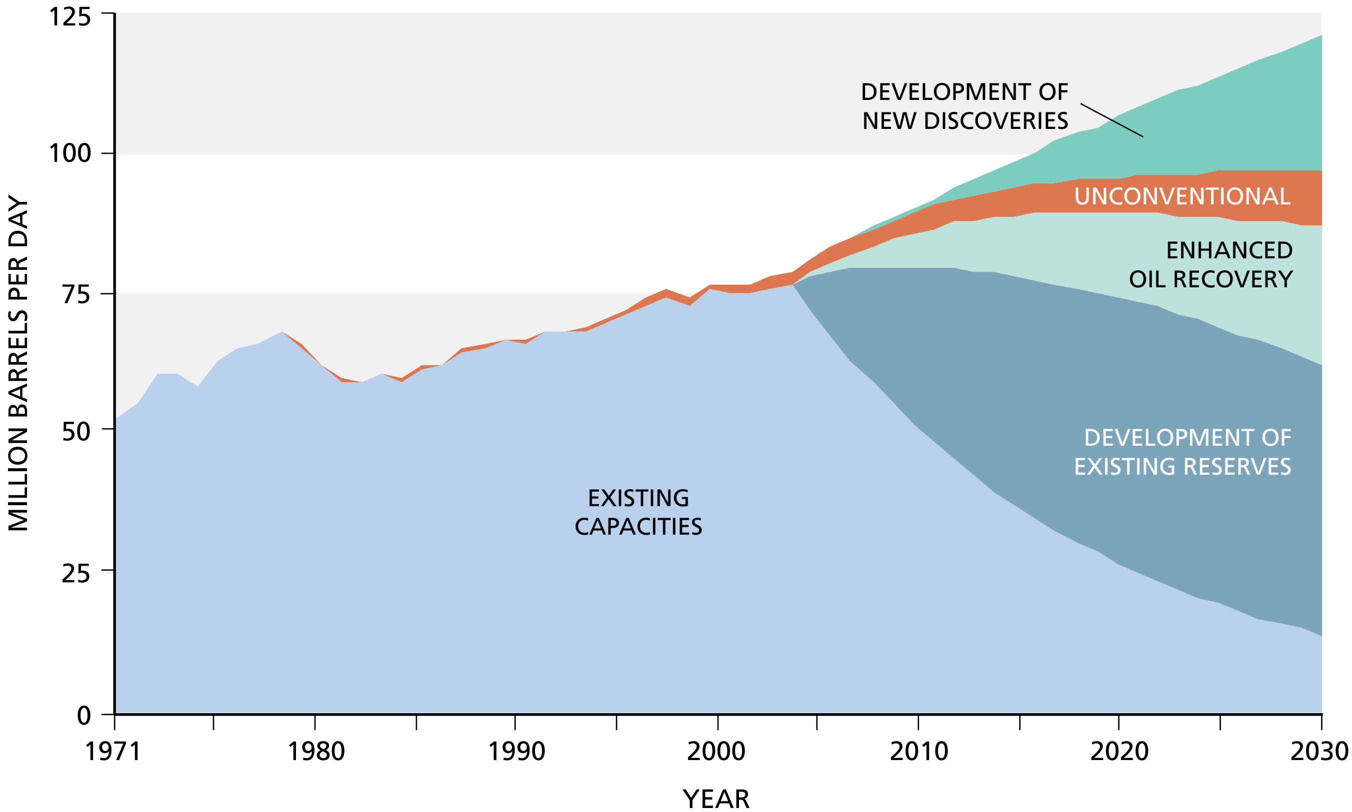
Source: *BP Statistical Review of World Energy 2006.*

FIGURE 2-2. *U.S. Oil Production and Consumption*

and IEA Reference Cases. The distribution of supply outlooks itself raises uncertainties and reflects different assessment of the risks involved in finding, producing, and delivering energy.

The USGS mean assessment indicates that natural gas resources are at least adequate for the increased production anticipated over the study period. However, the increased production will require replacing approximately 50 percent of the existing global natural gas reserve base by 2030.

Coal is a unique energy resource for the United States. Given its vast resource base—by many estimates, the world's largest—and major contribution to electricity generation today, coal is likely to remain a fundamental, long-term component of U.S. energy supply. Many studies forecast growth in coal use for power, plus additional growth through direct conversion of coal to liquids to diversify the fuel supply. However, coal combustion is also the largest source of carbon dioxide emissions from energy production. Adding coal-to-liquids production at scale, as with conversion of most heavy unconventional hydrocarbons, would generate large additional volumes of carbon dioxide. Addressing carbon capture at scale



Source: IEA, *World Energy Outlook 2004*.

FIGURE 2-3. *Illustrative Total Liquids Supply*

is therefore a prerequisite for retaining coal as a viable and critical part of the energy supply system.

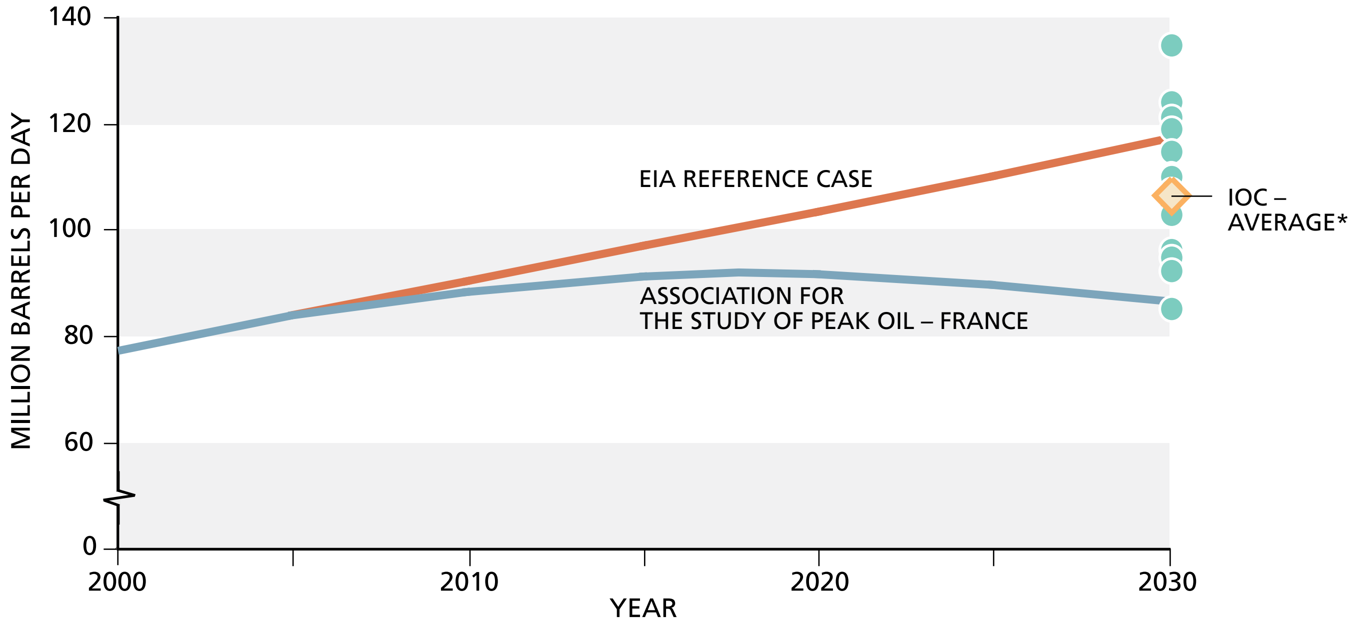
Understanding the Range of Production Forecasts

This study examined a comprehensive range of global oil production forecasts including integrated supply/demand studies from EIA and IEA (unless otherwise noted, all EIA data referred to in this chapter are from *International Energy Outlook 2006* and IEA data are from *World Energy Outlook 2006*); publicly available projections from a diverse range of other sources; and a unique set of aggregated proprietary forecasts from IOCs and energy consulting groups. The diversity of this range of projections is shown in Figure 2-4, which highlights the EIA reference, the Association for the Study of Peak Oil (ASPO) – France, and the average of the IOC forecasts for 2030. The distribution of production forecasts highlights the effect of assigning different levels of risk and uncertainty to both resource and above-ground factors. This distribution of outcomes, along with evaluation of assessments of the total resource base, indicates that the key consideration for energy supplies is not endowment but "producibility." Over the next 25 years, risks above ground—geopolitical, technical, and infrastructure—are more likely to affect oil and natural gas production rates than are limitations of the below-ground endowment. The range of outcomes emphasizes the need for proactive strategies to manage the accumulating risks to liquids delivery in 2030.

Explanations for the variance in projections for both conventional oil and natural gas production are widely discussed as part of the "peak oil" debate. As a result, this study sees the need for a new assessment of the global oil and natural gas endowment and resources to provide more current data for the continuing debate.

Diversification

Growing U.S. energy demand requires diversified energy sources that are economically and environmentally sustainable at commercial scale. Coal and



* Average of aggregated proprietary forecasts from international oil companies (IOC) responding to the NPC survey. See Analysis of Energy Outlooks, Global Total Liquids Production, later in this chapter for identification of other aggregations and outlooks shown here.
Source: EIA, *International Energy Outlook 2006*, and the NPC Survey of Outlooks.

FIGURE 2-4. *Global Total Liquids Forecasts*

nuclear power already play a significant role. Most forecasts expect them to at least retain their relative share of the supply mix. Many forecasts project significant growth for unconventional hydrocarbons, including very heavy oil and bitumen expansion from Canadian oil sands. At a more challenging technical and economic level, many forecasts also predict growing contributions from large-scale conversion of coal to liquids and the eventual development of vast U.S. oil shale resources. All unconventional hydrocarbons face the critical issue of their significant carbon footprint at large-scale implementation.

Biomass and other renewables are playing a growing role as options for transportation fuel or power generation, with high year-to-year growth rates. Biomass includes wood, cultivated crops, or naturally growing vegetation that potentially can be converted to energy sources at commercial scale. First-generation conversion of biomass to fuels is based on corn, sugarcane, soybeans, or other crops that are also food sources. Technically and economically successful, second-generation conversion of plant waste or fuel crops would allow non-food vegetation to be used as feedstock. As with all energy sources, technical, logistical, and market requirements will need to be met to achieve significant scale.

Energy projections generally show a continuing role for nuclear energy, notwithstanding unique concerns about safety, security, and waste disposal. In a carbon-constrained environment, nuclear energy may become a much larger part of the energy mix. However, the U.S. technical and industrial capability needed to maintain nuclear energy as an option is at risk.

Key Findings

Oil, gas, and coal—the fossil hydrocarbons—are by far the largest sources of energy in industrial economies. While alternative energy sources, particularly biomass and other renewables, are likely to increasingly contribute to total energy supply, hydrocarbons are projected to dominate through at least 2030.

The prospects for hydrocarbon supply are complex. They involve a growing set of global uncertainties ranging from production capabilities through environmental constraints, infrastructure requirements, and geopolitical alignments. Concentration of remaining oil and gas resources in a few countries, for example, challenges whether business-as-usual cases represent the most likely course of events during the period to 2030.

Economically disruptive supply shortfalls of regional, if not global, scale are more likely to occur during the outlook period than in the past. Increased demand will amplify the effects of any short-term events, which are likely to result in stronger reactions than in the past to protect national interests. The new dynamics may indicate a transition from a demand-driven to a supply-constrained system.

While uncertainties have always typified the energy business, the risks to supply are accumulating and converging in novel ways:

- Resource nationalism, bilateral trade agreements, or protectionist policies may remove resources from the market and make them unavailable for general world supply.
- Hydrocarbon resources are becoming more difficult to access and challenging to produce.
- Technology requirements are increasingly complex and demanding.
- Costs of developing and delivering energy are escalating.
- Demands on current and anticipated infrastructure are heavy and growing.
- Human resources may not be adequate to meet projected growth requirements.
- Environmental constraints on energy supply are evolving and indeterminate.

These risks and uncertainties are the basis for understanding supply prospects over the next several decades.

The energy supply system has taken more than a century to build, requiring huge sustained investment in technology, infrastructure, and other elements of the system. Given the global scale of energy supply, its significance, and the time required for substantive changes, inaction is not an option. Isolated actions are not a solution. The study's recommendations address the supply issue as a whole and contribute to building a secure, sustainable energy portfolio.

PROSPECTS FOR ENERGY SUPPLY

Energy Endowment and Recoverable Resources

Endowment and recoverable resource are fundamental concepts in any complete discussion of energy supplies. This section defines these and other concepts used in supply forecasts. For detailed review and discussion of endowment and recoverable resources, see the Endowment and Biomass Topic Papers on the CD included with this report.

The *endowment* of fossil energy sources refers to the earth's physical store of non-renewable hydrocarbons: tons of coal, cubic feet of natural gas, barrels of oil, etc. The total endowment of fossil hydrocarbons is fixed. Some fraction can be developed and depleted, but the endowment cannot be replenished in less than geologic time frames. Renewable resources, such as biomass, represent an additional potential energy endowment, which, in principle, is continuously replenished. *Recoverable resources* are the subset of the total endowment that can be ultimately produced and converted into fuel and power.

Why We Do Endowment Assessments

Hydrocarbon resource assessments fill a variety of needs for consumers, policy makers, land and resource managers, investors, regulators, industry planners, and others involved in energy policy and decision making.

Individual governments use resource assessments to exercise stewardship, estimate future revenues, and establish energy, fiscal, and national security policy. Energy industries and the investment community use resource estimates to establish corporate strategy and make investment decisions. Other interested parties use the estimates in developing their positions and recommendations on energy issues.

Types of Hydrocarbons

Fossil Fuel is a collective term for hydrocarbons in the gaseous, liquid, or solid phase. The global fossil fuel endowment includes the following: coal, crude oil (including condensate), natural gas liquids, and natural gas.

- Coal is the altered remains of prehistoric plants that originally accumulated in swamps and peat bogs. It is organic sedimentary rock that has undergone various degrees of coalification, which determines its current physical properties.

- **Crude Oil** is defined as a mixture of hydrocarbons that exists in a liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface production facilities.
- **Natural Gas Liquids** (NGLs) are those portions of the hydrocarbon resource that exist in gaseous phase when in natural underground reservoir conditions, but are in a liquid phase at surface conditions (that is, standard temperature and pressure conditions: 60ºF/15ºC and 1 atmosphere).
- **Natural Gas** is a mixture of hydrocarbon compounds existing in the gaseous phase or in solution with oil in natural underground reservoirs at reservoir temperature and pressure conditions and produced as a gas under atmospheric temperature and pressure conditions. Natural gas is principally methane, but may contain heavier hydrocarbons (such as ethane, propane, and butane) and inert compounds.

Hydrocarbon Assessment Terminology

Hydrocarbons In Place

The endowment, or hydrocarbons in place in an accumulation or in all accumulations in the world, is significant because some fraction of the in-place endowment is always the goal for extraction and conversion to resources. In-place estimates have relatively high uncertainty and require assumptions and constraints in the analysis. As an illustration, the following global in-place estimates are based on analyses by Rogner,[1] Schollnberger,[2] and others:

- **Coal:** 14,000 billion short tons (Rogner: grades A-E, several geographical areas not assessed)
- **Oil:** 15,000 billion barrels (Schollnberger: mid-case—included conventional, heavy, very heavy, and NGLs; not including oil shales)
- **Gas:** 50,000 trillion cubic feet (Schollnberger: mid-case—includes conventional, tight gas, and coal-bed methane; not including gas hydrates)

1 Rogner, H-H., Annual Review – Energy Environment 22:217–62: Institute for Integrated Energy Systems, University of Victoria, 1997.

2 Schollnberger, W.E., 1998b, Projections of the world's hydrocarbon resources and reserve depletion in the 21st century: Houston Geological Society Bulletin, November, p. 31-37.

While these volumes can only be estimated within wide ranges, they indicate the fossil hydrocarbon endowment is large compared to past produced volumes and current reserve estimates. However, only a fraction of the total hydrocarbon endowment can ever be technically converted into recoverable resources and producible reserves. While continuing technical advances are likely to increase this fraction as they have in the past, economic, political, and environmental factors will be important in determining the likely size of the recoverable resource base.

Resources and Reserves

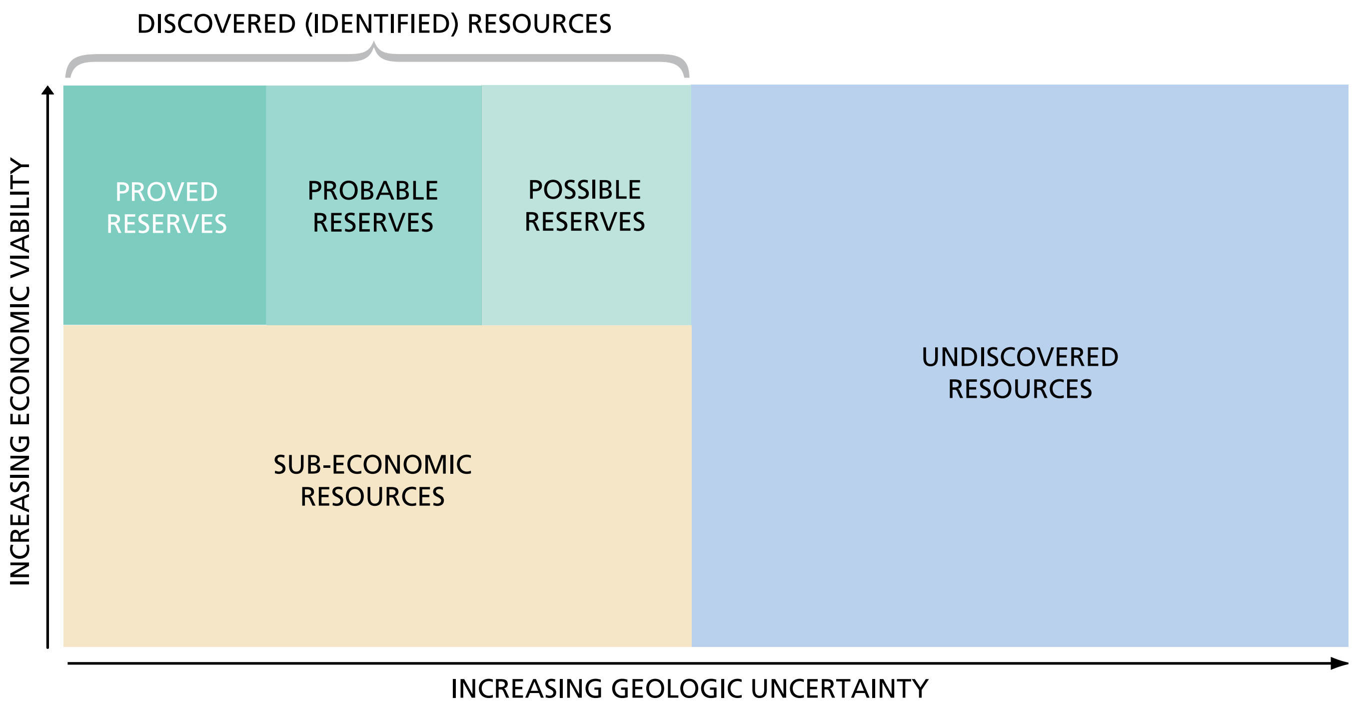
Resources and reserves are the strategically important elements of the hydrocarbon endowment remaining to be produced. Figure 2-5 shows various classifications of reserves and resources.

- **Resources** are those quantities of the endowment estimated, as of a given date, to be potentially recoverable from known or undiscovered accumulations. Resources are not considered commercial at the time of estimation.
- **Reserves** are those estimated quantities of the endowment anticipated to be commercially recoverable from known accumulations from a given date forward. Reserves must satisfy four criteria: they must be *discovered*, *recoverable*, *commercial*, and *remaining* based on the development technologies currently applied.

Reserves and Total Resource Growth

Growth in estimated reserves or resources occurs in almost all hydrocarbon systems in the world. Many analysts consider it to be the most important source for potential additional reserves in mature petroleum regions such as the United States. Many factors can increase the estimated ultimate recovery from known accumulations, including improved: (1) data as a field matures, (2) recovery techniques, (3) imaging for well placement, and (4) completion efficiency. Additions to reserves from growth are volumetrically significant, as most additions to world reserves in recent years are from growth of reserves in known accumulations rather than new discoveries.

The importance of reserves growth to estimating available future oil is the subject of considerable debate. One challenge stems from the fact that not all countries report reserves in the same way. For example, the percentage and rate of conversion of



Source: McKelvey, V.E., "Mineral Resource Estimates and Public Policy," *American Scientist*, 1972.

FIGURE 2-5. *Example of a McKelvey Diagram, Used to Illustrate the Technical Distinction Between Resources and Reserves*

reserves, and, therefore, the predicted amount of field growth, depends significantly on the reference point. In some cases, the reference point is proved reserves (often referred to as P1). In other cases, the basis is proved plus probable reserves (P1 + P2). The different reference points yield different results for reserves growth.

Oil fields today are also generally smaller and developed more quickly, completely, and with better technology than in the past. This situation raises the possibility that the growth patterns of older fields may no longer be reliable predictors for new development and estimates of future oil.

Undiscovered Resources

Undiscovered resources consist of potential recovery from accumulations that are postulated to exist on the basis of geologic knowledge and theory. There are many aspects of resource endowment that must be present for hydrocarbons to form and be preserved. In a comprehensive resource assessment, each of these aspects is examined and measured, but a great deal about these aspects remain uncertain. Examination of *known accumulations*, together with an analysis of how many have already been discovered in a hydrocarbon province, are used to project numbers and sizes of those which may remain to be discovered. The larger and more obvious potential accumulations are generally drilled first, and usually the largest discoveries are made early in the life of a basin.

Table 2-1 shows the USGS 2000 reserve and resource assessment for conventional oil and gas. Between the reference date of that study (1/1/96) and the end of 2005, approximately 275 billion barrels of conventional oil have been produced. Uncertainty around future additions from growth and undiscovered volumes provides a range of about 2 trillion barrels between low and high estimates.

Conventional and Unconventional Reserves and Resources

Until the 1990s, virtually all estimates of the global oil and gas endowment focused on *conventional* reserves and resources, defined as oils, NGLs, and gas expected to be economically produced using conventional technology and distributed in nature as discrete

	P95	Mean	P5
Oil & Natural Gas Liquids (Billion Barrels)			
Undiscovered and Reserves Growth	776	1,669	2,767
Cumulative and Remaining Reserves		1,676	
	2,452	**3,345**	**4,443**
Natural Gas (Trillion Cubic Feet)			
Undiscovered and Reserves Growth	4,096	8,856	14,770
Cumulative and Remaining Reserves		6,545	
	10,641	**15,401**	**21,315**

Note: P95 refers to a 95 percent probability that the resource size will exceed the estimate, while P5 indicates a 5 percent probability that the resource size exceeds the estimate—thus P95 represents the low end of an assessment and P5 the high end. USGS provides a range of outcomes for reserves growth and undiscovered resources. No range is provided for cumulative production and proved reserves.

Source: United States Geological Survey, 2000.

TABLE 2-1. *Global Resource Estimates for Conventional Oil and Natural Gas*

accumulations. More recent estimates of the endowment include significant additional potential from *unconventional* resources.

In most contemporary definitions, the primary differences between conventional and unconventional petroleum liquids are API gravity and viscosity, i.e., the density of the liquid and how easily it flows. For natural gas, the primary delimiter is the reservoir in which the accumulation is located. Viscosity is the basis of the following definitions:

- **Conventional Oil:** Petroleum found in liquid form (with gravity of greater than 20°API) flowing naturally or capable of being pumped at reservoir conditions without further processing or dilution.
- **Unconventional Oil:** Heavy oil, very heavy oil, oil sands, and tar sands (bitumen) are all currently considered unconventional oil resources. These compounds have a high viscosity, flow very slowly (if at all) and require processing or dilution to be produced through a well bore.
- **Continuous Resources:** The USGS uses the term *continuous resources* to define those resources that may be economically produced but are not found in conventional reservoirs. Continuous accumulations are petroleum accumulations (oil or gas) that have large spatial dimensions and indistinctly defined boundaries, and which exist more or less independently of the water column. Because they may cover hundreds, or even thousands, of square miles, continuous accumulations may occur across a wide range of stratigraphic environments, each of which may have widely varying reservoir properties. Or they may exist in their source rock, never having migrated into a carrier bed or reservoir.

Table 2-2 provides global resource estimates for various types of unconventional oil and gas.

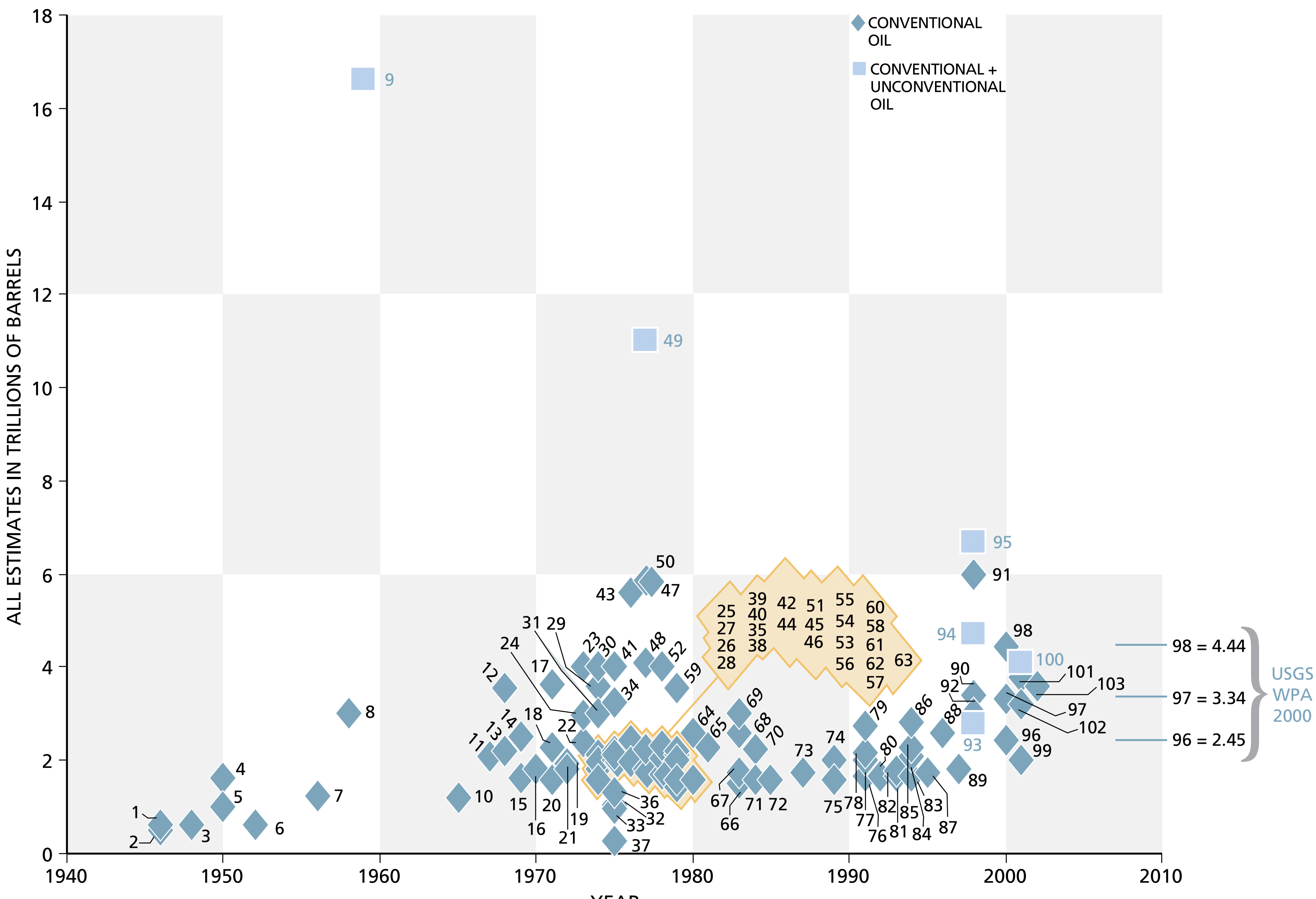
Previous Estimates—Results, Methodology, Differences, and Challenges

Many organizations conduct endowment and resource estimates, for a variety of purposes and with varying methodologies. Figures 2-6 and 2-7 show various global conventional oil and gas endowment estimates plotted against the date of the assessment. Most estimates before 1958 were relatively low, smaller than 2 trillion barrels of oil. Since 1958, both the number and range of estimates have grown.

	Heavy Crude Oil	Tar Sands (Bitumen)	Coalbed Methane	Tight Gas
Oil (Billion Barrels)	761	794		
Natural Gas (Trillion Cubic Feet)			8,225	4,024

Sources: Oil – BGR (Bundesanstalt für Geowissenschaften und Rohstoffe [Federal Institute for Geosciences and Natural Resources]) *Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen [Availability of Energy Reserves and Resources 1998]*, Germany, 1998. Natural Gas – Rogner, H-H., "World Energy Assessment – Energy and the Challenge of Sustainability," United Nations Development Programme, 2000.

TABLE 2-2. *Global Resource Estimates for Unconventional Oil and Natural Gas*



Source: Ahlbrandt, Thomas S., and Klett, T.R., "Comparison of methods used to estimate conventional undiscovered petroleum resources: World examples," *Natural Resources Research*, 2005.

FIGURE 2-6. *World Oil Resource Estimates, 1940 – Present*

Source: Ahlbrandt, Thomas S., and Klett, T.R., "Comparison of methods used to estimate conventional undiscovered petroleum resources: World examples," *Natural Resources Research*, 2005.

FIGURE 2-7. *World Natural Gas Resource Estimates, 1950 – Present*

Legend for Figure 2-6

Conventional Oil/Conventional + Unconventional Oil References

1	Duce
2	Pogue
3	Weeks
4	Levorsen (and up)
5	Weeks
6	Pratt
7	Hubbert
8	Weeks
9	Weeks
10	Weeks
11	Ryman
12	Weeks (H)
13	Weeks (L)
14	Hubbert (H)
15	Hubbert (L)
16	Moody
17	Weeks (H)
18	Weeks (L)
19	Bauquis
20	Warman
21	Warman
22	Hubbert
23	Odell
24	Schweinfurth
25	Hubbert (H)
26	Hubbert (L)
27	Kirkby, Adams (H)
28	Kirkby, Adams (L)
29	Parent, Linden
30	Parent, Linden (H)
31	Parent, Linden (L)
32	MacKay, North (H)
33	MacKay, North (L)
34	Moody, Esser (H)
35	Moody, Esser
36	Moody, Esser (L)
37	Moody, Geiger
38	Moody, Geiger
39	Moody, Geiger
40	National Academy of Science
41	Odell and Rosing
42	Barthel, BGR
43	Grossling (H)
44	Grossling (L)
45	Folinsbee
46	Klemme
47	Seidl, IIASA (H)
48	Seidl, IIASA (L)
49	Styrikovich
50	Styrikovich
51	World Energy Conference
52	IFP (4 estimates >4 TBO)
53	Klemme
54	Moody
55	Nehring (H)
56	Nehring (L)
57	Halbouty
58	Halbouty
59	Halbouty
60	Meyerhoff
61	Nehring (H)
62	Nehring (L)
63	De Bruyne
64	World Energy Conference
65	Halbouty
66	Masters
67	Masters
68	Masters
69	Odell and Rosing
70	Masters (H)
71	Masters (L)
72	Martin
73	Masters
74	Bookout
75	Campbell
76	Campbell
77	Masters
78	Masters
79	Masters
80	Campbell
81	Campbell
82	Laherrere
83	Campbell
84	Masters
85	Masters
86	Masters
87	Campbell
88	MacKenzie
89	Campbell
90	BP
91	Odell (H)
92	Odell L)
93	Schollnberger
94	Schollnberger
95	Schollnberger
96	USGS
97	USGS
98	USGS
99	Deffeyes
100	SHELL
101	SHELL (H)
102	SHELL (L)
103	Edwards

Legend for Figure 2-7

Convential Gas/Conventional + Unconventional Gas References

1	MacKinney
2	Weeks (H)
3	Weeks (L)
4	Weeks
5	MacKinney
6	Weeks
7	Ryman
8	SHELL
9	MacKinney
10	Weeks
11	Hubbert (H)
12	Hubbert (L)
13	Weeks
14	Hubbert
15	Parent, Linden (and up)
16	Adams and Kirkby (H)
17	Moody, Geiger
18	National Academy of Science
19	Barthel, BGR (and up)
20	Grossling (H)
21	Grossling (L)
22	International Gas Union
23	Parent, Linden (H) (and up)
24	Parent, Linden (L)
25	Desprairies (H)
26	Desprairies (L)
27	McCormick, AGA
28	Bois
29	Meyerhoff
30	Nehring (H)
31	Nehring (L)
32	Parent, Linden (H) (and up)
33	Parent, Linden (L)
34	Schubert
35	World Energy Conference
36	Masters
37	Masters
38	Masters
39	Masters
40	Masters
41	Masters
42	Masters
43	Riva
44	Schollnberger
45	Schollnberger
46	Schollnberger
47	USGS
48	USGS
49	USGS
50	CEDIGAZ (H)
51	CEDIGAZ (L)
52	SHELL
53	SHELL
54	BGR

Resource estimates as seen in Figures 2-6 and 2-7 are snapshots in time. They represent only what has been assessed: particular parts of the world (basins, plays, regions, or countries); specific commodities (oil, natural gas, conventional, unconventional); and data available at the time. Assessing additional types of resources or additional parts of the world can greatly change the estimates. Resource estimates are one basis of forecasting. Other important factors and risks can also significantly shape forecasted production profiles over time.

Finally, comprehensive assessments built from global, detailed geological studies are very limited. While the USGS survey of resources in 2000 is the most comprehensive U.S. agency assessment and the basis of many forecasts, the strategic importance of endowment and resource estimates emphasize the ongoing need for comprehensive, up-to-date data. For a detailed discussion of the hydrocarbon resource endowment, see the Endowment Topic Paper on the CD included with the report.

Primary Energy Mix

Energy forecasts generally show that fossil fuels will dominate the total energy mix, although their share may decline from today's 85 percent to slightly more than 75 percent in 2030. In several forecasts, gas and coal are expected to increase their share. Oil's share of the total primary energy mix is generally forecast to decrease, even as absolute oil volumes grow, principally for transportation use. While renewable energy, gas-to-liquids, coal-to-liquids, and coal-to-gas grow rapidly from a low base, they remain a smaller share of the energy mix in 2030. In any case, the enormous scale of global energy means that a prospective 10 percent decline in fossil fuel share will require a major reallocation of investment, infrastructure, and technical effort.

Historical Energy Consumption

Figure 2-8 shows that global primary energy consumption has grown just over 2 percent per year since 1980. U.S. primary energy consumption has grown just over 1 percent per year since 1980, as shown in Figure 2-9. Most demand forecasts include historical energy mix and consumption patterns as inputs to their projections.

Projected Energy Consumption

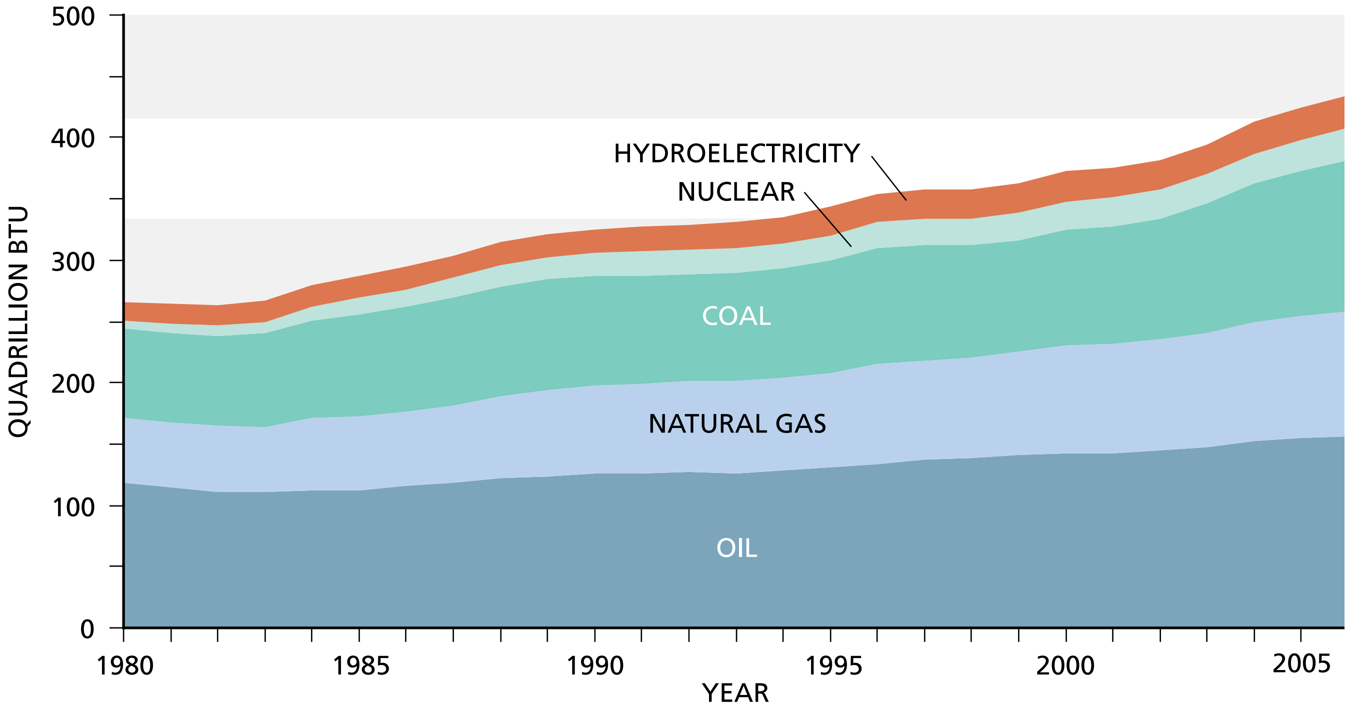
Energy forecasts are typically based on macro-economic inputs and historical factors that drive global energy consumption. Reference Cases generally use business-as-usual assumptions that do not consider (1) potential global supply disruptions resulting from geopolitical events, (2) technology breakthroughs that could substantially enhance supply or reduce demand, and (3) significant shifts in energy policies. In addition, most outlooks make separate forecasts for various scenarios that would materially change outcomes, such as carbon constraints or significant price changes. The Energy Demand chapter of this report provides an extensive discussion of demand outlooks that supplements the summary in this section.

Fossil fuels are projected to dominate the total global energy mix, contributing approximately 75 percent of global energy supplies in 2030 compared with some 85 percent today (Figure 2-10). Most business-as-usual outlooks show that total energy demand in 2030 will be 40 to 70 percent higher than the 2005 level of 425 quadrillion Btu. These forecasts assume the global fossil energy system will provide supply and infrastructure required to meet the increased demand.

Outlooks that assume no further restrictions on carbon dioxide emissions generally do not include significant carbon capture and sequestration (CCS). These forecasts show a significant increase in global carbon dioxide emissions by 2030. In the case of carbon-constrained energy use, projected reduction in carbon dioxide emissions is achieved through reduced energy consumption, fuel switching, and carbon capture and sequestration.

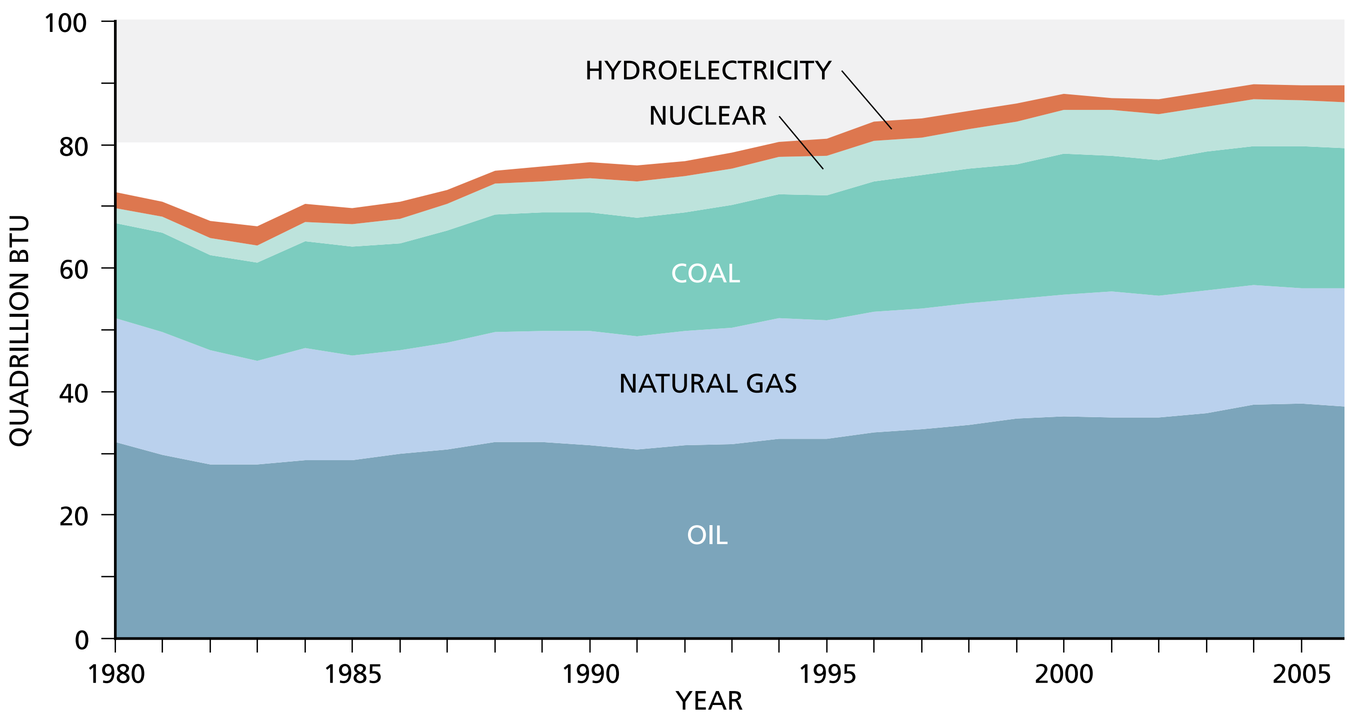
Gas and coal are generally expected to increase their share of the total primary energy mix, while the oil share continues to decrease even as oil volumes in most cases continue to grow. Figure 2-11 projects four EIA and IEA cases for global energy consumption to 2030. Crude oil continues its trend towards becoming primarily a source of transportation fuels. Renewable energy, as well as gas-to-liquids, coal-to-liquids, and coal-to-gas grow rapidly from a low base, but their shares of the total mix remain relatively small.

Carbon constraints without nuclear energy and CCS increase the demand for natural gas. However, in some carbon-constrained cases, nuclear power increases substantially as a share of total energy, although it remains flat in reference forecasts. The biomass share of total energy expands dramatically in several constrained cases, with the biggest impacts occurring after 2030.



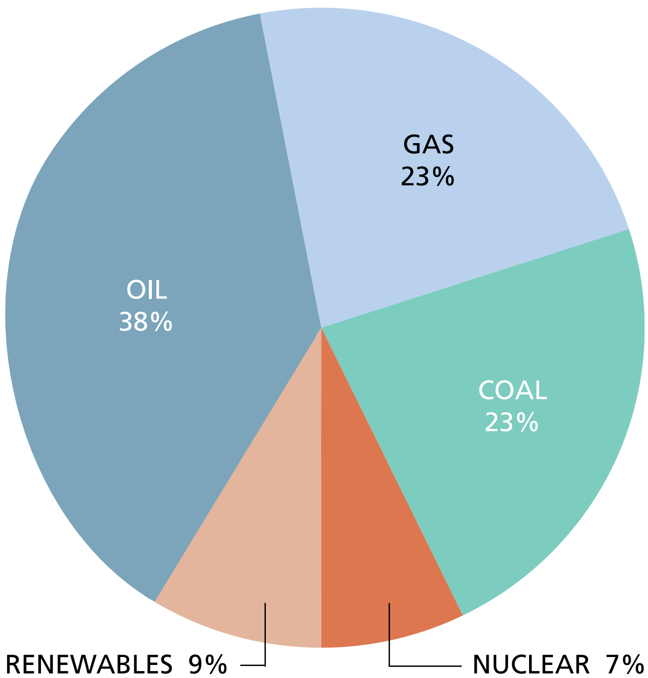
Source: *BP Statistical Review of World Energy 2007.*

FIGURE 2-8. *Global Primary Energy Consumption, 1980-2006*



Source: *BP Statistical Review of World Energy 2007.*

FIGURE 2-9. *U.S. Primary Energy Consumption, 1980-2006*



Source: International Energy Agency, *World Energy Outlook 2006.*

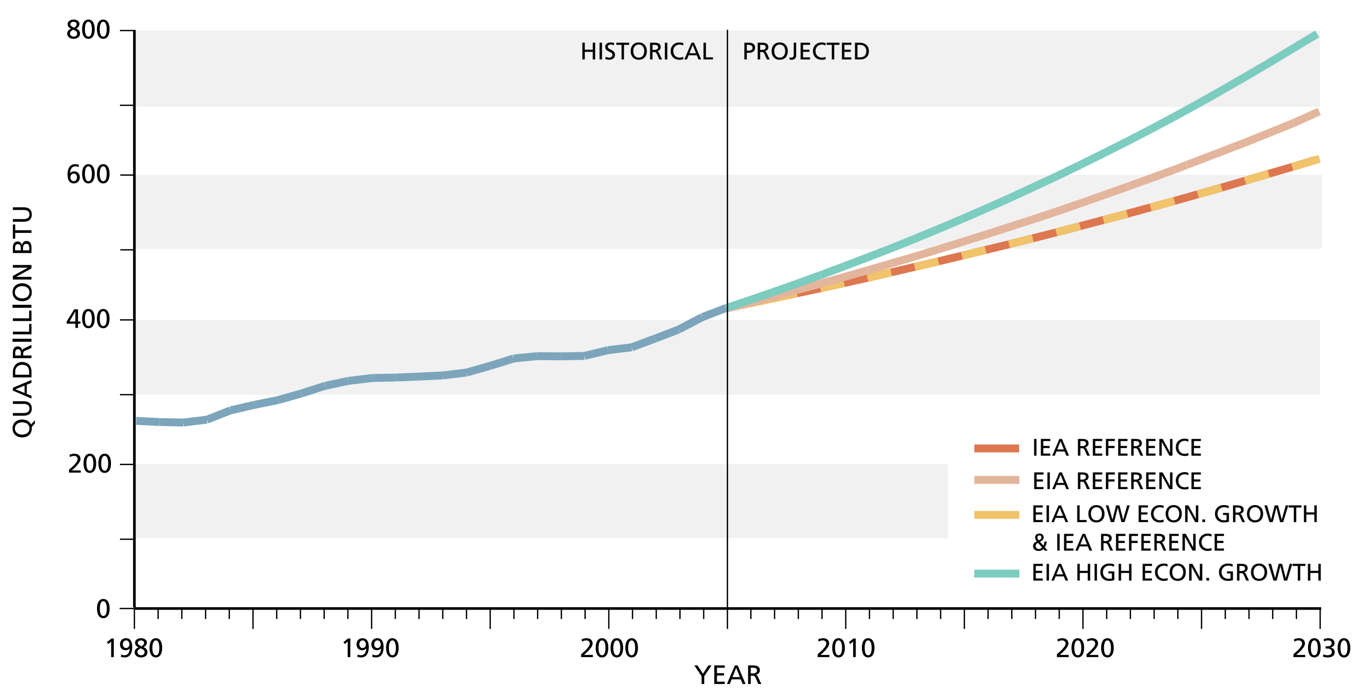
FIGURE 2-10. *Global Energy Consumption Shares in 2005*

Oil and Natural Gas Supply

Oil

Total energy supply forecasts are wide-ranging, based largely on variations in oil demand outlooks and differing views on the deliverability of oil. Some views of future oil production consider lower limits on the available recoverable oil resource while others extrapolate historical successes in expanding the recoverable resource base. Current endowment and resource assessments for both oil and gas indicate large in-place volumes and development potential. The gas resource base is more than adequate to meet the increased gas production typically anticipated by energy outlooks over the study period. However, this will require replacing 50 percent of existing gas reserves by 2030.

There is more uncertainty about the capacity of the oil resource base to sustain growing production rates. The uncertainty is based on (1) the rate and timing at which significant quantities of unconventional oil enter the supply mix, and (2) the ability of the oil industry to overcome growing supply-development risks.



Sources: International Energy Agency (IEA) *World Energy Outlook 2006;* and Energy Information Administration (EIA) *International Energy Outlook 2006.*

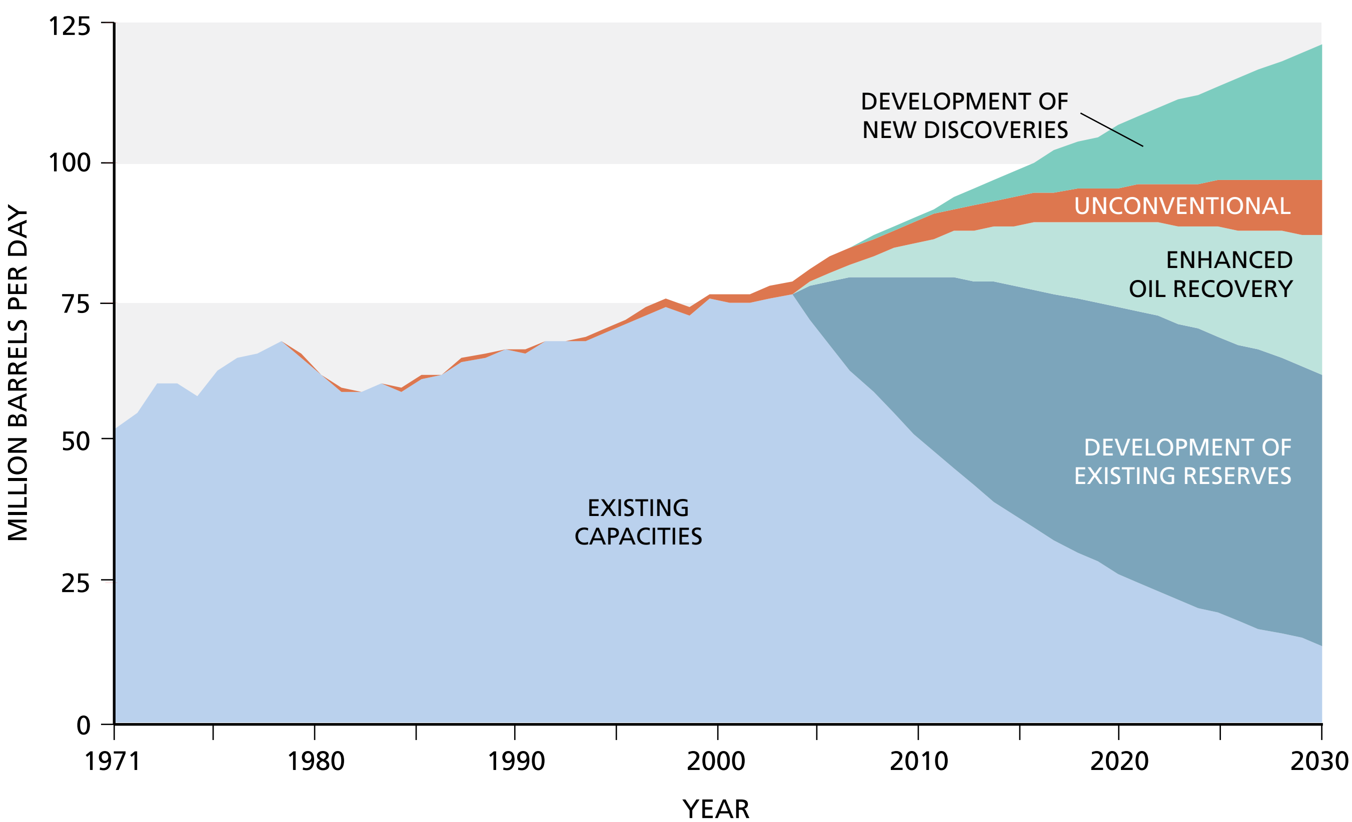
FIGURE 2-11. *Projected Global Energy Consumption*

The finite nature of the oil endowment and the prospect that production will reach a peak and eventually decline contribute to the debate about oil supply. The timing of the decline is subject to interpretation because:

- The underlying decline rate in currently producing fields is not universally well-reported. Many observers think that 80 percent of existing oil production will need to be replaced by 2030—in addition to the volumes required to meet growing demand. Figure 2-12 is an illustrative example showing various components of total liquids supply as depicted in the IEA World Energy Outlook 2004. Resource components such as existing production capacity, booked reserves, enhanced oil recovery, etc., contribute to virtually all projections of liquids supply, although the combination and timing of components may differ.
- Opinions differ about the world's estimated ultimately recoverable oil resource and whether fields can continue to increase production if more than half of today's estimated ultimately recoverable resources (URR) has already been produced.
- The increased cost of producing oil (both conventional and unconventional including alternative liquids) raises concerns about the timing and scale of major energy development.
- Timing of development for alternative liquid supplies at scale is uncertain.

Supply outlooks reflect uncertainty about oil supplies, at least partly based on recent difficulties in increasing production. Forecast global liquids production in 2030 ranges from less than 80 million to 120 million barrels per day, compared with current daily production of approximately 84 million barrels.

Conventional oil is forecast to contribute the largest share of global liquid supply, principally through increased production in Saudi Arabia, Russia, Venezuela, Iran, and Iraq. Unconventional oil such as Canadian and Venezuelan heavy oil and U.S. oil shale is also



Source: IEA, *World Energy Outlook 2004*.

FIGURE 2-12. *Illustrative Total Liquids Supply* likely to play a growing role in liquids supply. However, most forecasts project that unconventional oil, together with coal-to-liquids (CTL) and gas-to-liquids (GTL), is unlikely to exceed 10 million barrels per day globally by 2030.

Natural Gas

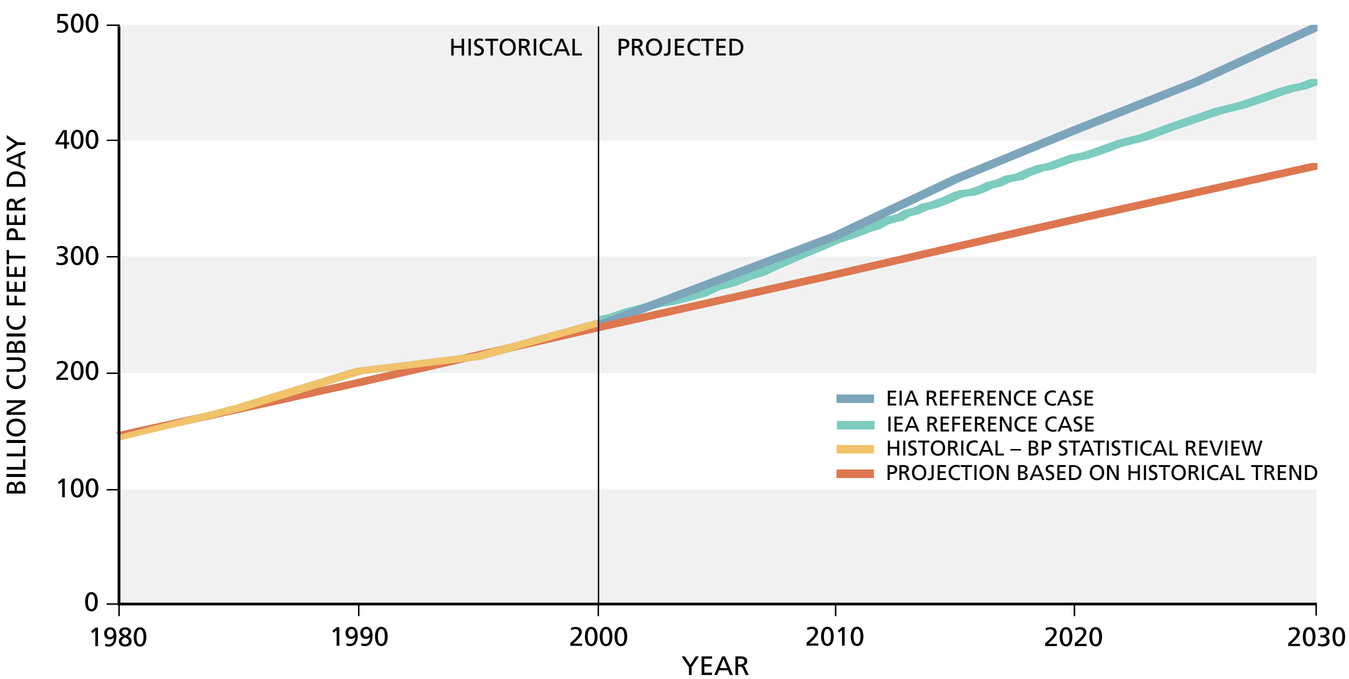
Most outlooks project that natural gas production to 2030 will grow faster than it has historically, ranging from 400 billion to 500 billion cubic feet per day. The EIA high-production cases, for example, are at the upper end of the range, with a projected doubling of production from today's 250+ billion cubic feet per day. Figure 2-13 shows the EIA and IEA projections for natural gas production.

While there is some concern about the gas resource base relative to projected demand growth, most outlooks consider it more than adequate to meet demand. However, nearly two-thirds of natural gas resources are concentrated in four countries, Russia, Qatar, Iran, and Saudi Arabia, which are projected to show the biggest growth in production. Since these countries are relatively distant from likely consuming regions, global gas supply chains will be needed to connect producers and markets—similar to the trading system that has been developed over decades for oil. In North America, major new additions to gas resources are possible, given expansion of unconventional U.S. gas production and development of infrastructure to transport Arctic gas. Generally, production growth in resource-owning countries, creation of a global gas supply chain, and very large infrastructure investments are all elements of risk in matching projected gas supply to demand.

Coal

The global coal endowment is considerably larger than either the oil or gas endowment, with only a small portion of the resource base having been produced to date. The United States, Russia, China, India, and Australia hold over three quarters of the world's proved coal reserves. As other fossil fuels become relatively more costly or difficult to secure, these large resource owners may increase domestic coal production and use. However, the same constraints that apply to other resources may also apply to coal development globally and in the United States:

- Environmental constraints including carbon management, water use, land use, and waste disposal.



Sources: Energy Information Administration (EIA), *International Energy Outlook 2006;* International Energy Agency (IEA), *World Energy Outlook 2006;* and *BP Statistical Review of World Energy 2006.*

FIGURE 2-13. *Projected Global Natural Gas Production*

- Limits on transport and delivery infrastructure development within local markets.

These environmental and infrastructure limitations are potentially more severe for coal than for other conventional fossil fuels.

Business-as-usual energy outlooks, without significant environmental constraints, generally show a 50 to 60 percent increase in global coal production between 2005 and 2030. Most coal production growth will occur in rapidly expanding Asian economies, with China and India accounting for nearly 80 percent of the annual increment. Figure 2-14 shows projected growth in coal production in business-as-usual cases without carbon constraints.

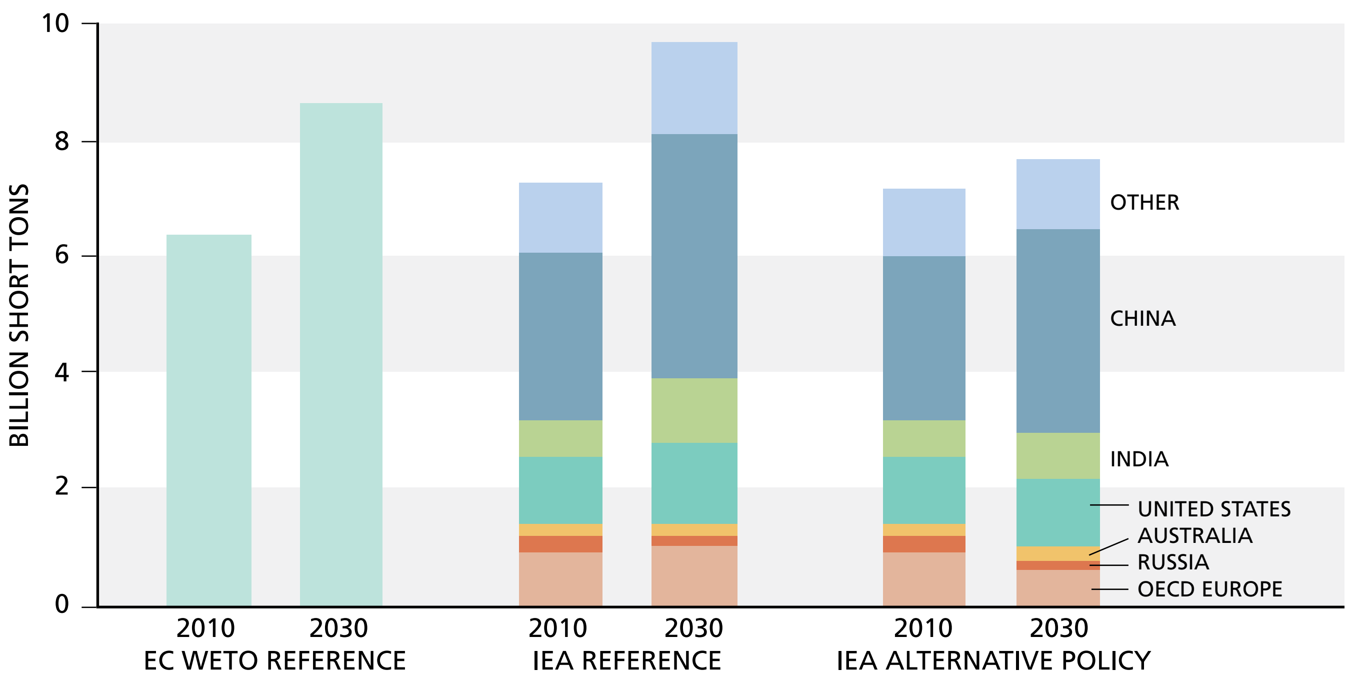
In alternative policy/carbon constrained cases that do not consider carbon CCS, coal production is generally flat-to-declining from today's levels, as energy demand is met by fuels with a lower carbon impact. Where CCS is considered, the balance between growth in natural gas demand, biomass energy sources, and coal provides for growth in coal production and use.

Most technology development for new uses of coal, such as coal-to-liquids and CCS, addresses the technical, environmental, and economic barriers to increasing coal use. The delivery infrastructure needed for expanding coal use appears to receive less attention.

Biomass

Biomass refers to wood, cultivated crops, or natural vegetation that potentially can be converted to energy. As with coal, biomass is an abundant, indigenous resource for the United States and some other major centers of energy demand. Accordingly, biomass could be seen as an important option to reduce risks related to supply security. First-generation biomass conversion to fuels has been based on crops such as sugarcane, corn, and soybeans, which are also food sources, giving rise to concerns about crop competition among food, animal feed, and fuel use. Second-generation conversion technologies such as cellulosic ethanol seek to address these concerns by using plant waste as a feedstock. See the Biomass section later in this chapter for a discussion of potential sources of biomass energy.

Numerous studies have assessed the potential of agriculture to produce both energy and food for the



Sources: European Commission, *World Energy Technology Outlook 2050* (EC WETO), 2006; and International Energy Agency (IEA), *World Energy Outlook 2006.*

FIGURE 2-14. *Projected Growth in Global Coal Production without Carbon Constraints, 2010 to 2030* world. While conclusions vary, most estimate that 250 to 500 exajoules (approximately 238 to 476 quadrillion Btu) of biomass energy could be produced while still feeding a growing global population. These estimates represent a potentially substantial contribution to a 2030 global energy demand projected at about 740 exajoules, or 702 quadrillion Btu, in the EIA *International Energy Outlook 2007* (IEO 2007) Reference Case. Meeting both food and large-scale fuel demand would require successfully developing and deploying second-generation crop production and conversion technology. Most business-as-usual forecasts (EIA, IEA, European Commission, and aggregated proprietary outlooks) suggest that biomass will meet 5 to 10 percent of total energy demand in 2030, comprising less than 5 million barrels per day of total global liquids production. Other forecasts that are not business as usual show substantially higher biofuels production.

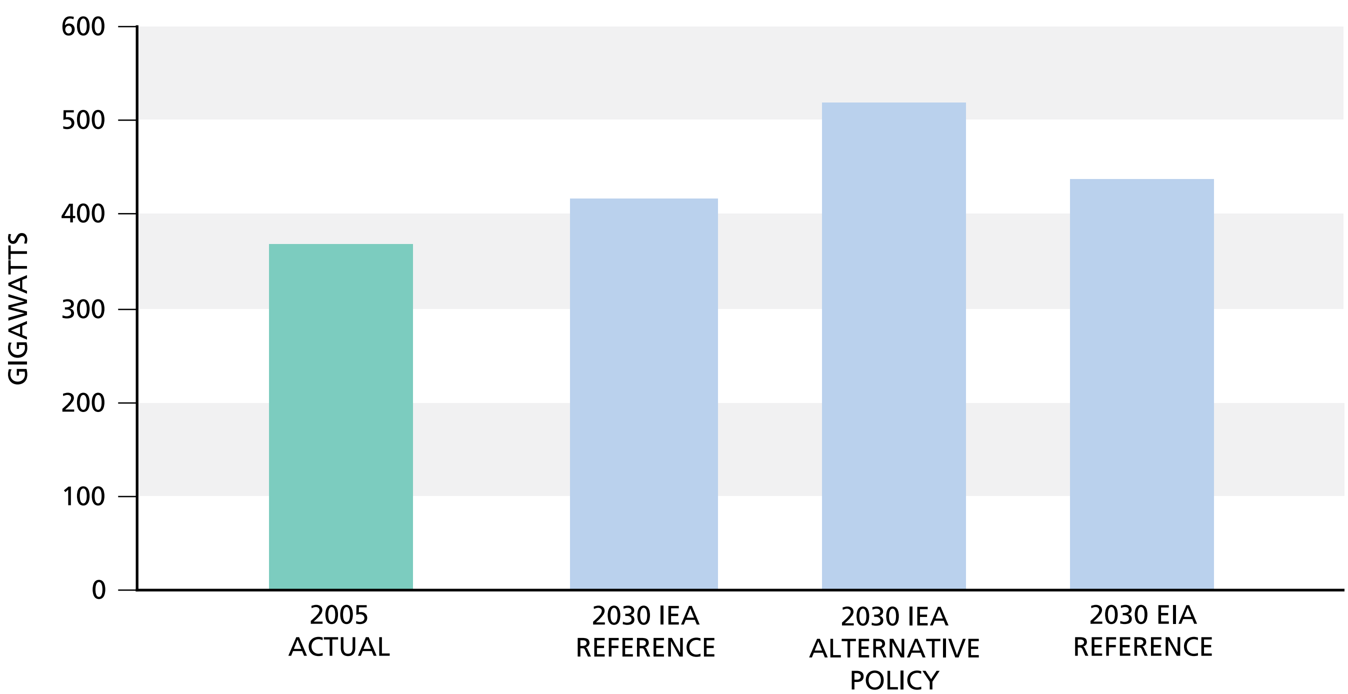
As with any large-scale energy source, technical, logistical, and market requirements will need to be met for biofuels to achieve their potential. Milestones along this development path will include: investments in rail, waterway, and pipeline transportation; scale-up of ethanol distribution; and technology deployment for cellulosic ethanol conversion. The time frames required in many cases to move technology from concept to full-scale application may make such sources available only later in the outlook period. For a detailed discussion of biomass, see the Biomass Topic Paper on the CD included with the report.

Nuclear

Nuclear power faces unique controversy based on concerns about safety, security, and management of the nuclear fuel and waste cycle. In addition, the capital intensity of nuclear generation increases the risk profile for investors. Accordingly, nuclear power's current 5 to 6 percent of the total energy mix is not projected to increase over the study timeframe, unless nuclear generation is promoted for policy objectives such as limiting carbon dioxide emissions or enhancing energy security. Figure 2-15 shows projected global growth in the installed nuclear power base.

Non-Bio Renewables

Hydroelectric generation has historically been the dominant non-bio source of renewable energy, providing vast amounts of electricity at very low marginal



Sources: Energy Information Administration (EIA), *International Energy Outlook 2006;* and International Energy Agency (IEA), *World Energy Outlook 2006.*

FIGURE 2-15. *Projected Global Installed Nuclear Power Base* cost of production. Most hydroelectric resources have been tapped in industrialized nations, while there may be limited additional opportunities in industrializing and economically developing nations. Wind and solar energy, which have shown significant growth in recent decades, are forecasted to grow several times faster than overall energy demand, starting at their current base of less than 2 percent of global energy supply. Geothermal presents more limited opportunities for new supplies and is not expected to outpace global energy supply growth.

Non-bio alternative and renewable energy sources require unique technologies that tap natural energy flows in different ways. Collectively, however, they have several common characteristics, in addition to mainly producing power rather than fuels: (1) high initial capital costs of construction or fabrication and installation; (2) low operating costs and minimal fuel or feedstock expenses; and (3) possible economies of scale that have not been fully developed. Some of these technologies require energy storage solutions to offset highly variable power production rates. As costs have risen for developing and converting fossil resources to power and fuel, non-fossil options have become more economically competitive and attractive for their potential renewable and environmental benefits. However, large-scale development of these energy options raises concerns about their potential ecological impacts.

Most forecasts of future energy supplies suggest that the total contribution from new renewable and alternative energy sources will remain small for the next two decades since they start from a relatively small base. Although the potential contribution of solar and wind power, waves, tides, and geothermal energy is vast, the economic cost of harnessing most of these sources at scale has been high, relative to other sources such as fossil fuels, hydro, and nuclear. However, the cost differential continues to decline. As with any energy source, resolution of ecological, technical, and commercial issues will favor some technologies rather than others.

Energy Conversion and Delivery Infrastructure

Finding and developing resources are two steps in the energy supply chain. Converting the resources to usable products and delivering them to consumers are equally essential steps that rely heavily on conversion, storage, and transportation infrastructure. However, the total requirements for new infrastructure to 2030 are difficult to assess with any certainty, since energy outlooks generally do not directly account for infrastructure development.

Energy outlooks typically assume supply infrastructure for any energy source will be built if it is economically viable, without regard to potential constraints on financing, permitting, and building. In addition to these potential constraints, the United States faces the issue of maintaining its refining and manufacturing capability, a contentious problem familiar in other industrial sectors. New energy sources will add their own infrastructure demands. Finally, much of the projected increase in global oil and gas trade is likely to move through narrow sea lanes, raising a security challenge for this part of the transportation system. Taken together, infrastructure issues add additional, often unrecognized, risks to prospective energy supply.

ANALYSIS OF ENERGY OUTLOOKS

Oil and Other Liquids

Key Observations—Oil and Other Liquids

- *While crude oil will remain a primary energy source throughout the study time frame and beyond, the capacity of the production and delivery system to increase supply is subject to multiple, increasing risks.*
- *The global in-place oil endowment is very large, but the recoverable resource and the rate at which it can be produced are subject to considerable uncertainty. Forecasted oil production rates vary widely: some rely heavily on OPEC to meet rising demand; others on contributions from unconventional oil and alternative liquids; a third set of forecasts project a production plateau or peak.*
- *As production from existing oil fields declines, future oil supply is likely to rely increasingly on:*
  - *Growth from existing accumulations through use of new technology, better knowledge of reservoir characteristics, or enhanced oil recovery*
  - *Production of unconventional resources such as oil sands or oil shale*
  - *Exploration discoveries, many from new frontiers such as the Arctic and ultra-deepwater*
  - *Conventional oil from hydrocarbon provinces where access is currently restricted.*

Alternative liquids such as biofuels, gas-to-liquids, and coal-to-liquids will also contribute materially to fuel supply.

- *U.S. oil production is generally projected to rise modestly, at best, or decline somewhat during the study time frame. With limited growth from conventional oil sources, the ability to meet expected demand growth will rely increasingly on heavier and unconventional domestic supplies, ultra-deepwater basins, and alternative fuels.*[3]

- *Few projections of domestic supply assume changes in access to U.S. onshore and offshore basins currently under drilling moratoria or subject to significant development restrictions. The time required to explore and develop newly released areas means that production from these areas would appear only later in the study time frame.*

- *Oil production growth after 2015 appears subject to increasing risks as both subsurface and above ground issues become more challenging. The risks include:*

  - *Production declines of many of the world's maturing fields*

  - *Increasingly restricted access to resources*

  - *Unprecedented investment requirements under uncertain fiscal regimes.*

  The risk of not meeting forecasted demand over the study time frame also increases dramatically without sustained technology development and the pursuit of all economically viable fossil and alternative liquid fuel sources.

Crude Oil Endowment

Ancient biomass was converted to oil over millions of years as it was exposed to high temperature and high pressure deep in sedimentary layers. Migration of the oil from source rocks into porous formations at accessible depths in the earth's crust creates the opportunity to locate and produce oil from this endowment.

The global conventional and unconventional oil in place endowment has been variously estimated at 13 trillion to 15 trillion barrels. These barrels represent the estimated total volume of liquid hydrocarbons generated and retained in geologic formations over time. Since oil generates very slowly, the current endowment is relatively fixed and is considered a non-renewable resource.

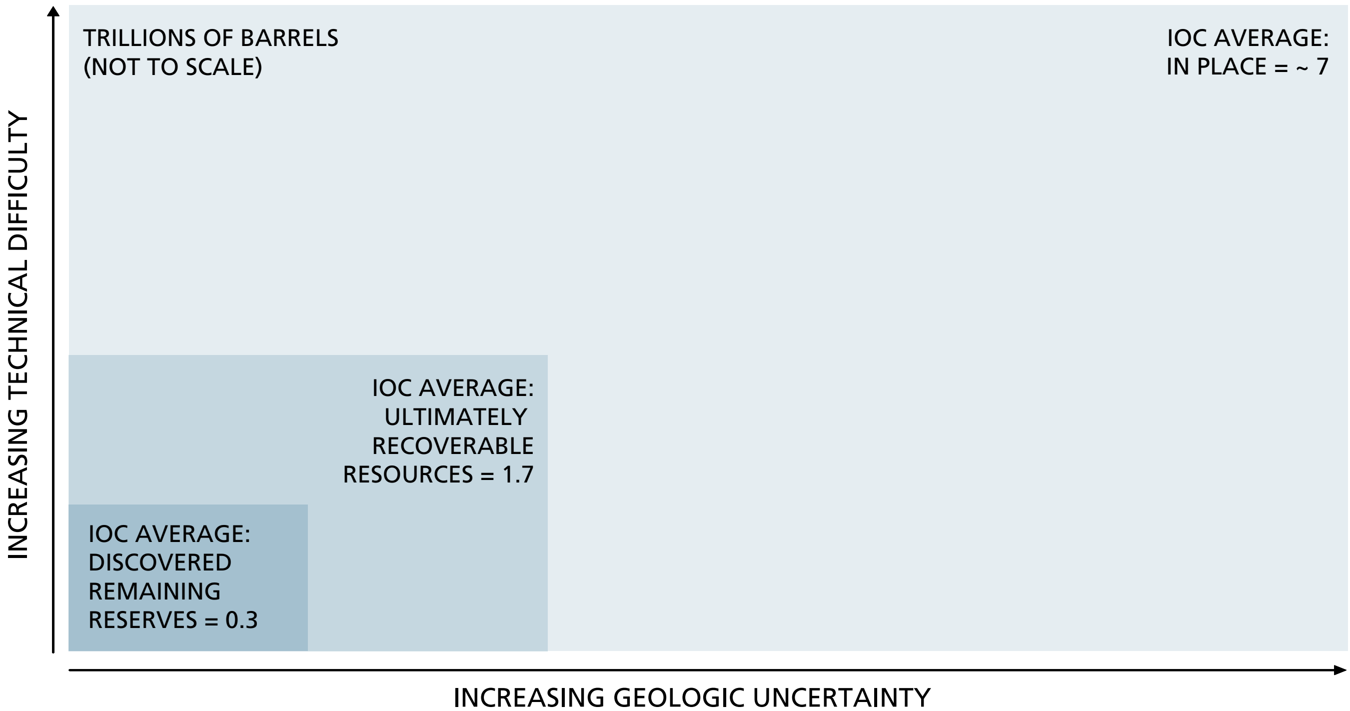
Recoverable resources are the portion of the estimated in-place endowment thought to be technically recoverable from their geologic setting. Recoverable resource assessments have generally grown as new technology, or political and economic factors, made more of the in-place endowment recoverable. Based on geological and geophysical data, these assessments require judgments about finding and development costs, extraction efficiencies, oil prices, and other factors. Generally, about one-third of the oil in place is currently assumed to be ultimately recoverable. This assumption yields an estimated 4.5 trillion barrels or more of conventional and unconventional ultimately recoverable oil.

Unconventional Oil Endowment and Resource Development

The global endowment of unconventional oil in place is large, as much as 7 trillion barrels (Figure 2-16). Recovery factors vary widely but are expected to be lower than for conventional oil due to technical challenges and huge capital requirements associated with extraction. Current public and proprietary assessments of URR are similar: 1.5 trillion barrels estimated by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and an average 1.7 trillion barrels estimated by IOCs. The estimates are uncertain, but likely to grow as new technologies emerge. Development of heavy oil and oil shale has lagged that of conventional oil because it is more expensive and technically difficult to bring liquids on-line from these sources. Nonetheless, unconventional oil will likely play an increasing role in meeting future energy needs.

Unconventional oil has a much different global distribution than conventional oil. Very heavy oil in Venezuela, oil sands in Canada, and oil shale in the United States account for more than 80 percent of unconventional resources, while conventional oil resources are mainly in the Middle East, West Africa, and Russia. Factors that particularly affect unconventional supplies include technology development, environmental impact, geopolitical climate, capital and operating costs, and material and human resource availability. Uncertainty about each of these factors is a major consideration in projecting future energy supply.

3 The U.S. Energy Information Administration defines *conventional production* to include crude oil (including lease condensates), natural gas plant liquids, other hydrogen and hydrocarbons for refinery feedstocks, alcohol and other sources, and refinery gains. *Unconventional production* includes liquids produced from energy crops, natural gas, coal, oil sands, and shale.



Source: NPC Survey of Outlooks.

FIGURE 2-16. *Global Unconventional Oil Endowment*

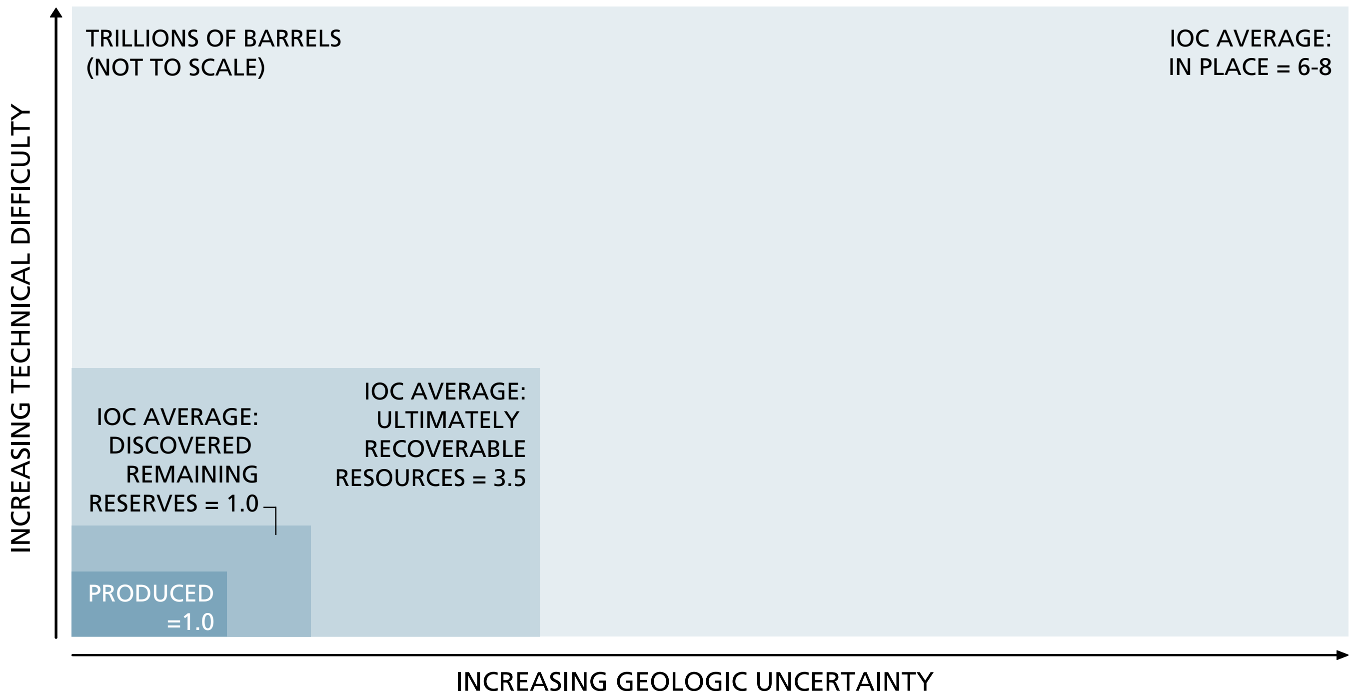
Conventional Oil Endowment and Resource Development

Conventional oil and natural gas liquids have historically received the greatest development attention. The IEA estimates between 6 and 7 trillion barrels of conventional oil and NGL in place, while other estimates are somewhat higher (Figure 2-17). About 1 trillion barrels of the conventional oil endowment have been produced since the late 19th century.

The USGS assessment published in 2000 is one of the few comprehensive, publicly available resource assessments for conventional oil. Many outlooks provided to this study include USGS estimates in their projections after adjusting to reflect newer or proprietary information. For example, EIA will routinely adjust estimated recoverable resources to reflect cumulative production or evolving knowledge that has not been included in USGS assessments.

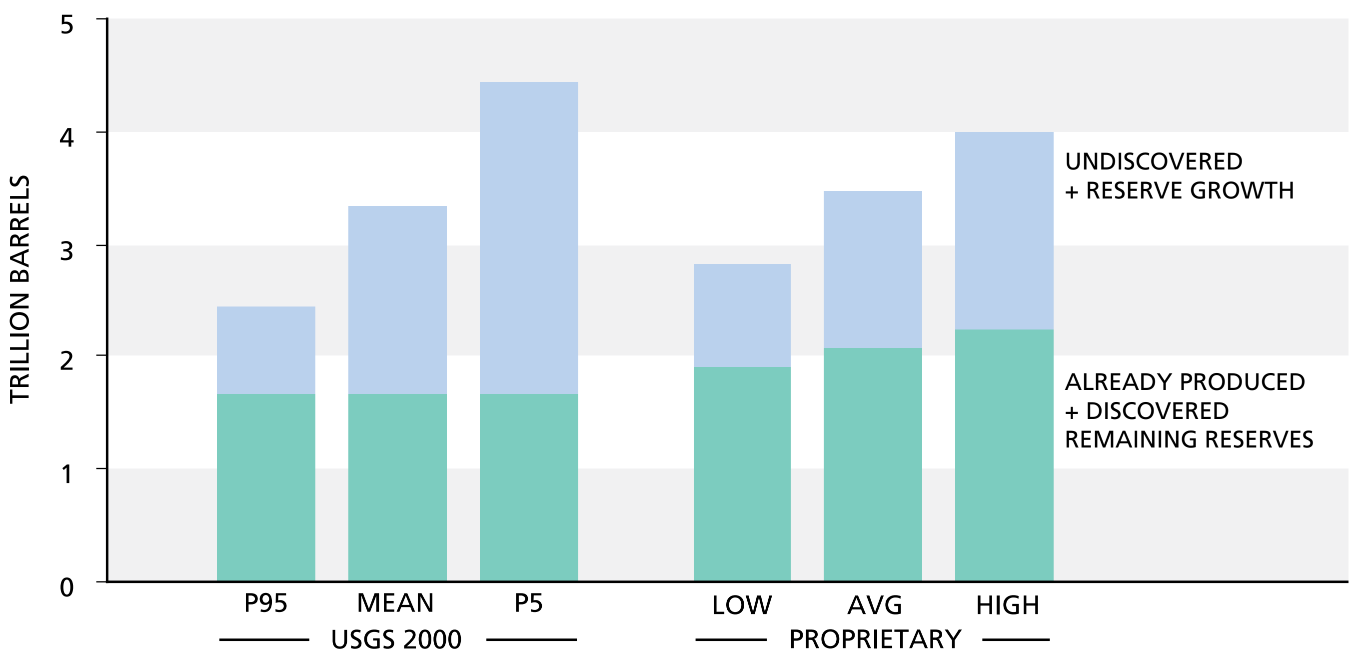
The USGS mean estimate of ultimately recoverable global conventional oil plus NGL is 3.345 trillion barrels at the beginning of 1996. The estimates range from 2.5 to 4.4 trillion barrels, expressed in statistical terms as P95 and P5 estimates, respectively. P95 refers to a 95 percent probability that the resource size will exceed the estimate, P5 indicates a 5 percent probability that the resource size exceeds the estimate. By comparison, IOCs responding to the NPC data survey provided an average projection of 3.5 trillion barrels. The IOC most-likely estimates for ultimately recoverable global conventional oil range from 2.8 to 4.0 trillion barrels. While the USGS and proprietary ranges are statistically different, Figure 2-18 allows approximate comparison.

After taking into account the approximately 1.0 trillion barrels that have been produced to date, the estimated USGS range of remaining, ultimately recoverable global conventional oil and NGL is 1.5 to 3.4 trillion barrels. A higher URR for conventional oil and NGL would sustain oil production growth for a longer time or faster rate, assuming adequate investment and access to the resources. However, the opposite is true if the actual URR is at the lower end of the range. This uncertainty, combined with above-ground risks that could hinder production, fuels the debate about supply outlooks and has a material impact on policy and investment decisions.



Source: NPC Survey of Outlooks.

FIGURE 2-17. *Global Conventional Oil and NGL Endowment*



Note: P95 refers to a 95 percent probability that the resource size will exceed the estimate, while P5 indicates a 5 percent probability that the resource size exceeds the estimate – thus P95 represents the low end of an assessment and P5 the high end.
Source: NPC Survey of Outlooks.

FIGURE 2-18. *Conventional Global Oil and NGL Ultimately Recoverable Resource Estimates*

Reserve Growth and *Undiscovered Resources* are two categories of the USGS 2000 assessment with greatest uncertainty. Reserve Growth refers to the increase in reserves in oilfields. Reserve Growth typically occurs through improved knowledge about the field's productive potential and application of new technology. Reserve Growth accounted for 0.7 trillion barrels of the USGS mean estimated URR at the beginning of 1996. Growth in fields discovered before 1995 added about 65 percent of this volume to proved reserves from 1995 to 2004.[4] Reserve Growth often requires significant additional capital and energy input, especially as recovery factors are increased through enhanced recovery processes.

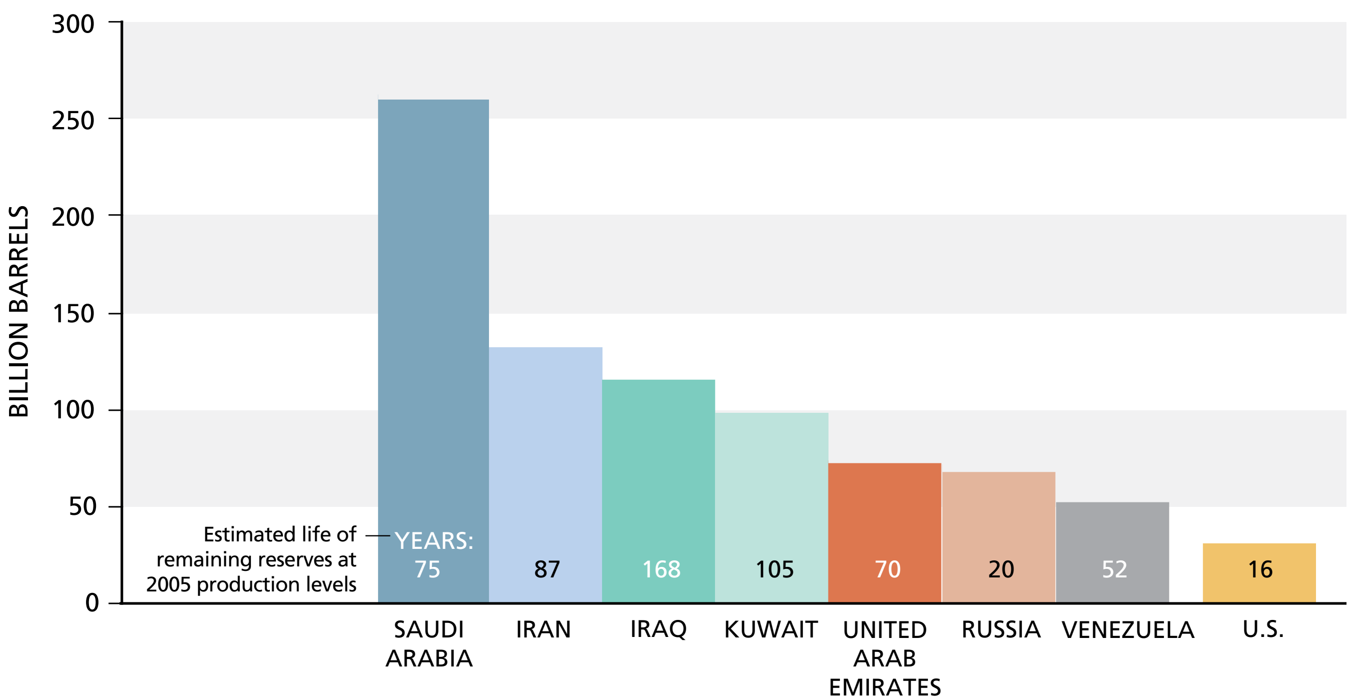
Undiscovered Resources accounted for an additional 0.9 trillion barrels in the USGS mean case at the beginning of 1996. Only 18 percent of this estimated volume, or about 17 billion barrels per year, has been discovered through exploration in the decade following.[5] Exploration discoveries have shown a declining trend over the past several decades, partly as a result of restricted access to promising hydrocarbon provinces. Significant technology advances, access to unexplored basins, or discovery of very significant fields will be necessary to replace produced resources over the study time frame.

4 K. Chew and P.H. Stark, "Perspectives on Oil Resource Estimates," IHS Energy – 2006.

5 Ibid.

Discovered Remaining Reserves is the portion of URR that is technically and economically producible in the future under current technical and economic conditions. The *BP Statistical Review 2006* estimates that Remaining Reserves grew from 0.9 to 1.2 trillion barrels from 1996-2005, primarily through reserve additions to fields discovered before 1995. The current estimate of reserves is one indicator of how much oil production capacity could be developed in the near to medium term. The quality of reserve additions and undisclosed estimating methods for countries that hold most remaining reserves are significant uncertainties in making supply forecasts.

Globally, conventional oil reserves are concentrated in the Middle East (Figure 2-19). The seven countries with the largest conventional oil reserves account for more than 70 percent of the world total. Saudi Arabia holds approximately 20 percent of conventional reserves, equal to 75 years of production at 2005 rates.



Source: NPC Survey of Outlooks.

FIGURE 2-19. *Large Holders of Discovered Remaining Reserves*

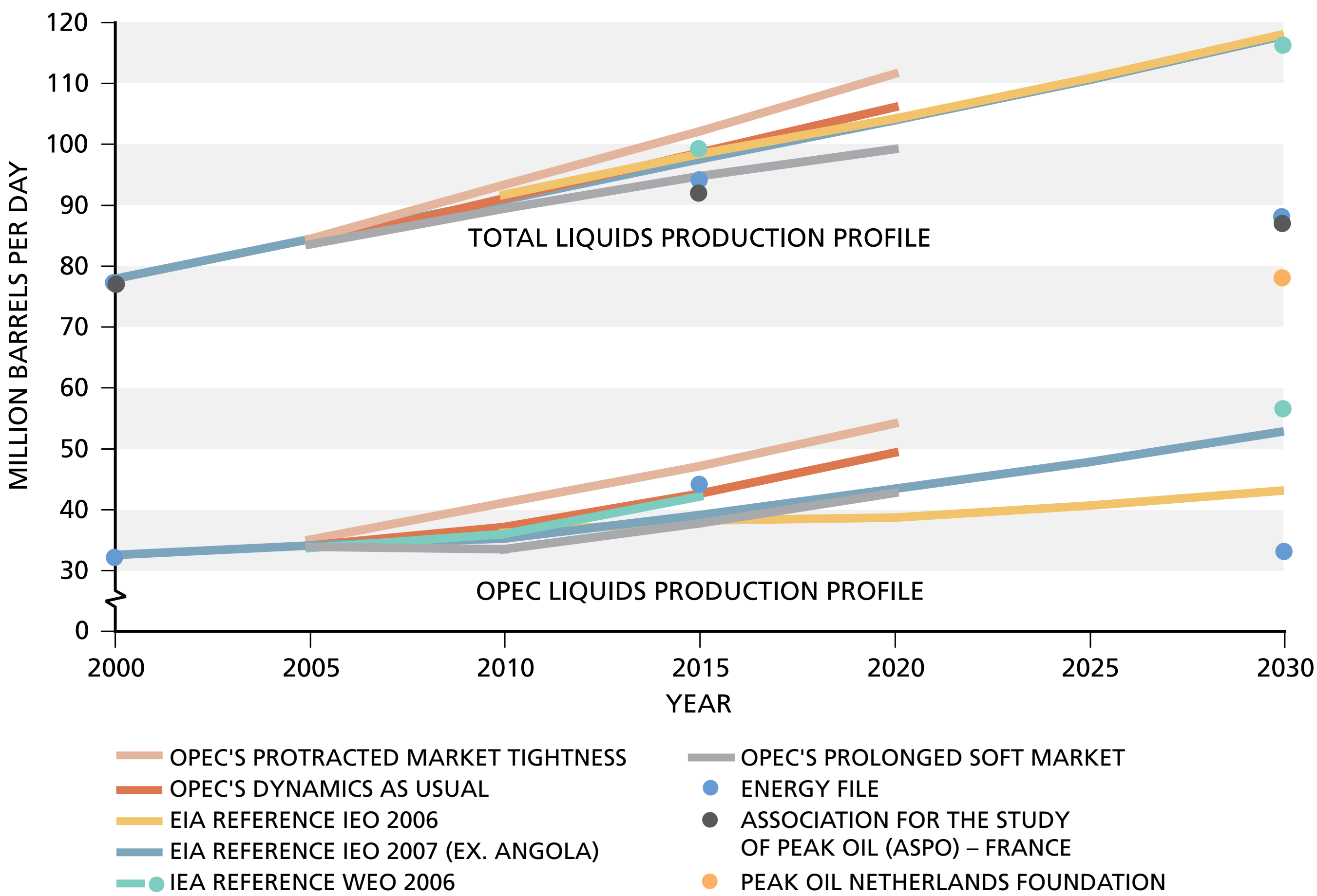
The United States has 31 billion barrels of reserves, 16 years of production at 2005 rates. The estimated life of remaining reserves was calculated by dividing reserves numbers provided to the NPC study by the 2005 production volumes reported in EIA IEO 2007.

The reserves-to-production (R/P) ratio is often used to describe how effectively a country or region has developed oil resources that are currently economically and technically recoverable. High ratios may indicate opportunities for further development and additional rate capacity. Low ratios may indicate that a country has fully developed its available accumulations and production is in decline. Alternately, low R/P ratios may mean that known accumulations have not been fully delineated in order to add them to more certain reserve classifications. The R/P ratio does not by itself indicate remaining production capacity in a field or region. Investment and technology often allow R/P ratios to remain stable over many years even as annual production rates remain unchanged or increase.

Estimates of remaining reserves are not adequate indicators of how much oil remains to be produced under future conditions or potential long-term production capacity. The additional components of URR should be considered for these purposes. Resource size will determine how much oil is likely to be produced in the long term, while the distribution and nature of the oil will determine the likely production rate.

Global Total Liquids Production

Conventional oil will remain the largest source for liquid fuel supply in the near to intermediate term, with forecasts almost unanimously predicting at least modest growth in conventional oil supply for the next 5 to 10 years. However, there are great uncertainties



Source: NPC Survey of Outlooks.

FIGURE 2-20. *Projected Global and OPEC Total Liquids Production* about long-term forecasts of oil and total liquid production rates, ranging from business-as-usual cases that show few constraints, to alternative scenarios constrained by the resource base, environmental concerns, or geopolitical issues.

The EIA IEO 2007 Reference Case projects total liquids production of 118 million barrels per day (MB/D) in 2030, with similar estimates in the IEA Reference Case (116 MB/D), the IOC Average (107 MB/D), and Consultant Average (115 MB/D). Higher and lower forecasts include:

- EIA IEO 2007 Low Price: 134 MB/D
- EIA IEO 2007 High Price: 103 MB/D
- Peak Oil Netherlands and Association for the Study of Peak Oil (ASPO) – France: 78-88 MB/D.

The lower production figures in specific cases are driven by carbon constraints, investment constraints, higher oil prices, geological challenges, or other issues. The highest demand projections for 2030 assume favorable development policies in resource-holding countries, technology advances, investment, infrastructure, project completion, and personnel.

Several projections in Figure 2-20 show that total liquids production may not increase after 2015. The lowest total liquids forecasts in 2030 are consistent with a URR at the low end of the USGS range and constraints to developing the conventional oil resource base or alternatives. This set of forecasts projects that liquids production will reach a maximum within the study time frame, although the precise date is uncertain.

Forecasts for declining production are based on various above- and below-ground factors, including: declines in volumes discovered; conventional oil production peaks and subsequent declines in countries such as the United States and the United Kingdom; and anticipated oil production plateaus in countries such as Russia and China. The discussion of peak oil forecasts later in this chapter considers these views more fully.

The production rate for unconventional oil is an additional uncertainty in projected total liquids supply. In the EIA IEO 2007 Reference Case, for example, Canadian oil sands and Venezuelan heavy oils supply 5.2 MB/D in 2030, assuming sustained investment in development. Forecasts that include constraints on development project lower supplies from unconventional sources (Figures 2-21 and 2-22).

Conventional Oil Production

All forecasts project that a few countries, where resources are concentrated, will supply most conventional oil, although specific contributions vary. Geographic concentration generally creates more uncertainty in supply availability or deliverability due to infrastructure, resource, and geopolitical risks; increases the market power of resource holders; and enhances the global role of national oil companies (NOCs).

The EIA and IEA have somewhat different views on the balance of conventional oil supply between OPEC and non-OPEC countries (Figure 2-23). The IEA expects non-OPEC conventional oil production to decline after 2015, with OPEC increasing its share of conventional oil production from 42 percent in 2005 to 52 percent in 2030. The EIA projects that non-OPEC conventional oil production (including Angola) will increase through 2030. In the EIA IEO 2007 Reference Case, OPEC is expected to increase production to meet growing demand, but its share of conventional oil production will only rise to 47 percent.

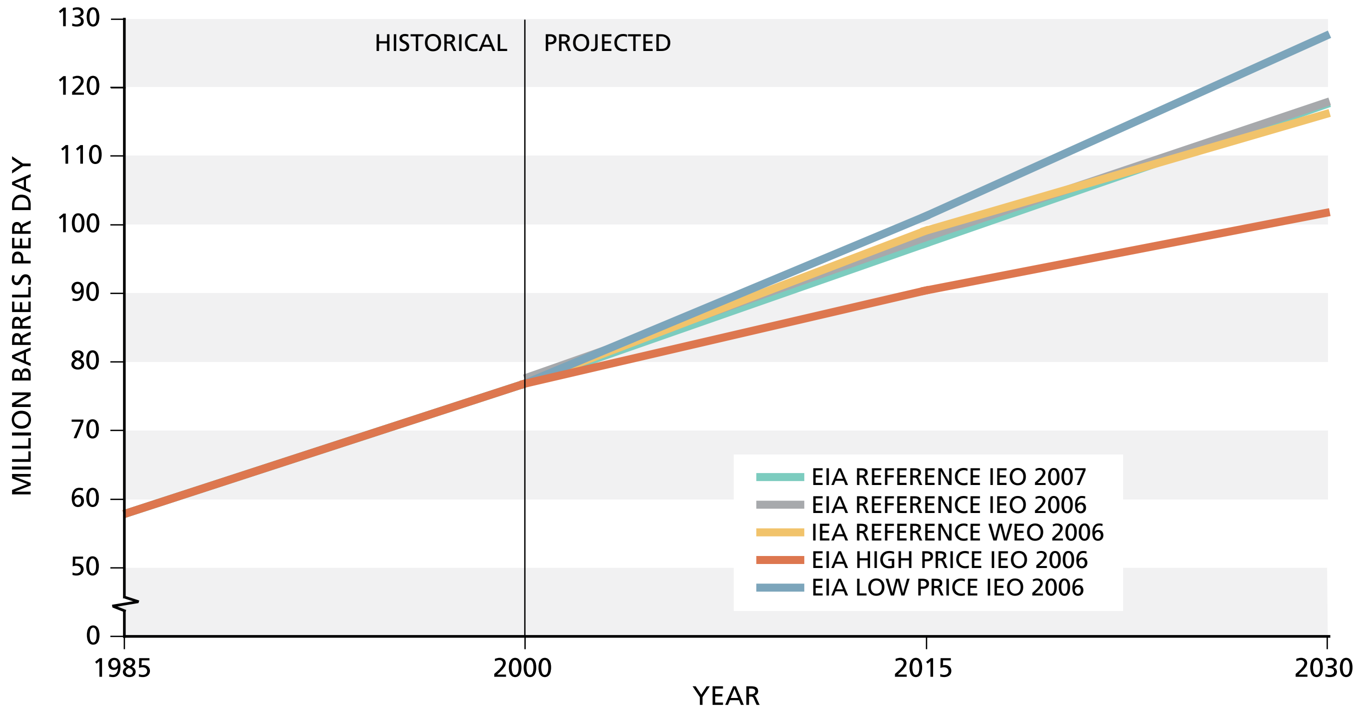
Non-OPEC Production

Estimates for non-OPEC total liquids production vary significantly. Some forecasts indicate that production of non-OPEC conventional oil will decline in the next decade. Other forecasts show production growth through 2030 (Figures 2-24 and 2-25). In the EIA IEO 2007 Reference Case, non-OPEC output rises through 2030. Russia and other Caspian region producers provide about half the increase. Angola is included in non-OPEC production, since most forecasts were completed before it joined OPEC.

By comparison, the IOC Average and all peak oil cases show that non-OPEC production peaks within the outlook period. The IEA WEO 2006 Reference Case shows that non-OPEC production may not grow after 2010 due to high decline rates of currently producing fields and rising costs. The IEA Reference Case also shows that only Russia, Central Asia, and Latin America achieve significant increases in conventional oil production through 2030.

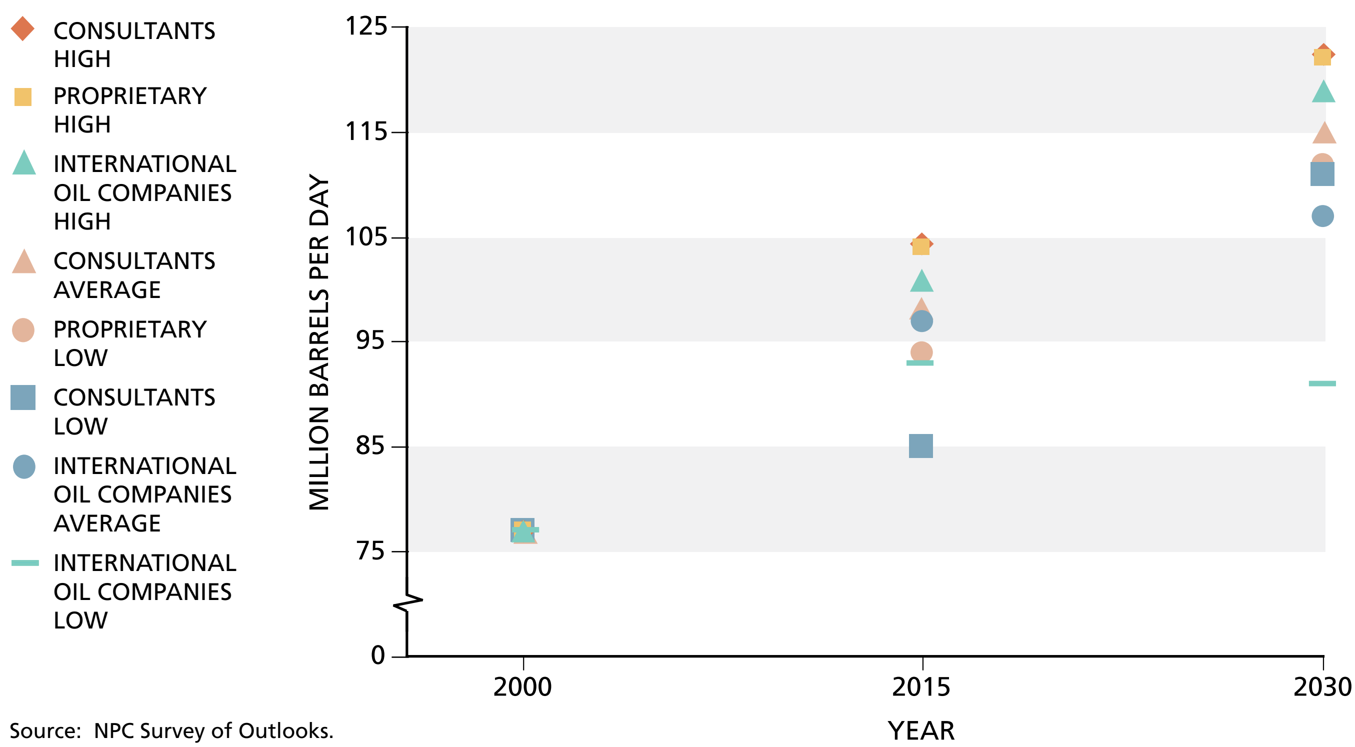
U.S. Production

The United States is the third-largest oil producing country in the world, after Saudi Arabia and Russia. The United States produced 5.2 MB/D of conventional crude oil in 2005, but its production is at best rising



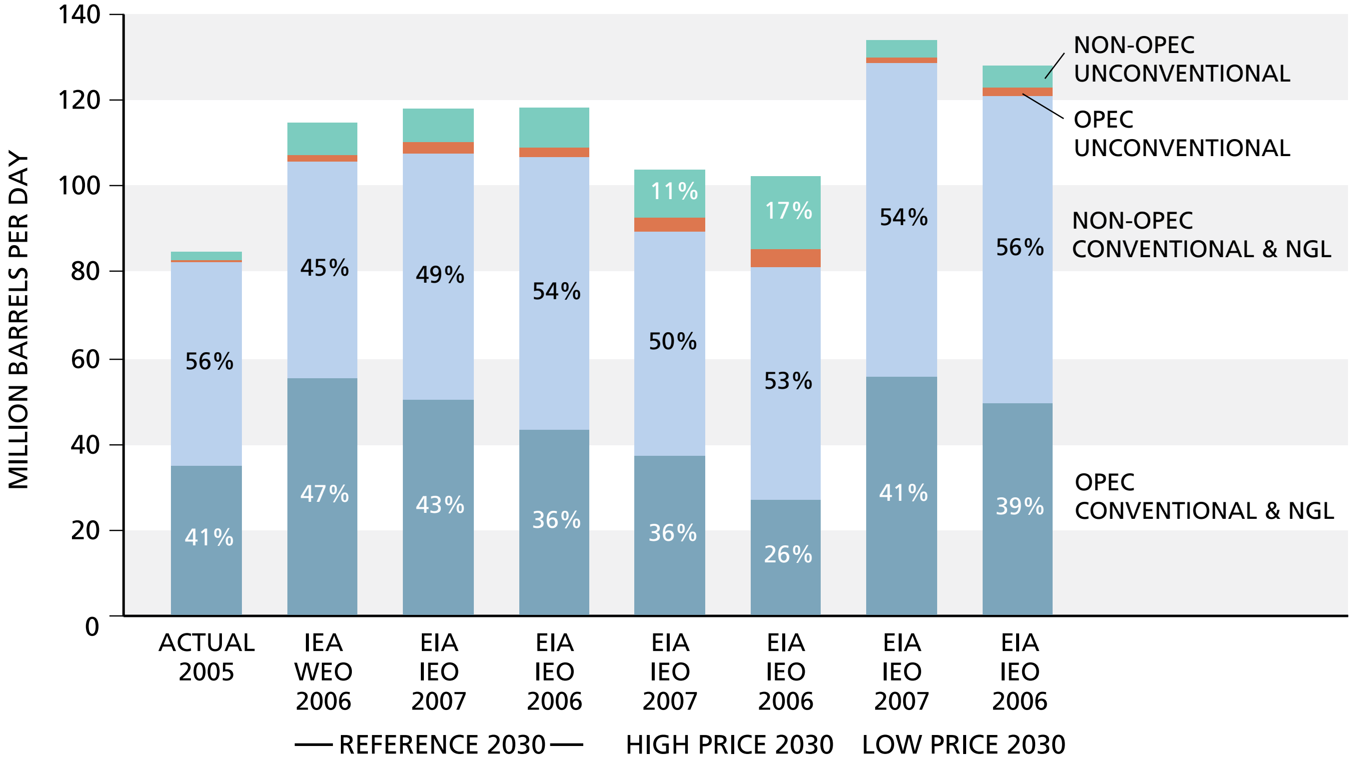
Source: NPC Survey of Outlooks.

FIGURE 2-21. *Projected Global Total Liquids Production*



Source: NPC Survey of Outlooks.

FIGURE 2-22. *Projected Global Total Liquids Production — Proprietary Aggregated Cases*



Source: NPC Survey of Outlooks.

FIGURE 2-23. *OPEC and Non-OPEC Total Liquids Production Shares, 2005-2030*

slightly in absolute terms while declining as a share of domestic demand. This production volume is a subset of the conventional production shown in Figure 2-26. Total conventional production is comprised of crude oil, including lease condensates, natural gas plant liquids, other hydrogen and hydrocarbons for refinery feedstocks, alcohol and other sources, and refinery gains.

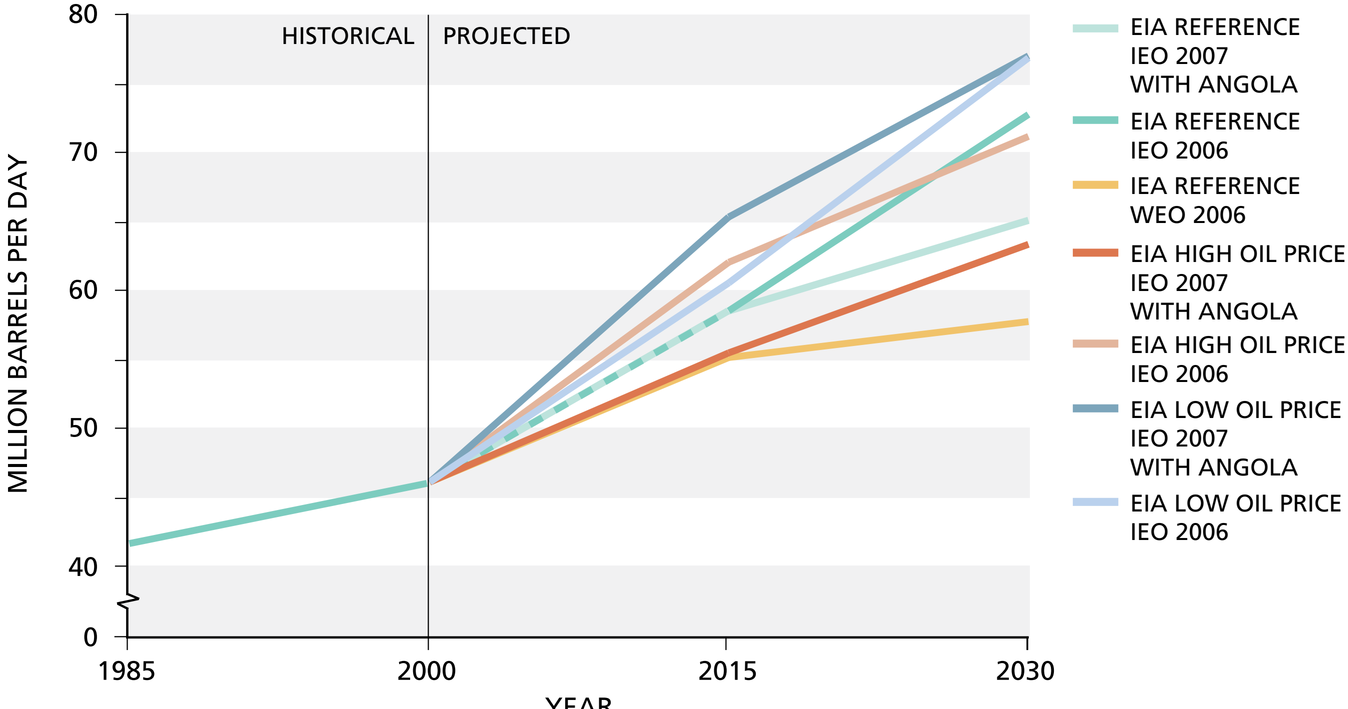
Existing fields, which are maturing onshore and offshore, in Alaska and the lower-48 states, are generally not seen as having the potential to reverse existing declines. The EIA Annual Energy Outlook 2007 (AEO 2007) includes cases showing U.S. conventional crude oil production ranging between 5.25 MB/D and 6.04 MB/D in 2030. An AEO 2007 case that simulated access to the Arctic National Wildlife Refuge (ANWR) sees U.S. crude oil production rising to 6.03 MB/D in 2030, which is about 0.8 MB/D higher than the 2005 rate. By comparison, the IEA Reference Case forecasts U.S. production dropping about 1 MB/D by 2030.

Increasing domestic total liquids production more than marginally would depend on access to basins that have both substantial undeveloped liquid resources and exploration potential and a significant contribution from unconventional oil. Access issues are discussed later in this report. Figure 2-26 shows how substantial production from unconventional sources would affect North American oil imports. Unconventional production is greatest in the EIA High Oil Price case, where imports in all years are below the 2005 level.

Production from Other Large Non-OPEC Countries

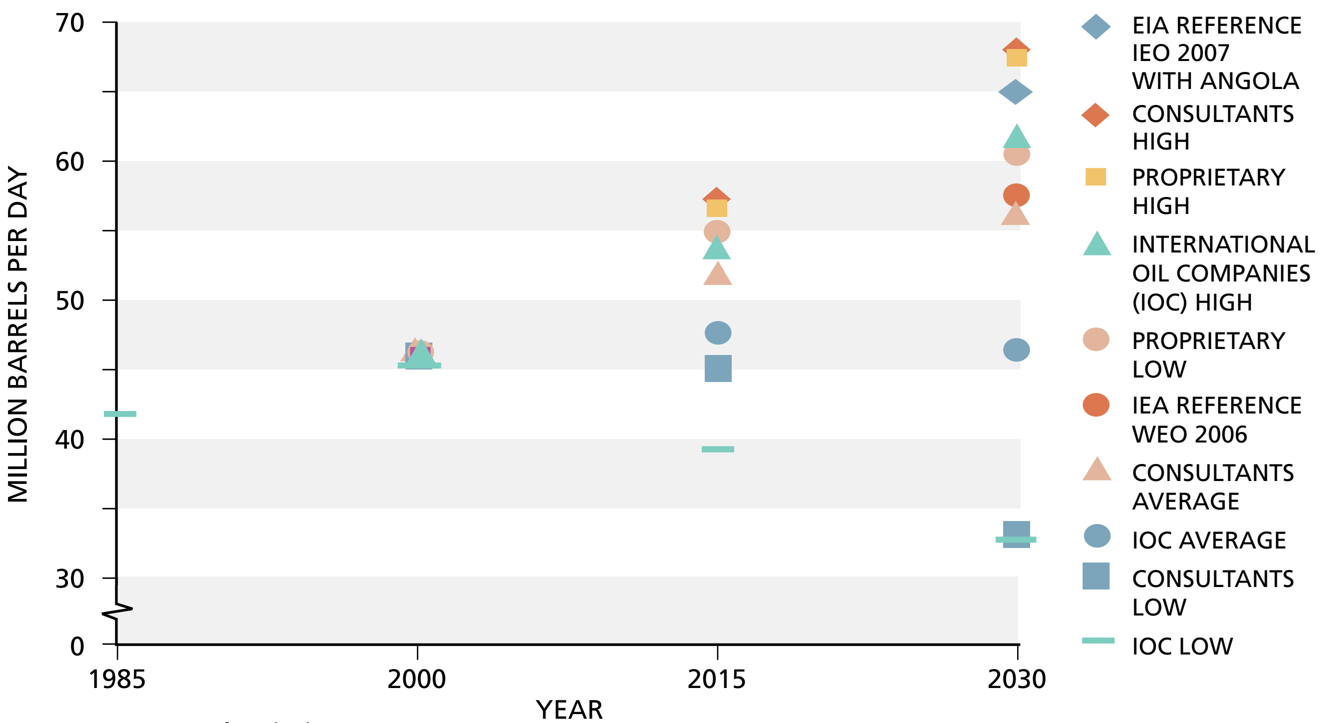
Of the other large non-OPEC producers, Russia will be a critical supply source. All forecasts show Russian production rates increasing from just under 10 MB/D currently to a range of 11 to 13 MB/D by 2030 (Figure 2-27).

Production from two primary sources of U.S. supply, Mexico and Canada, could be headed in opposite directions. Future Mexican production (Figure 2-28) is uncertain. Some forecasts see modest increases, despite recent production declines at a major field. Other forecasts, including the EIA IEO 2007, indicate lower Mexican production in 2015 and 2030 than in 2005. Conventional oil production from Canada is not expected to be material, but expanded development



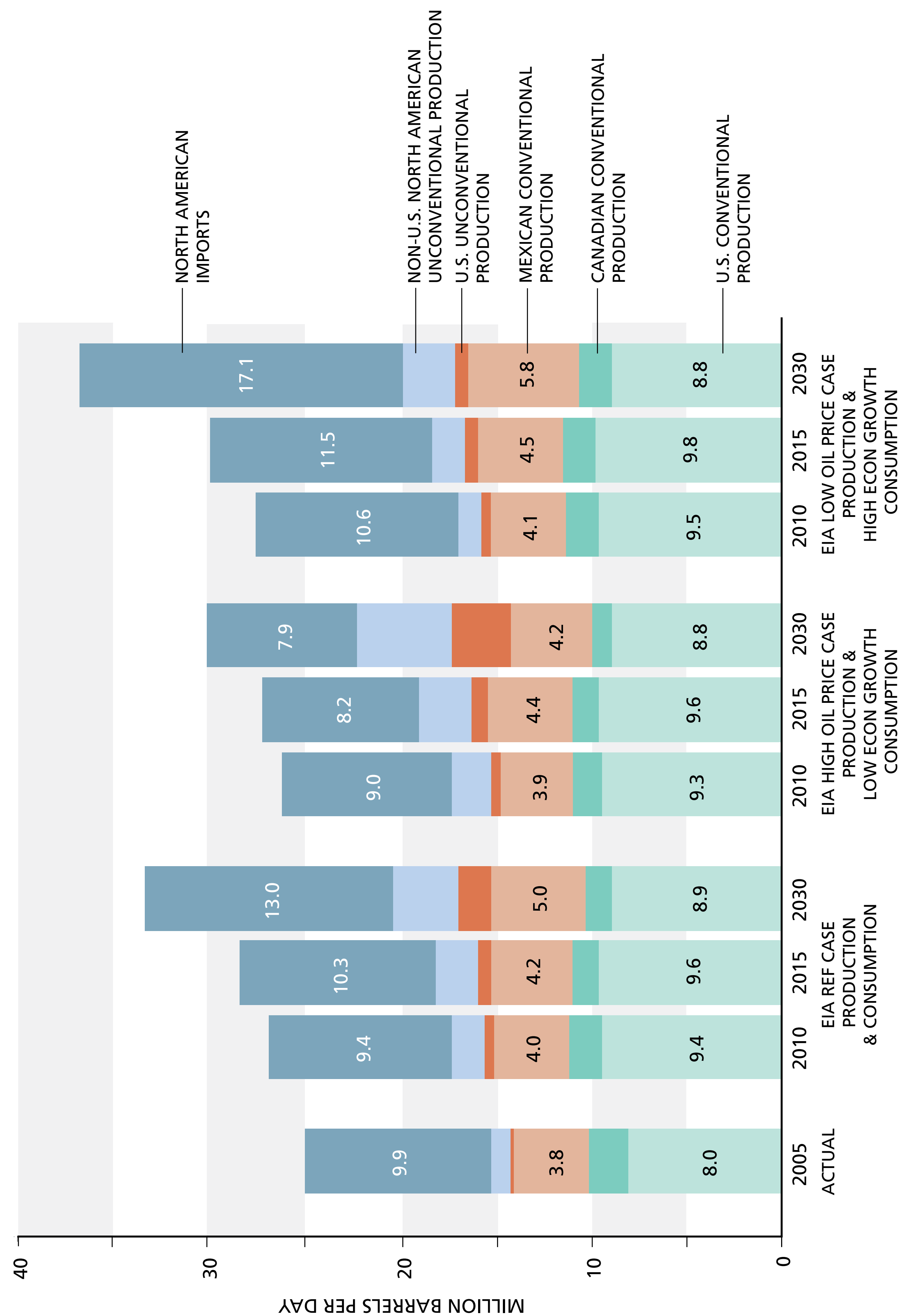
Source: NPC Survey of Outlooks.

FIGURE 2-24. *Projected Non-OPEC Total Liquids Production*



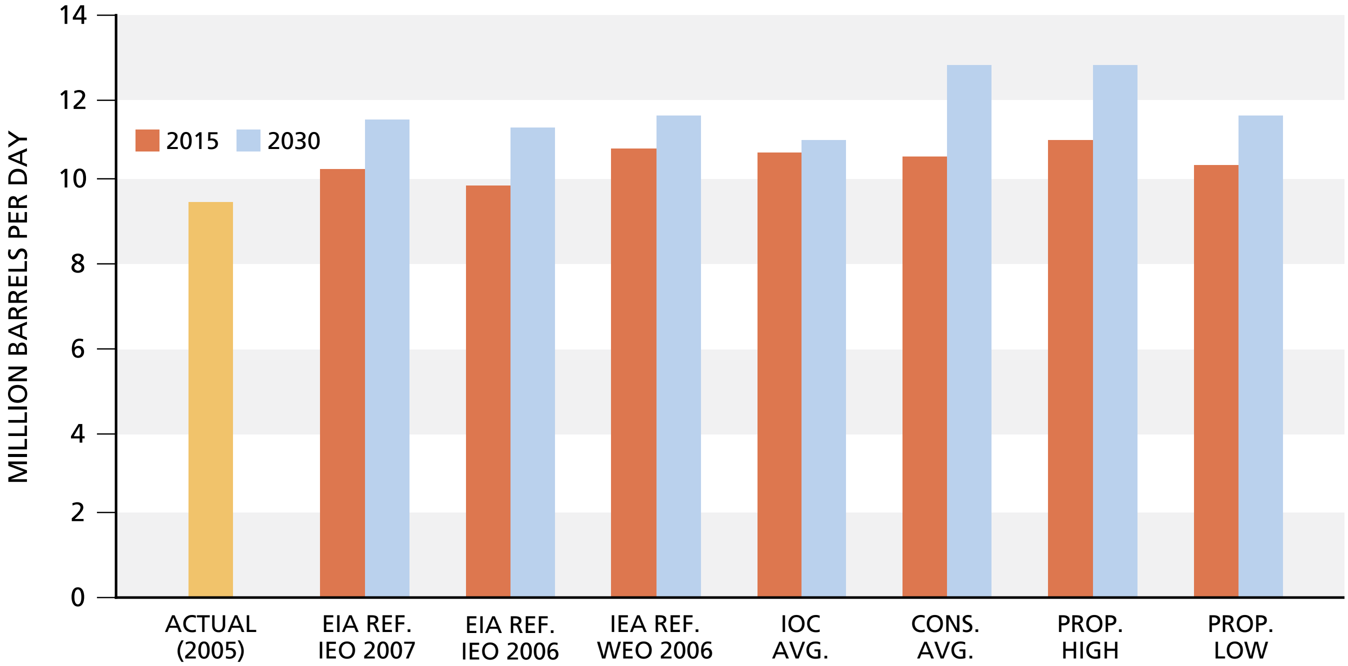
Source: NPC Survey of Outlooks.

FIGURE 2-25. *Non-OPEC Total Liquids Production — Proprietary Aggregated Cases*



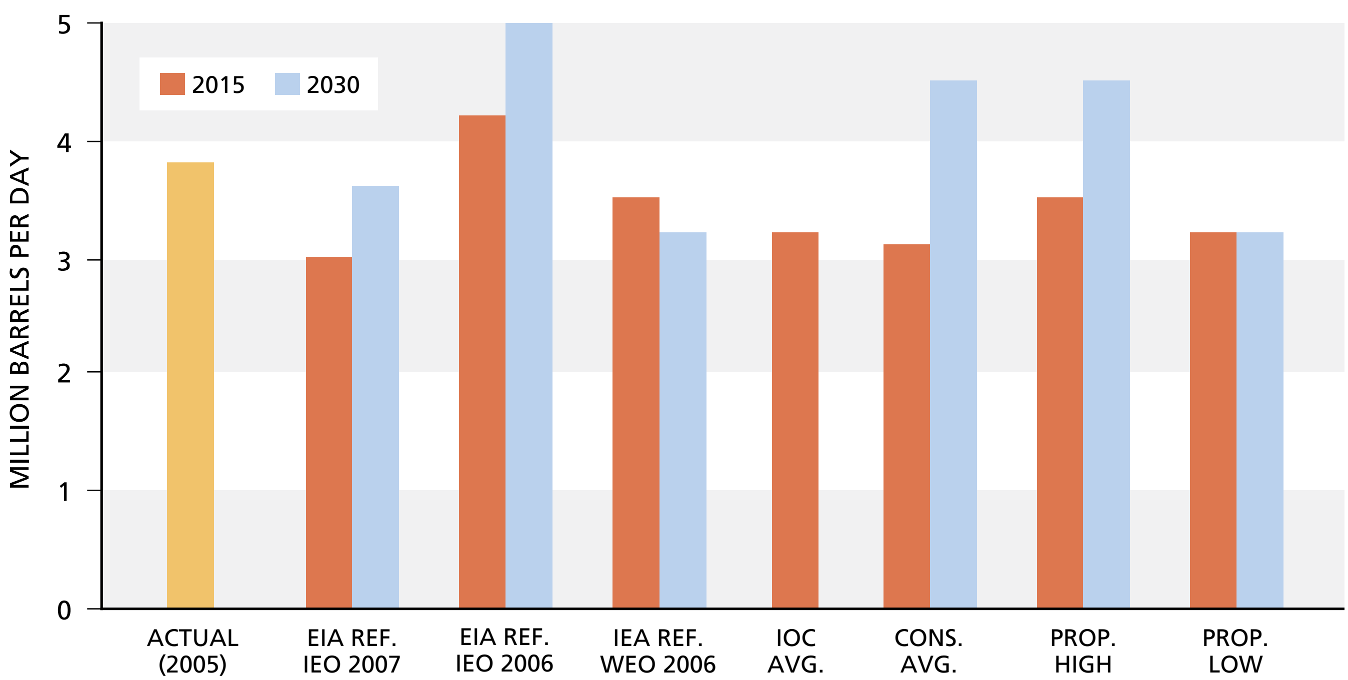
Source: NPC Survey of Outlooks.

FIGURE 2-26. *North American Production and Imports*



Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

***FIGURE 2-27.** Russian Total Liquids Production Outlooks*



Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

***FIGURE 2-28.** Mexican Total Liquids Production Outlooks* of Canadian oil sands is forecast to bring considerable unconventional production into North American supply (Figure 2-29).

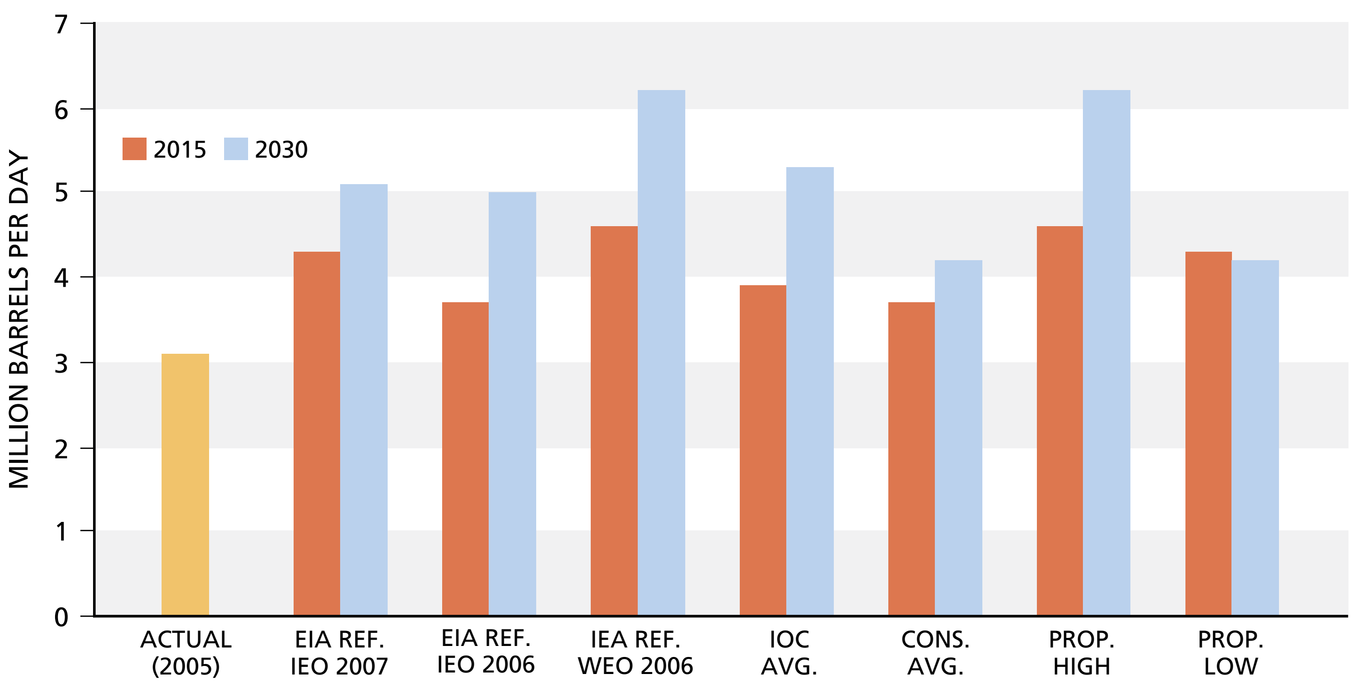
OPEC Oil Production (Excluding Angola)

Almost all long-term forecasts expect production to increase rapidly in OPEC countries. This is especially true of the Middle East, where resources are much larger and production costs generally lower than in other regions. Several forecasts suggest that OPEC is capable of raising total liquids production by 20 MB/D above present levels. The IOC Average case forecasts OPEC production at about 44 MB/D by 2030. The EIA IEO 2007 Reference Case, excluding Angola, projects 53 MB/D. The IEA Reference and Consultant Average cases indicate OPEC production above 50 to 55 MB/D (Figures 2-30 and 2-31). The range of projected OPEC total liquids production, relative to projected global production is shown in Figure 2-32.

Saudi Arabia continues to be the largest OPEC producer in every forecast. The IEA assigns the kingdom a vital role in supplying the global oil market. The IEA WEO 2004 considers timely Saudi Arabian investment in oil-production capacity to be a major determinant of future supply trends. Saudi Arabian production in the IEA case rises from 10.6 MB/D of conventional oil and NGL to 17.3 MB/D by 2030. As Figure 2-33 shows, the IEA has the highest forecast for Saudi Arabia's total liquids production in 2030.

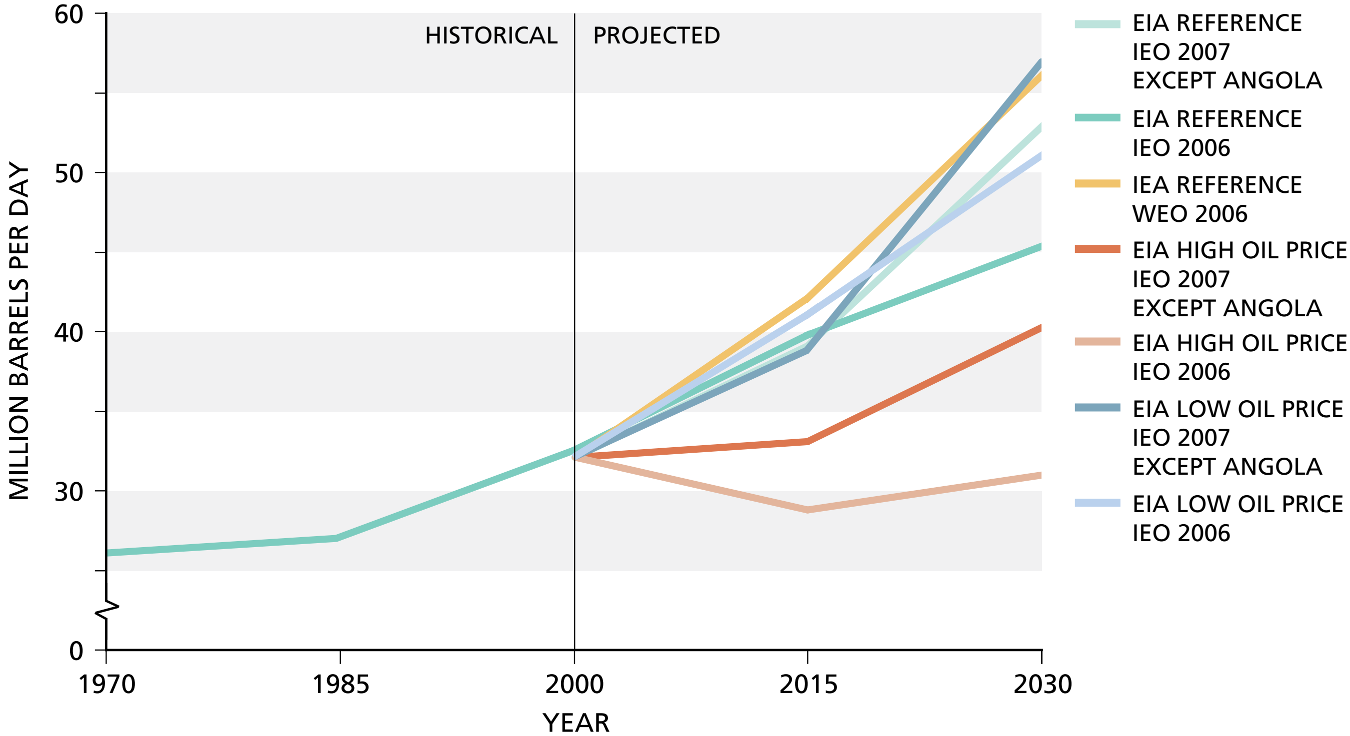
In addition to projected Saudi Arabian production, significant conventional oil production increases from Iraq, Iran, Venezuela, and Nigeria will be needed to meet projected global demand in 2030. Among these producers, the near-term prospects for oil production in Iraq remain very uncertain. Nonetheless, the projected production increases for 2015 differ by a relatively small 0.5 MB/D, from 0.9 to 1.4 MB/D more than in 2005. By 2030, the difference between forecasts expands to 2.3 MB/D. IEA projects Iraqi production as growing to 6 MB/D in 2030, double its current share of OPEC conventional oil production. (Figure 2-34)

Forecasts show a wide range for total Iranian liquids production. The difference between production forecasts for 2015 is 1.5 MB/D, with some showing a drop in production and others showing flat production, or growth of almost 1 MB/D. By 2030, the differences broaden to 1.6 MB/D, with the highest production forecast at more than 6 MB/D. (Figure 2-35)



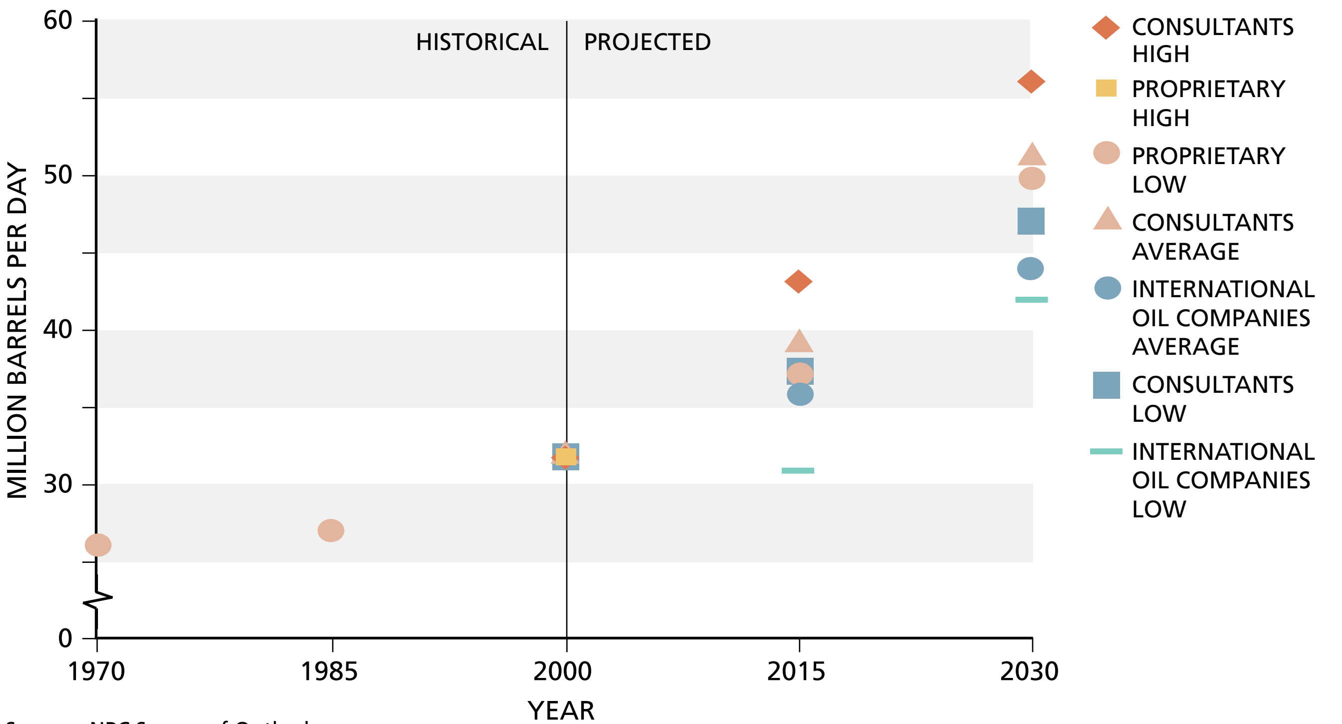
Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

FIGURE 2-29. *Canadian Total Liquids Production Outlook*



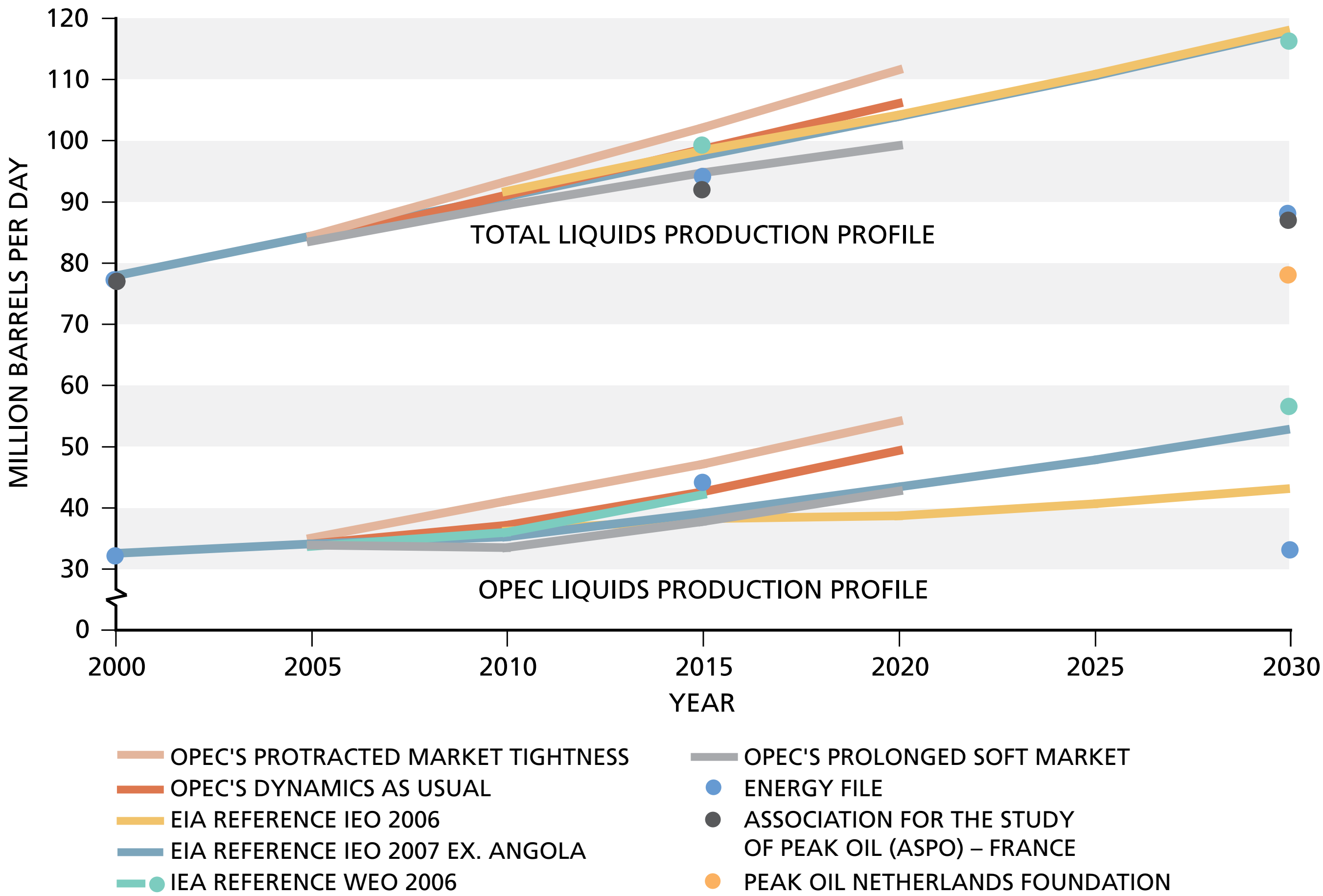
Source: NPC Survey of Outlooks.

FIGURE 2-30. *Projected OPEC Total Liquids Production*



Source: NPC Survey of Outlooks.

FIGURE 2-31. *Projected OPEC Total Liquids Production — Proprietary Aggregated Cases*



Source: NPC Survey of Outlooks.

FIGURE 2-32. *Projected Global and OPEC Total Liquids Production*

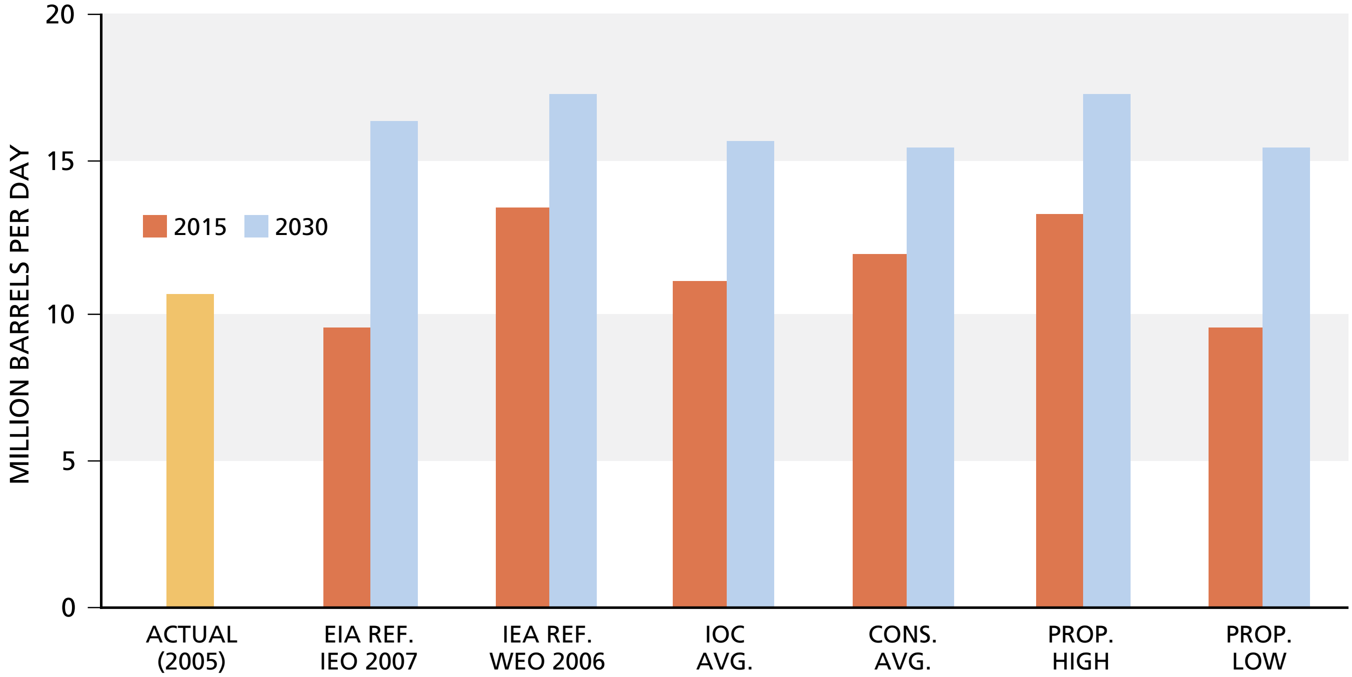
Unconventional Liquids Production

Unconventional liquids are projected to grow to about 10 percent of total liquids production by 2030 (Figure 2-36). The EIA IEO 2007 Reference Case shows total unconventional liquids production above 10 MB/D, with Canadian oil sands and Venezuelan heavy oil comprising the major part of the increase. Commercial considerations and the relative immaturity of production technologies for unconventional liquids lead to much uncertainty about the availability and timing of these fuels. Oil sands projects in Alberta will be pivotal to forecasted growth in Canadian total liquids production, if they overcome infrastructure, environmental, and cost challenges. While all forecasts expect growth, the range between them widens to 2 MB/D by 2030.

Most forecasts project that Venezuelan production will increase from 2005 levels. Venezuela's national oil company, Petroleos de Venezuela (PDVSA), projects the highest growth, expecting to more than double its total liquids production capacity to 5.8 MB/D by 2012.[6] The IEA forecast, which is lower than PDVSA's, expects new production from both extra-heavy oil projects in the Orinoco area and conventional oil fields. Forecasted production in 2015 compared to 2005 ranges from flat to an increase of 0.6 MB/D. Production in 2030 ranges from 0.5 to 2.3 MB/D more than in 2005. (Figure 2-37)

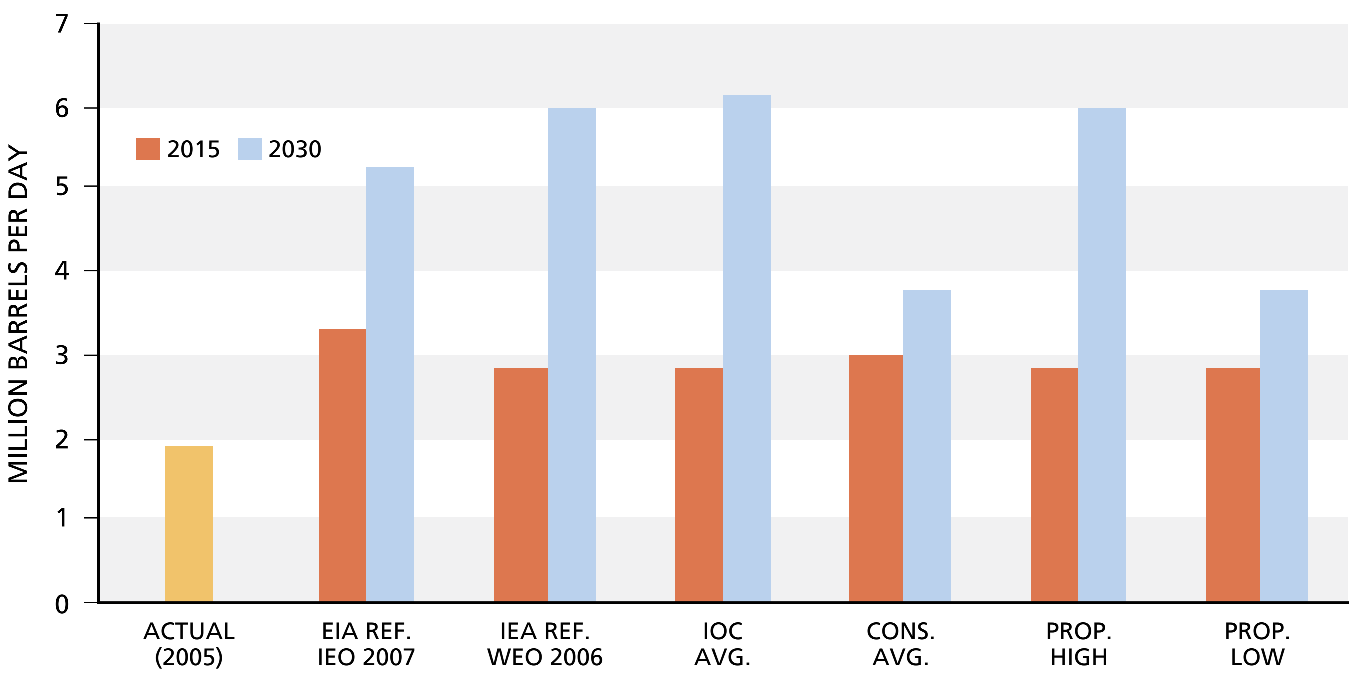
The EIA Reference Case expects the remaining increase in unconventional liquids production to come mainly from: biofuels derived from agricultural products (16 percent); gas-to-liquids (11 percent); and coal-to-liquids (23 percent). Indicative of this trend, the United States has announced a production goal for ethanol and other unconventional fuels of 2.3 MB/D by 2017, up from about 0.4 MB/D in 2006 and 0.5 MB/D in 2012.

6 http://www.pdvsa.com/index.php?tpl=interface.en/design/home.tpl.html



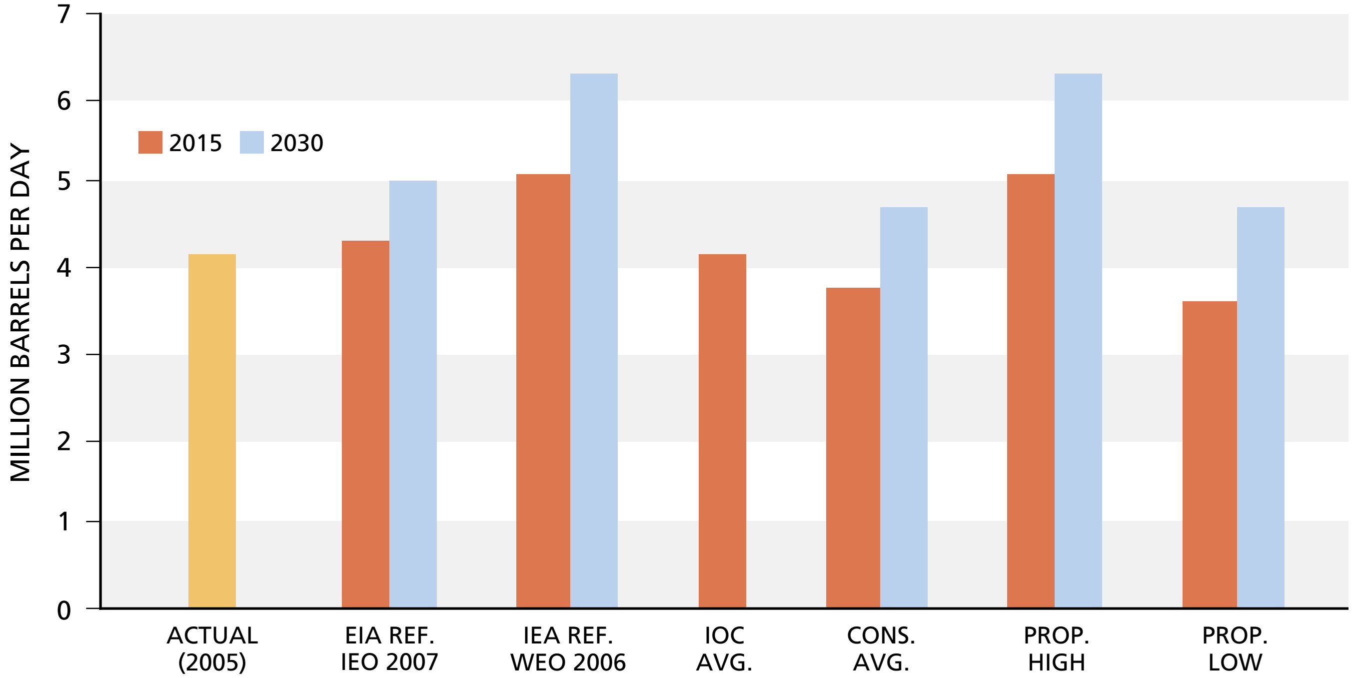
Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

FIGURE 2-33. *Projected Saudi Arabian Total Liquids Production*



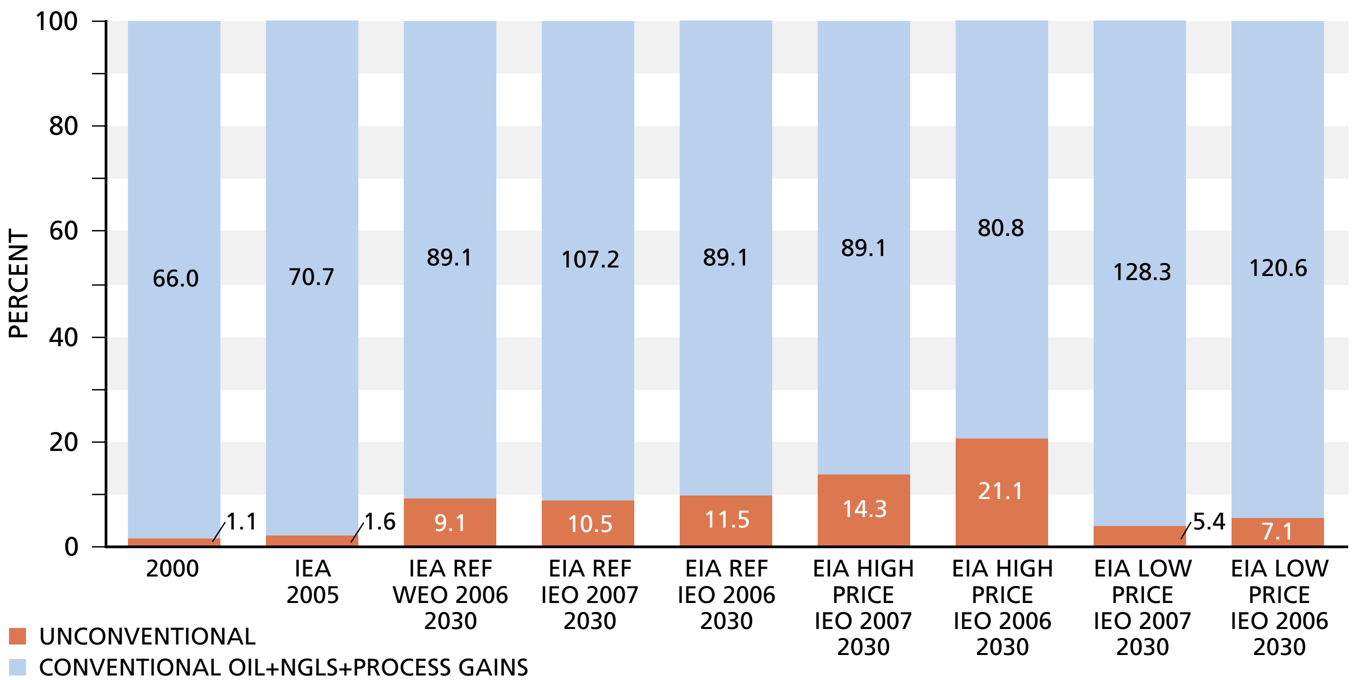
Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

FIGURE 2-34. *Projected Iraqi Total Liquids Production*



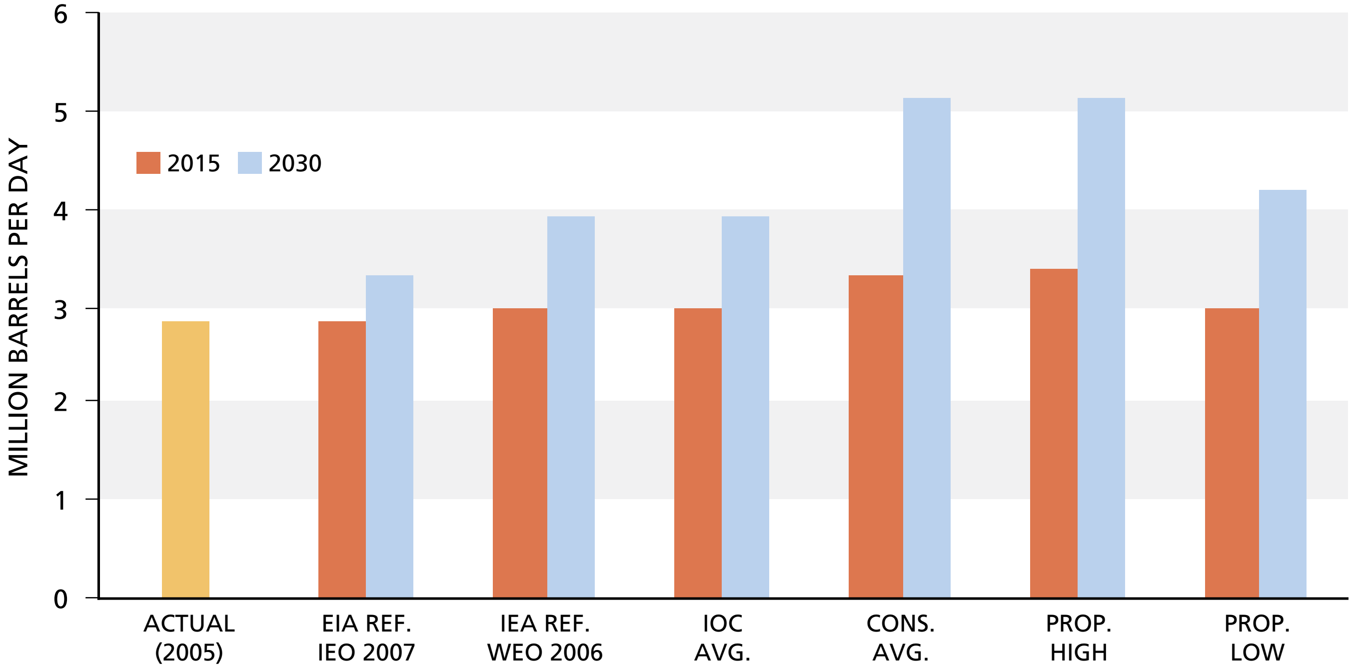
Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

FIGURE 2-35. *Projected Iranian Total Liquids Production*



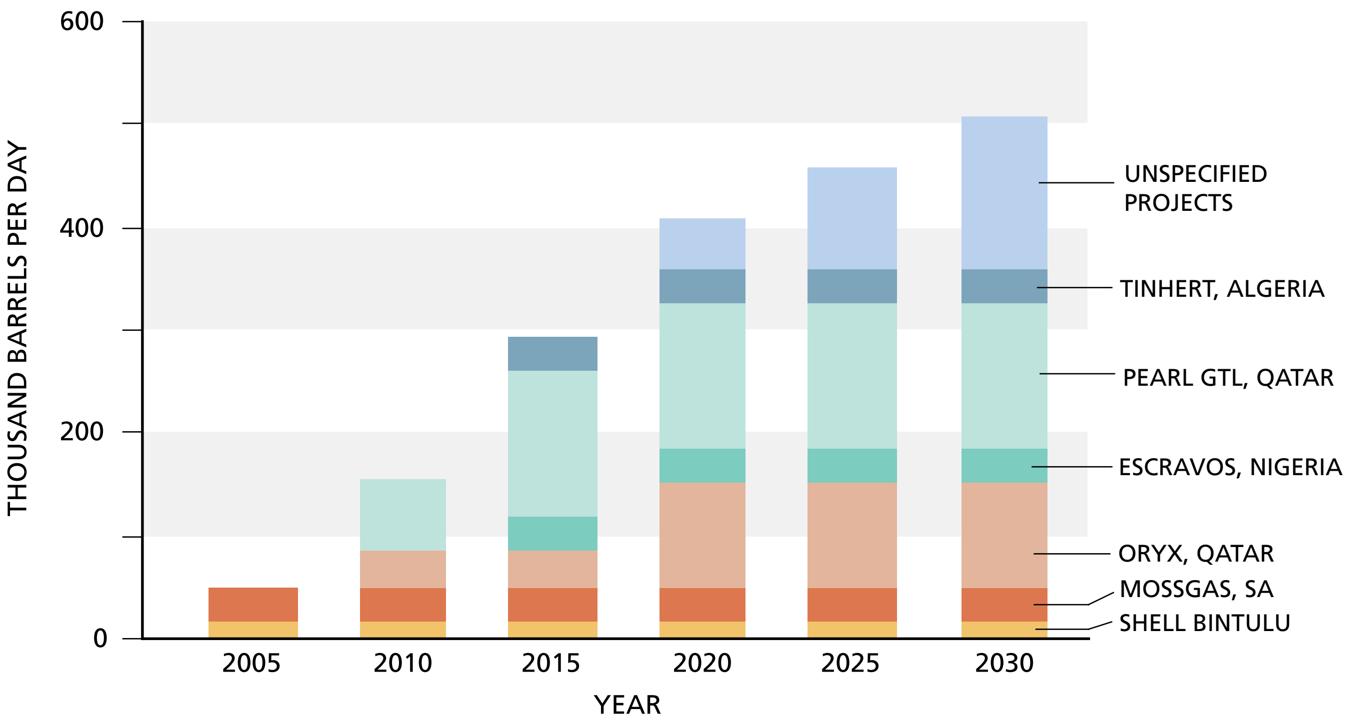
Note: Units shown in million barrels per day.
Source: NPC Survey of Outlooks.

FIGURE 2-36. *Projected Global Conventional and Unconventional Total Liquids Production*



Note: IOC = International Oil Companies; CONS. = Consultants; and PROP. = Proprietary.
Source: NPC Survey of Outlooks.

FIGURE 2-37. *Projected Venezuelan Total Liquids Production*



Source: NPC Survey of Outlooks.

FIGURE 2-38. *Projected Gas-to-Liquids Plant Capacity Based on Current Projects*

		Access	Investment	Infra-structure	People and Equipment	Environ-ment	Geopolitics
Production Source	*Current Production Forecasts 2005-2030 (Million Barrels per Day)*						
Conventional Non-OPEC	35-75		X	X			X
Russia	10+	X	X	X			X
Conventional OPEC	30-55	X	X	X	X		X
Saudi Arabia	10-17+						
Unconventional Crude	1-10		X	X	X	X	
Heavy	1-10						
Shale Oil	<1						
Alternatives	1-5						
Biofuels	1-3		X	X	X		
Gas-to-Liquids	~1			X			
Coal-to-Liquids	~1		X			X	
Production Growth	*2005-2030 Expected Growth (Million Barrels per Day)*						
Saudi Arabia	+5-7		X		X		
Iraq	+4		X	X	X		X
Canada	+2			X	X		
Venezuela	+2	X	X	X	X		X
Nigeria	+2		X				X
Iran	1-2	X	X	X	X		X
Kuwait	1-2		X		X		
UAE	1-2		X		X		
Libya	1-2		X		X		

Note: An X in any column means that the matter is problematic or open to question for that resource type or country.

TABLE 2-3. *Oil Production Challenges*

GTL and CTL plants typically convert natural gas and coal to liquid fuels. The product is usually about 70 percent ultra-clean diesel fuel and 25 percent naphtha for chemical feedstock.

In the past ten years, several world-scale GTL plants have been developed or announced. However, given recent cost increases, several large projects (e.g., in Qatar) have been cancelled or postponed in 2006 and 2007. All forecasts received for the study project that GTL will grow quickly from a very low base, but not enough to significantly affect oil product or natural gas markets. Several estimates for GTL capacity growth show only 0.5 MB/D of GTL fuels being produced worldwide through 2030, mainly clean diesel and naphtha (Figure 2-38). In this event, GTL would provide only about 1 percent of global middle distillate fuel requirements. By comparison, EIA IEO 2007 shows stronger GTL production growth to 1.2 MB/D in 2030, with Qatar as the primary source. For further discussion, see the Gas-to-Liquids Topic Paper.

For a further discussion of coal-to-liquids, see the Coal section of this chapter and the Coal-to-Liquids Topic Paper on the CD that accompanies this report.

Oil Supply Challenges

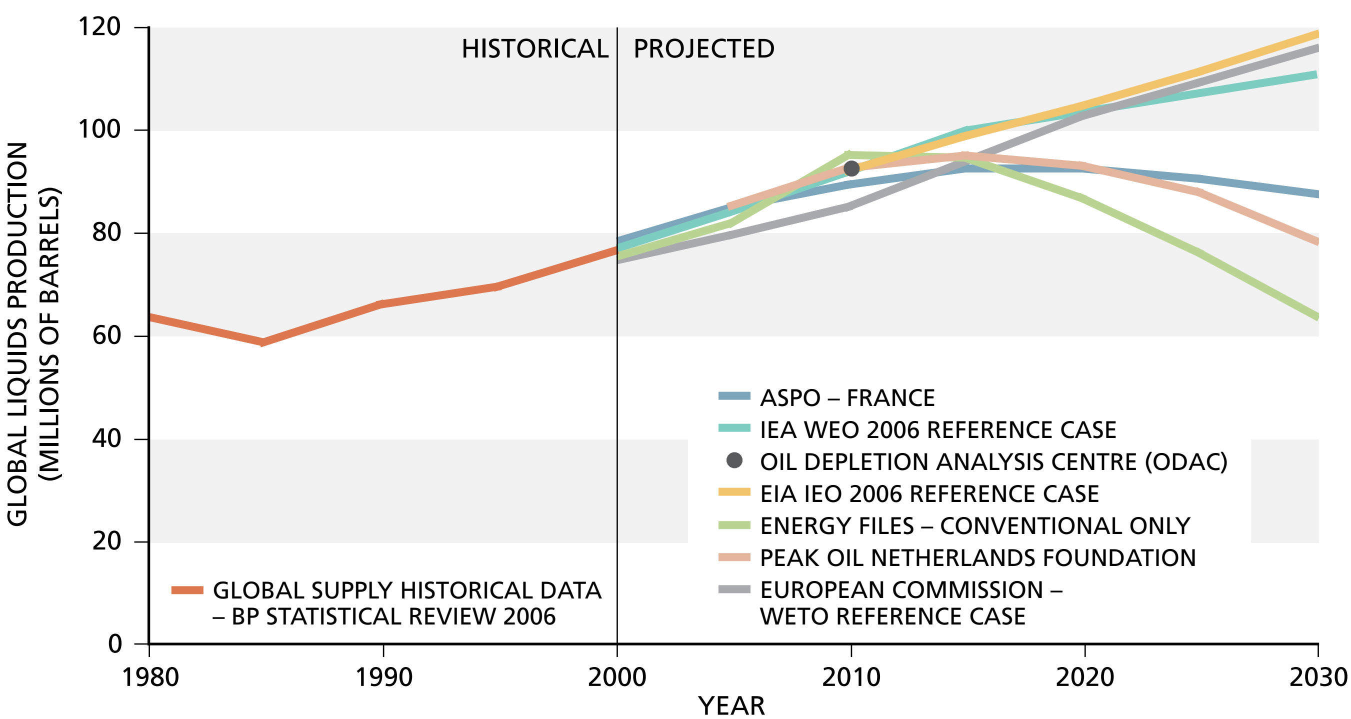
The forecasts and data received for this study lead to the conclusion that oil supply increasingly faces above-ground challenges in addition to geological and technical hurdles. The challenges include access, geopolitics, investment requirements, commercial and trade regimes, infrastructure, and workforce availability. Table 2-3 is a snapshot of above-ground challenges that affect the resource types and sources of projected oil supplies to 2030. The prospects are likely to be further complicated since the challenges change with place, resource, and time.

Peak Oil

Concerns about the reliability of production forecasts and estimates of recoverable oil resources are the basis of warnings about future oil supplies and the deliverability of oil. The concerns are compounded by the challenges some companies face in adding new reserves to replace those already produced. The warnings are strongly expressed in a set of forecasts known collectively as *peak oil*. The term derives from the *Hubbert's Peak* analysis of U.S. oil production written by M. King Hubbert.

Peak oil forecasts project that oil supply will not grow significantly beyond current production levels and therefore may not keep pace with projected global demand; a peak and decline in oil production is inevitable and may be near-at-hand. The conclusions lead to calls to develop additional resources to increase supply, accelerate the use of unconventional resources as substitutes for oil, and moderate demand in order to bridge the forecast supply shortfalls. Such actions generally converge with the recommendations of this study.

The forecasts reviewed for this study that do not consider new policies such as carbon constraint show considerable agreement until 2015 (Figure 2-39). After 2015, views about supply trends diverge, with peak oil forecasts providing the lower bound. The divergent views of oil supply after 2015 fuel growing concern about the



Source: NPC Survey of Outlooks.

FIGURE 2-39. *Global Total Liquids Production — Reference Forecasts 2000-2030* deliverability of the resource base and the uncertainty regarding timing and volume of future supplies.

Peak oil forecasts emphasize various physical limitations to raising production rates, including: reserve estimates that are lower than reference cases; limited future development opportunities; and insufficient volumes from unconventional production over the study time frame. These forecasts generally consider oil supply independently of demand and point to supply shortfalls. Such views contrast with forecasts and economic models that expect market forces to provide incentives for developing global hydrocarbon and other resources to meet fuel needs through at least 2030.

Peak oil forecasts use several indicators to support the case for an imminent peak in global production. One leading indicator is the difficulty of adding new reserves to make up for produced volumes, especially through exploration. However, companies and countries use different methods to estimate recoverable resources and what they term reserves. The lack of transparency and consistency in this reporting confuses the situation and is a concern in all forecasts.

A second indicator is the growing number of countries that show a historical peak in their oil production. Many forecasts rely on the shape of production curves in countries that have displayed a peak to extrapolate future production rates for that country and to develop forecasts for countries whose production has not peaked. The extrapolations are based on the observed physical behavior of most oilfields. This method raises considerable debate, since many factors affect production from a field, basin or country.

In the absence of production restrictions, oil production from a well usually declines from its initial levels. As other wells are incorporated in a field, oil production rises to a given rate at the field level and then declines. Production costs generally increase throughout the development of the field as the productivity of wells decreases. This well and field production profile is often extrapolated to represent producing basins, countries and the world. If a fixed or slowly growing resource base is also assumed, forecasted global production would inevitably follow a similar pattern of decline.

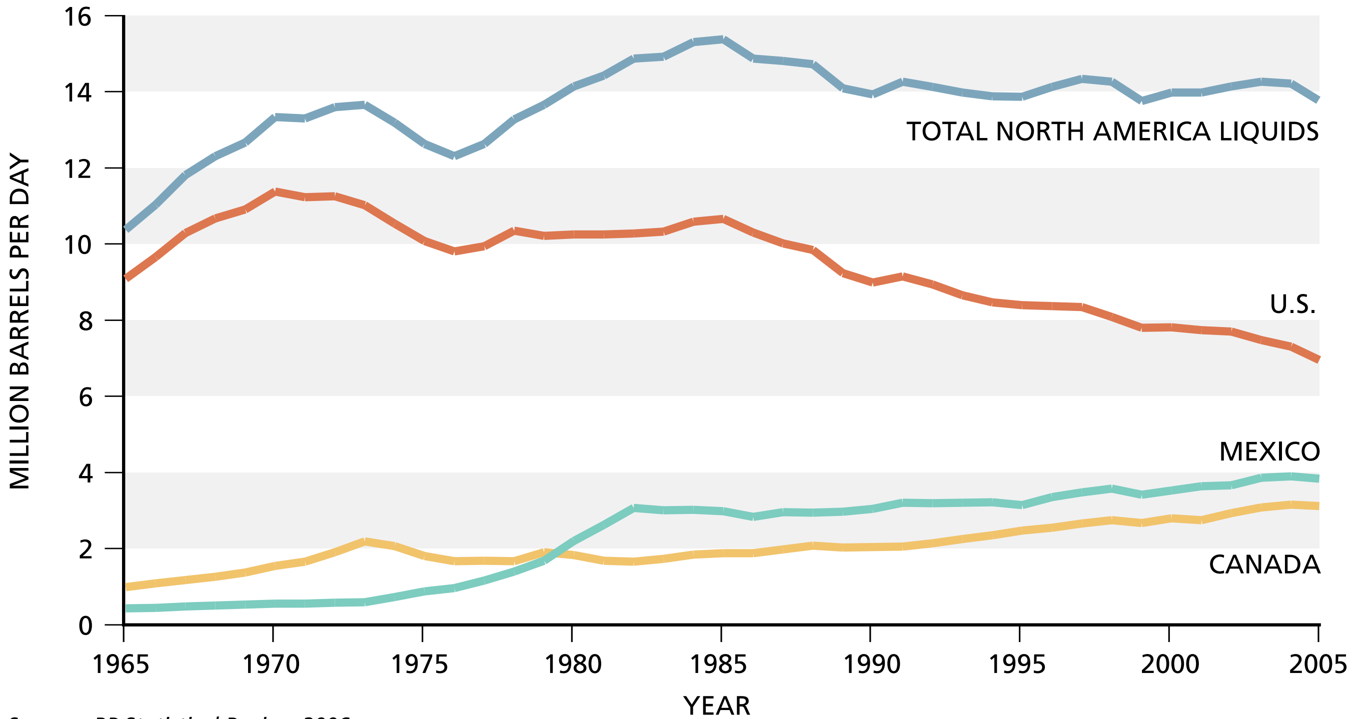
Peak oil forecasts point to the importance and dominance of large fields, since they have produced most of the world's oil. In general, large fields are among the first to be found, and have economically attractive scales and production costs. Production from such large reservoirs is usually considered conventional oil that did not require technology to stimulate oil flow during the early stages of production.

Views of an impending peak in liquids production are usually countered by expectations for new discoveries, additions to the resource base, new technologies, and greater operating experience that change the production profile of new and existing producing fields. Production rates are not fixed and can be influenced by these and other factors such as costs and price.

Peak oil forecasts are concerned about the ability to extend and apply experience from mature areas to less produced areas. As a hydrocarbon province matures, production transitions from large reservoirs to smaller, less prolific, and possibly higher-cost reservoirs. In the United States, for example, production from smaller and mature reservoirs dominates supplies. Peak oil forecasts assume that remaining smaller reservoirs will not compensate for declines in the larger reservoirs, resulting in declining conventional oil production in the near future. However, the North Sea has seen the evolution away from larger, depleted fields to smaller fields that can be brought online using existing infrastructure. North Sea production has actually been sustained for many years at significantly higher levels than was generally thought likely in the 1980s and early 1990s. Production growth from 1990 to 2000 shows how production in mature basins can revive as a result of new technology, price, or market dynamics.

As conventional oil development moves to smaller reservoirs in regions where access remains feasible, the industry is increasingly turning to frontier resources, deep and ultra-deepwater fields, and unconventional very heavy and sour fields. New developments include the Alaskan Arctic, deepwater Gulf of Mexico, offshore West Africa and Brazil, and Alberta oil sands. Frontier and unconventional resources in North America have compensated for declines in United States oil production, keeping total liquids production nearly flat over the last 15 years (Figure 2-40). This view of sustained North American production is challenged by expected and announced decreases in production from the Cantarell field in Mexico, the fourth largest producer in the world and source of most of Mexico's production in recent decades. Peak oil forecasts argue that development of smaller reservoirs will not be able to reverse Mexico's decline.

Although production growth from frontier and unconventional resources will require long lead times



Source: *BP Statistical Review 2006.*

FIGURE 2-40. *North American Liquids Production*

and very large investments, there is considerable agreement about continued growth in the supply of unconventional oil and alternative liquids. However, peak oil forecasts do not see these resources as offsetting declines in existing conventional oil production.

A country's oil production profiles are the sum of the production profiles of the fields in that country, just as fields are the sum of profiles of individual wells. The overall decline rate of a field is a combination of the decline from existing wells and the production volumes from new wells. In addition, changes in production technology and the use of enhanced recovery techniques can reduce expected declines.

Figure 2-41 shows typical production profiles as they evolve over time. The curves can apply at different scales from individual oil wells to fields, countries, or larger regions. Wells and fields vary in their stage of development: some may be declining, some at a production plateau, while others may be ramping up production. The global production profile is the aggregate of the profiles from all individual fields with diverse profiles.

While most fields have production profiles shaped like Part A of Figure 2-41, many have other more

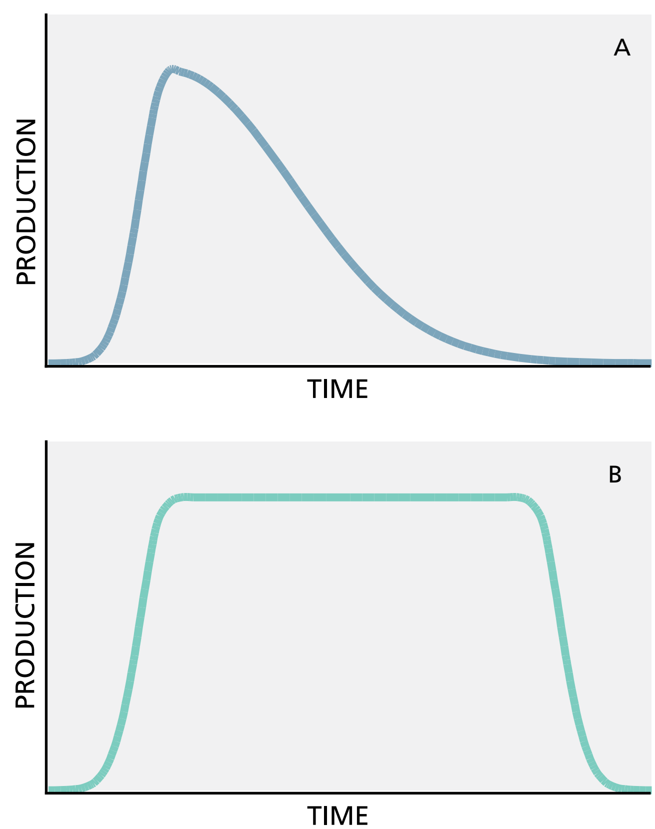


FIGURE 2-41. *Typical Oil Production Profiles*

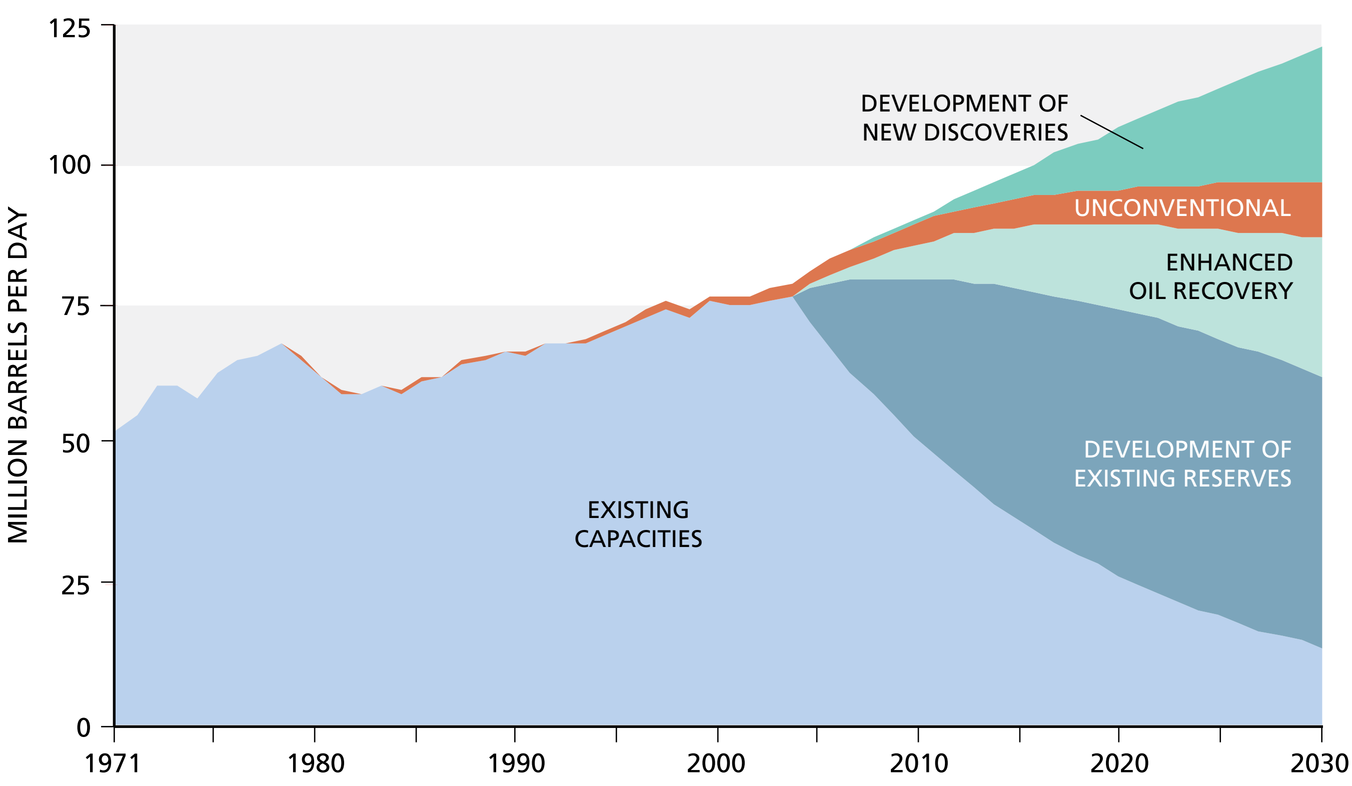
general profiles. For example, where downstream bottlenecks constrain production, the profile may plateau as in Part B. Historically, technology advances have increased the recovery factors, or percent of resources, recovered from a reservoir. Technical advances, such as enhanced oil recovery (EOR), will continue to improve recovery factors and thus modify production profiles for individual wells and fields. For a complete discussion of production profiles and potential technology effects, see the Conventional Oil section in the Technology chapter of this report.

Figure 2-41 is illustrative. It demonstrates that managing the shape and duration of the production profile is a central issue not only in the peak oil debate but in all prospects for oil supply.

Investment

The IEA WEO 2006 Reference Case estimates that the global oil industry will need a total investment of about $4.3 trillion between 2005 and 2030, or about $164 billion annually, to meet projected demand. Most of the projected investment will be in the upstream sector, largely devoted to maintaining existing production capacity. The IEA investment figure is substantially higher than prior years, partly based on sharp increases in unit capital costs. Other causes for the higher projection include the cost of developing remote, technically challenging, or deeper reservoirs, or oil in smaller accumulations. Additional capital will be needed to minimize production declines at the world's largest, aging fields. A recent OPEC study showing strong correlation between exploration and production (E&P) investment and oil production rates suggests that projected capital requirements are likely to increase.

Much of the world's existing oil production will need to be replaced by 2030. Figure 2-42 is an illustrative example of the various resource components that contribute to total liquids supply. These components contribute to virtually all liquids supply projections, although the combination and timing of the components may differ. Maintaining current oil supply levels will require slightly more than half the $4.3 trillion



Source: IEA, *World Energy Outlook 2004*.

FIGURE 2-42. *Illustrative Total Liquids Supply* investment. The remaining investment will be needed to expand supply to meet projected demand and build or replace infrastructure. Financing this investment is likely to be a major undertaking, with enormous requirements in individual countries and regions. For example, projected investment in China alone is about $350 billion, or half the total for Middle Eastern countries. Of the total global investment, more than half is expected to be in developing countries.

Geopolitics

Oil is currently a fungible commodity traded in global markets. Changes in oil trading patterns are expected during the study's time frame, based on evolving relationships between importing and exporting countries and regions. Global redistribution of infrastructure and manufacturing capability will also change commodity and product trade flows. These changes are likely to have important and uncertain geopolitical dimensions. For example, the IEA reports that OECD countries imported 17.9 million MB/D from OPEC producers in 2003, or 57 percent of OPEC's petroleum exports. The IEA Reference Case shows these exports rising by 3.2 MB/D at the end of the study time frame, with slightly more than 40 percent of the increase supplied from the Persian Gulf. The projection assumes that the existing OECD–OPEC trading relationship can be reliably extrapolated. If this is not case, the availability of supply becomes a more uncertain and pressing issue. Such geopolitical factors apply to all energy forecasts and are fully addressed in the Geopolitics chapter of this report.

Natural Gas

Key Observations—Natural Gas

- *Most forecasts project that global natural gas production will grow rapidly to meet increasing demand.*
- *Current estimates of recoverable natural gas resources are sufficient to sustain the large, anticipated increase in production over the study time frame, providing above-ground issues and challenges do not become major constraints.*
- *As gas production in OECD countries lags demand growth, these demand centers will require major additional infrastructure to ensure delivery by pipeline and liquefied natural gas (LNG).*
- *Growth in global natural gas trade is expected to occur at a faster pace than historically, with the largest new supply volumes originating in Russia and the Middle East.*
- *Additions to LNG supply capacity are capital intensive, complex, and face development uncertainty. Growing risks in the investment climate for LNG and for long-distance natural gas pipelines may delay or reduce supply availability.*
- *North American and U.S. natural gas production is likely to lag projected demand growth over the study time frame, requiring significant growth in LNG imports. The wide range of projected U.S. LNG import requirements raises uncertainty about whether these requirements will be met, particularly at the higher estimates.*
- *Unconventional natural gas is expected to make up an increasingly important share of U.S. gas production*
- *Development of Arctic natural gas resources, both in the United States and Canada, could contribute significantly to North American gas supply if major infrastructure is developed*
- *Increased access to restricted and moratoria areas on U.S. offshore and onshore public lands could increase natural gas supplies available to the United States.*
- *Natural gas demand in a carbon-constrained world is likely to be significantly higher than in a business-as-usual future, increasing the importance of timely supply and infrastructure development.*

Global Natural Gas Endowment and Technically Recoverable Resources

In 2000, the USGS estimated that remaining recoverable conventional gas resources totaled about 12,000 trillion cubic feet (TCF). This is the mean estimate in a range from 8,000 to 19,000 TCF. This gas volume is equivalent to about 2 trillion barrels of oil, or double the total amount of oil produced globally to date. Many gas supply forecasts base their projections on the USGS estimate, which is somewhat higher than proprietary estimates aggregated for this study. For example, the IOC aggregated mean for total recoverable resources is 12,000 TCF, with a range of 11,300 to 13,900 TCF. The IOC range for remaining recoverable resources is 8,000 to 12,000 TCF, with a mean of 10,300 TCF. The USGS recoverable resource assessments do not include unconventional gas, which may represent a significant addition to gas supplies over the next 25 years. Similarly, the assessments do not include natural gas hydrates, a potentially significant resource that is not currently considered technically recoverable and is unlikely to be developed over the study time frame.

About 3,000 TCF of natural gas has already been produced (Figure 2-43). The projected supply of natural gas to 2030 ranges from 3,100 to 3,650 TCF. Thus, current mid-range estimates of conventional, global, technically recoverable resources are considerably greater than combined historical and projected production. Indeed, mid-range projections expect less than 50 percent of USGS-estimated conventional gas reserves to be produced by 2030. If IOC mean or low-range estimates prove more accurate, global gas production will exceed 50 percent of the technically recoverable resource by 2030. Whether or not global natural gas production reaches a plateau during the study time frame, the possibility becomes greater within the next 50 years, unless a major technical breakthrough allows economic production of significant volumes of unconventional gas and gas hydrates.

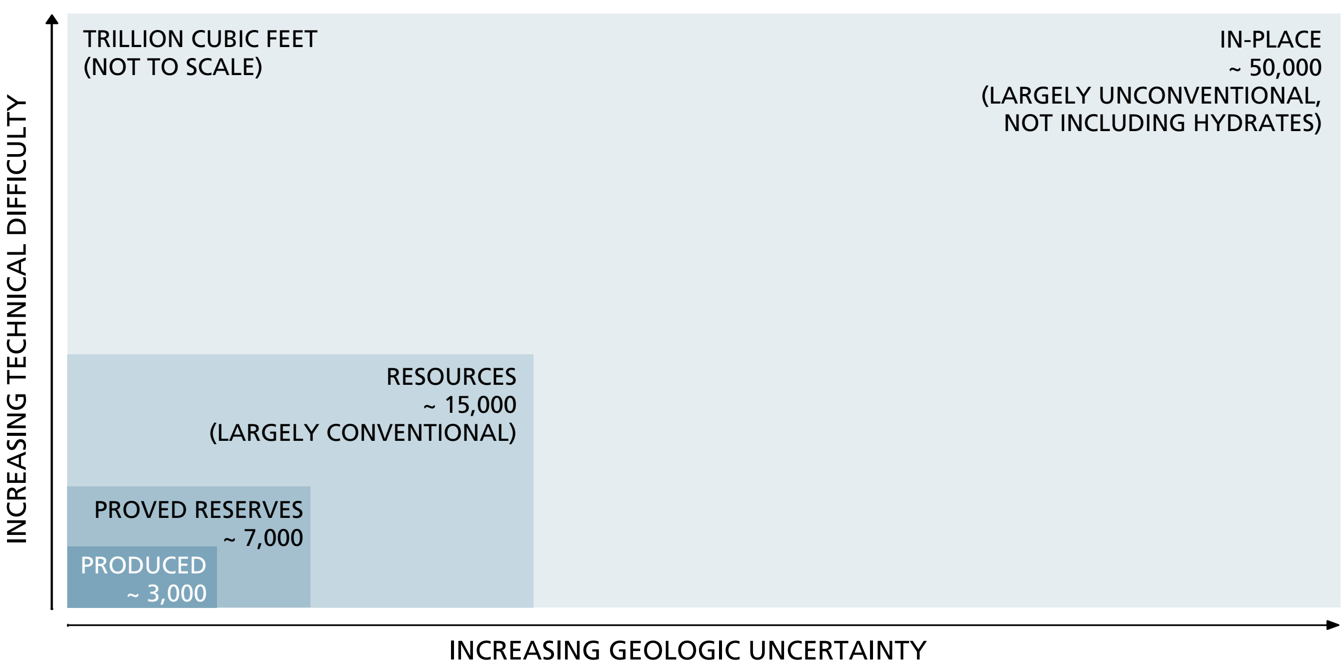
Nearly 83 percent of technically recoverable natural gas resources are in the Middle East, Non-OECD Europe, Asia/Oceania, and Africa (Figure 2-44). The overall distribution of resources is becoming more remote from major natural gas markets, with the exception of Russia, a major gas consumer as well as resource holder.

Current proved reserves of natural gas are concentrated in a few countries, with Russia, Iran, Qatar, and Saudi Arabia comprising more than two-thirds of the global total (Figure 2-45). Of the 12 largest resource owners, 11 are outside the OECD, comprising more than 75 percent of global gas reserves. Such concentration raises issues about risks and the costs of developing and producing the reserves to meet growing gas demand.

U.S. Technically Recoverable Gas Resource

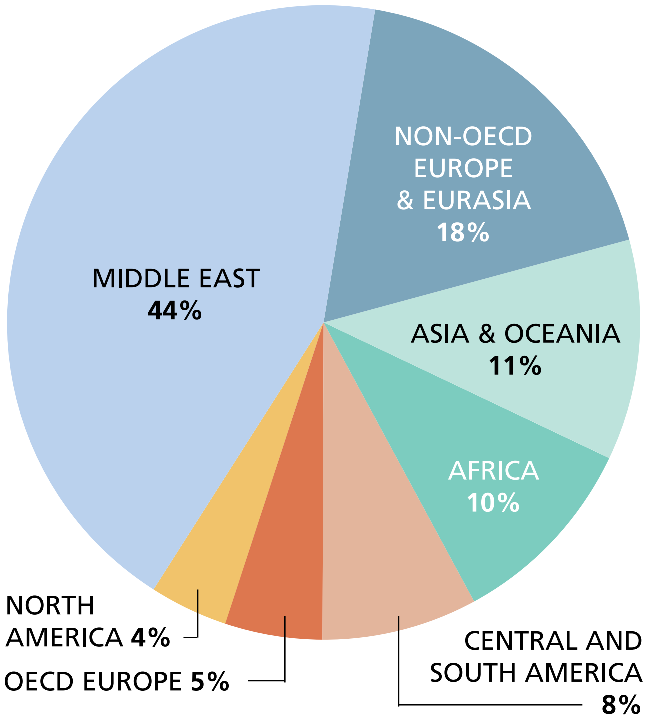
The 2003 NPC study, *Balancing Natural Gas Policy*, estimated that about 1,450 TCF of technically recoverable resource remain in the United States. Technical advances may add an additional 400 to 500 TCF by 2030 (Table 2-4).

The technically recoverable domestic gas resource is subject to numerous restrictions. About 162 TCF of the U.S. onshore recoverable natural gas resources



Sources: U.S. Geological Survey, 2000; and Rogner, H-H., "An Assessment of World Hydrocarbon Resources," Institute for Integrated Energy Systems, University of Victoria, 1997.

FIGURE 2-43. *Global Natural Gas Endowment*

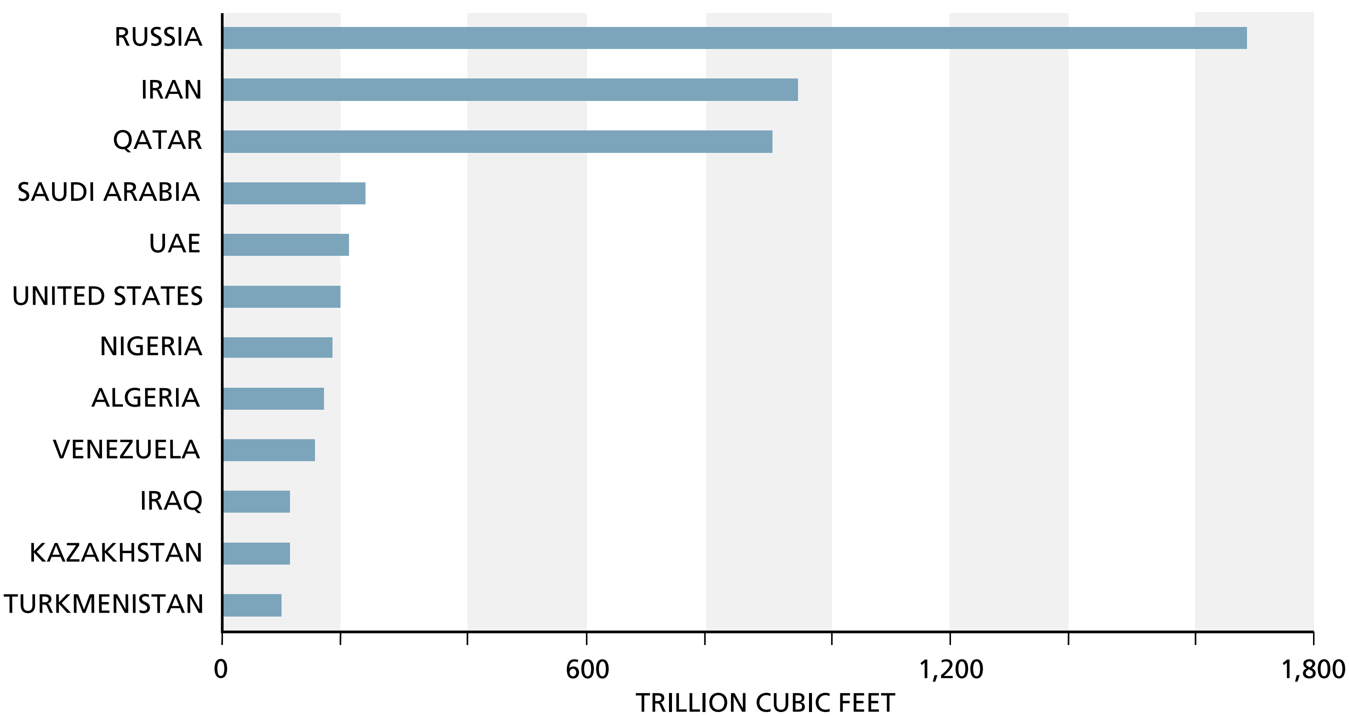


Source: U.S. Geological Survey, 2000.

FIGURE 2-44. *USGS Estimated Natural Gas Resource Shares, 2000*

lie beneath federal lands that are restricted beyond standard lease terms or are entirely off limits. This estimate was developed by government studies conducted in accordance with the U.S. Energy Policy and Conservation Act of 2000 and the Energy Policy Act of 2005. The restricted areas range from Alaska to the Rockies, the Gulf Coast, and Appalachia. Approximately 92 TCF of U.S. offshore technically recoverable natural gas resources are also currently off limits for leasing and development. Of these, almost 86 TCF of natural gas are in the federal U.S. Outer Continental Shelf (OCS) moratoria areas (Table 2-5). Resource estimates for all restricted areas are very uncertain, since the last seismic data acquisition or drilling in some cases occurred 25 to 40 years ago.

In aggregate, access is restricted to 76 percent of U.S. technically recoverable natural gas resources. About 66 percent of domestic resources (882 TCF) are on state, tribal, and private lands, predominantly in onshore tight gas and shale formations. The technical challenges to developing domestic gas resources are compounded by urban growth, competing land use, and changing public values that increasingly constrain existing and new natural gas development.



Source: *BP Statistical Review of World Energy 2006.*

FIGURE 2-45. *Largest Natural Gas Reserve Holders, 2005*

	Current Tech-nology	2015 Tech-nology	2030 Tech-nology
Lower-48 Onshore	764	839	1,006
Lower-48 Offshore	384	415	486
Alaska	303	331	395
Total U.S.	1,451	1,585	1,887

Source: National Petroleum Council, *Balancing Natural Gas Policy,* 2003.

TABLE 2-4. *U.S. Natural Gas Resource Base (Trillion Cubic Feet)*

Moratoria Areas	Resources
Gulf of Mexico	22
Alaska	9
Atlantic	37
Pacific	18
U.S. Federal OCS	**86**
Great Lakes	5
State Waters	1

Sources: Department of the Interior (MMS and USGS) and Interstate Oil and Gas Compact Commission.

TABLE 2-5. *U.S. Offshore Natural Gas Resources in Moratoria Areas (Trillion Cubic Feet)*

The United States has almost 290,000 marginal gas wells.[7] In 2005, marginal wells accounted for 1.7 TCF of natural gas per day, or more than 9 percent of domestic onshore production. Increasing operational and regulatory costs and diminishing pipeline access to markets may contribute to premature abandonment of these wells and loss of gas production. When marginal wells and fields are prematurely abandoned, the associated oil and gas resources may never be recovered due to economics, lease termination, and related issues—thus widening the gap between projected gas demand and domestic supply.

7 Interstate Oil and Gas Compact Commission (IOGCC), *Marginal Wells: Fuel for Economic Growth* (2006). The IOGCC defines marginal wells as those producing 60 thousand cubic feet or less of natural gas per day. The Internal Revenue Service defines marginal wells as producing 75 thousand cubic feet or less of natural gas per day.

Global Natural Gas Production

Global gas production to 2030 is forecast to grow faster than the historical rate since 1980 of about 50 billion cubic feet per day per decade. The EIA and IEA 2006 Reference Cases project growth rates of 2.4 percent and 2.0 percent, respectively. Both rates are higher than the growth rates for coal and oil over the study time frame (Figure 2-46).

The proprietary forecasts aggregated for the study show average gas production of about 450 billion cubic feet per day in 2030, a value very similar to the IEA Reference Case. The upper and lower limits are approximately 425 and 500 billion cubic feet per day (Figure 2-47).

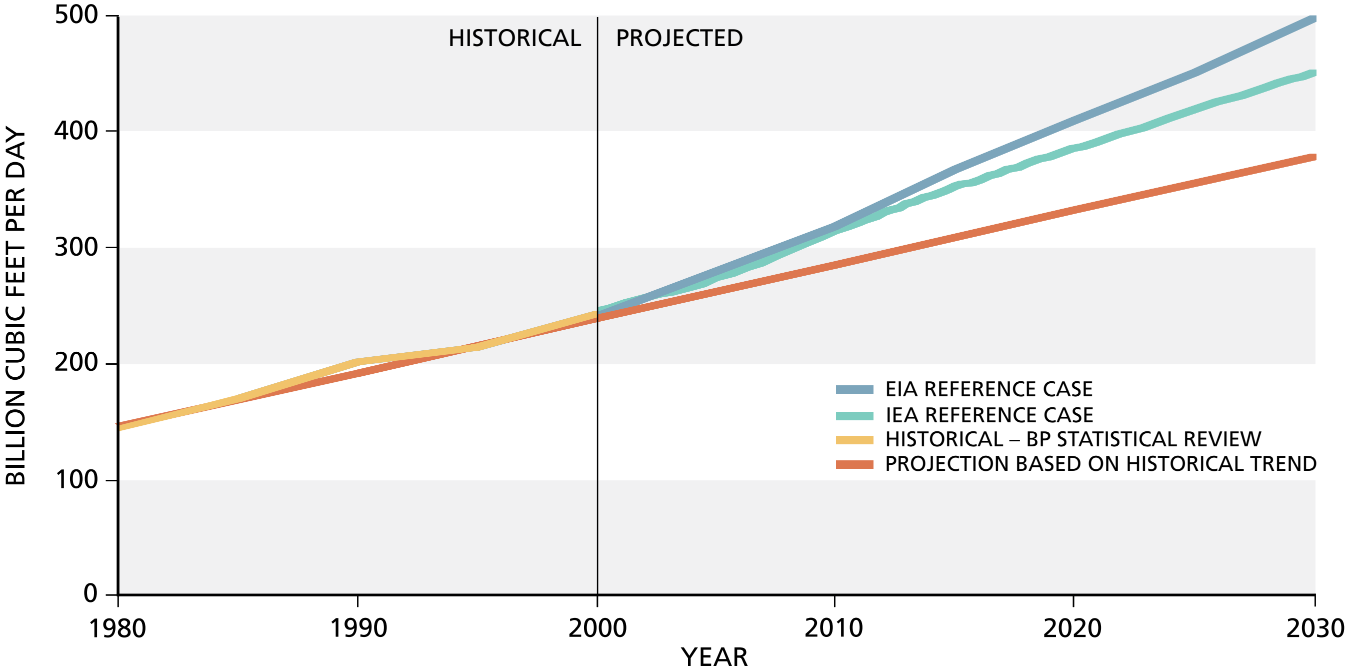
The highest projected natural gas production in 2030 is 530 billion cubic feet per day. This forecast requires a high supply of gas to balance energy demand, since it also projects that oil production in 2030 will be below today's level (Figure 2-48). Most Alternative Policy cases in Figure 2-48 also project gas production above 400 billion cubic feet per day, as the energy mix increasingly favors lower carbon fuels that reduce carbon dioxide emission levels.

Regional Supply Patterns

Regional supply patterns for natural gas are shifting. Forecasts show that production and exports from the Middle East, Non-OECD Europe (Russia), and Asia (Australia) will increase substantially over the next 25 years, although in total Asia will probably remain a net importer of natural gas (Figure 2-49). The United States and OECD Europe are likely to increase their dependence on gas imports, since most projections show continued growth in demand but flat or declining production in these regions.

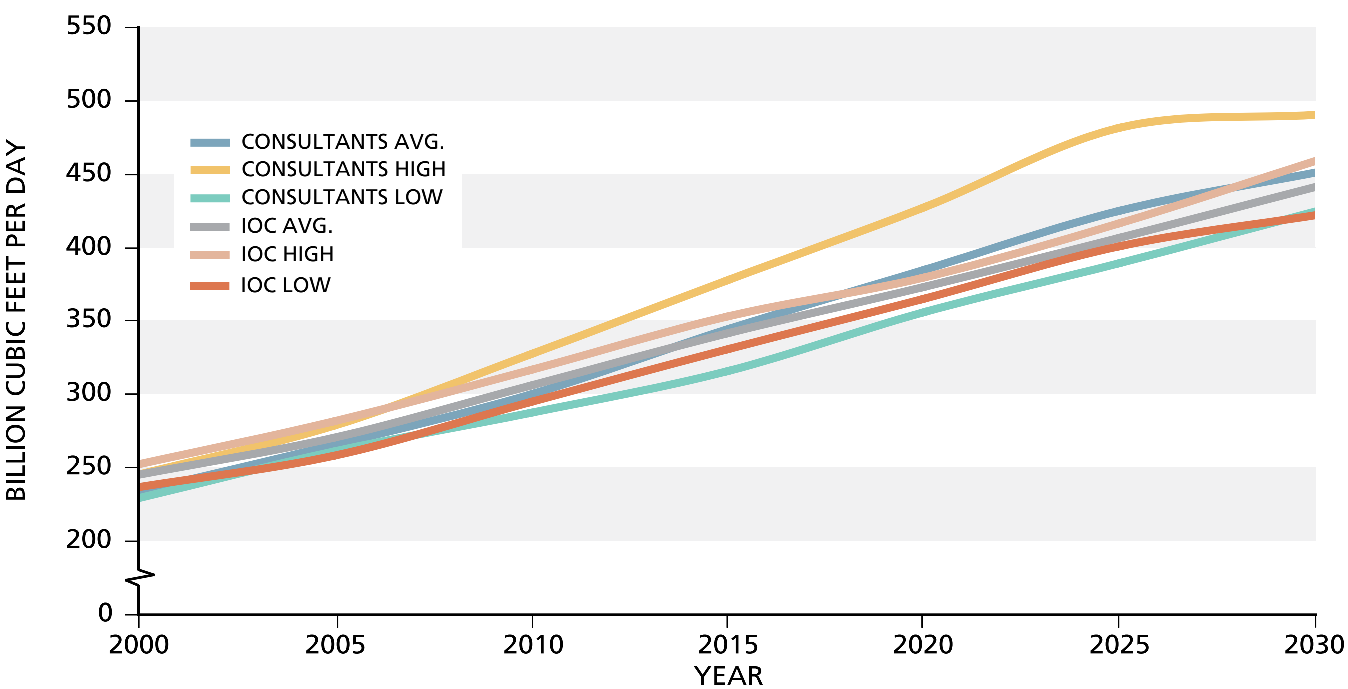
Most growth in natural gas production is expected to occur in exporting countries. Transporting the gas to consuming regions will require substantially increased investment in production and transportation infrastructure, particularly:

- Liquefaction plants in producing countries and regasification terminals in consuming countries for LNG.
- Long-distance, high-capacity natural gas pipelines.



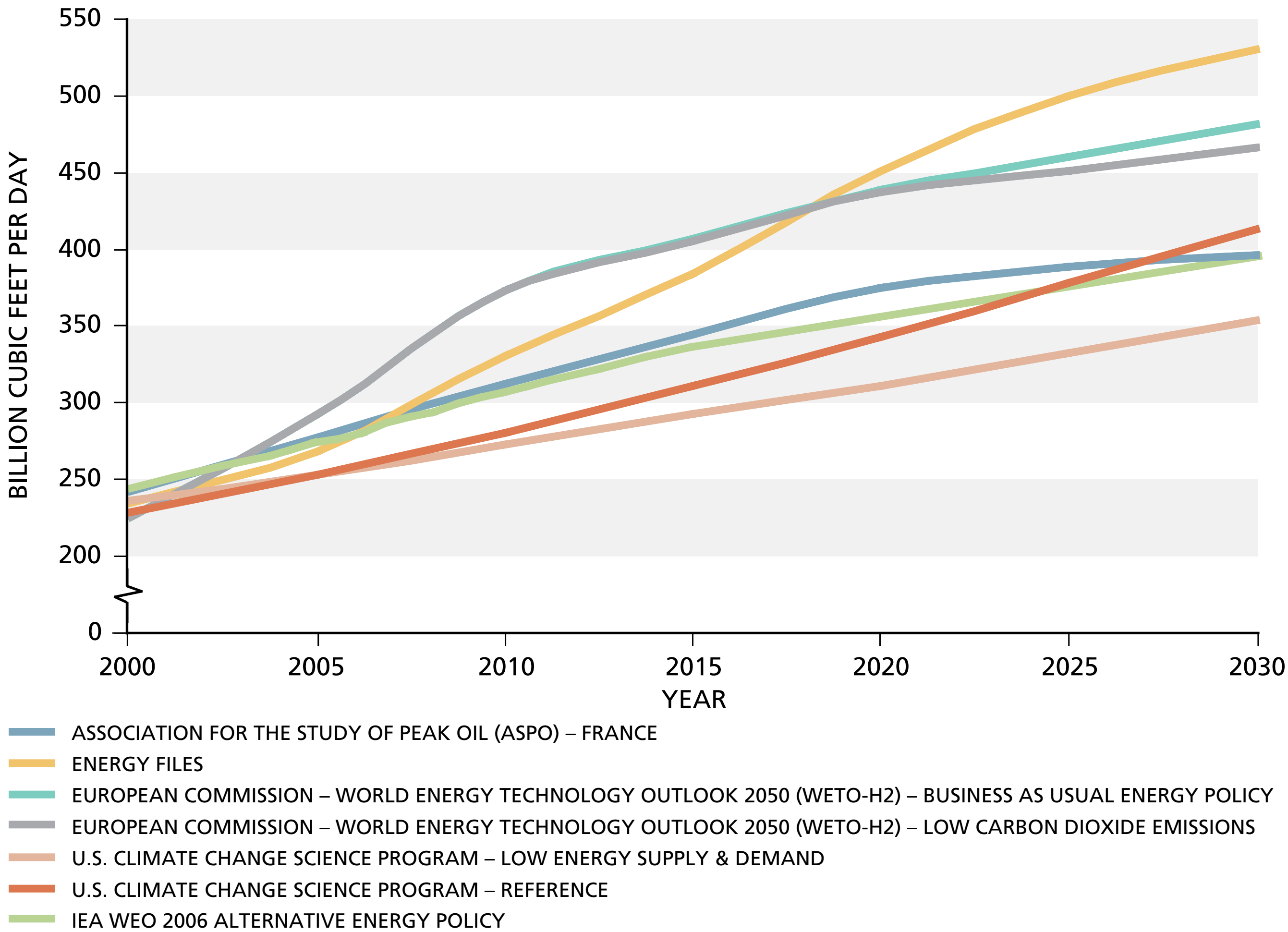
Sources: Energy Information Administration (EIA), *International Energy Outlook 2006;* International Energy Agency (IEA), *World Energy Outlook 2006;* and *BP Statistical Review of World Energy 2006.*

FIGURE 2-46. *Projected Global Natural Gas Production*



Note: IOC = International Oil Companies.
Source: NPC Survey of Outlooks.

FIGURE 2-47. *Projected Global Natural Gas Production — Proprietary Aggregated Data*



Source: NPC Survey of Outlooks.

FIGURE 2-48. *Projected Global Natural Gas Production — Public Data*

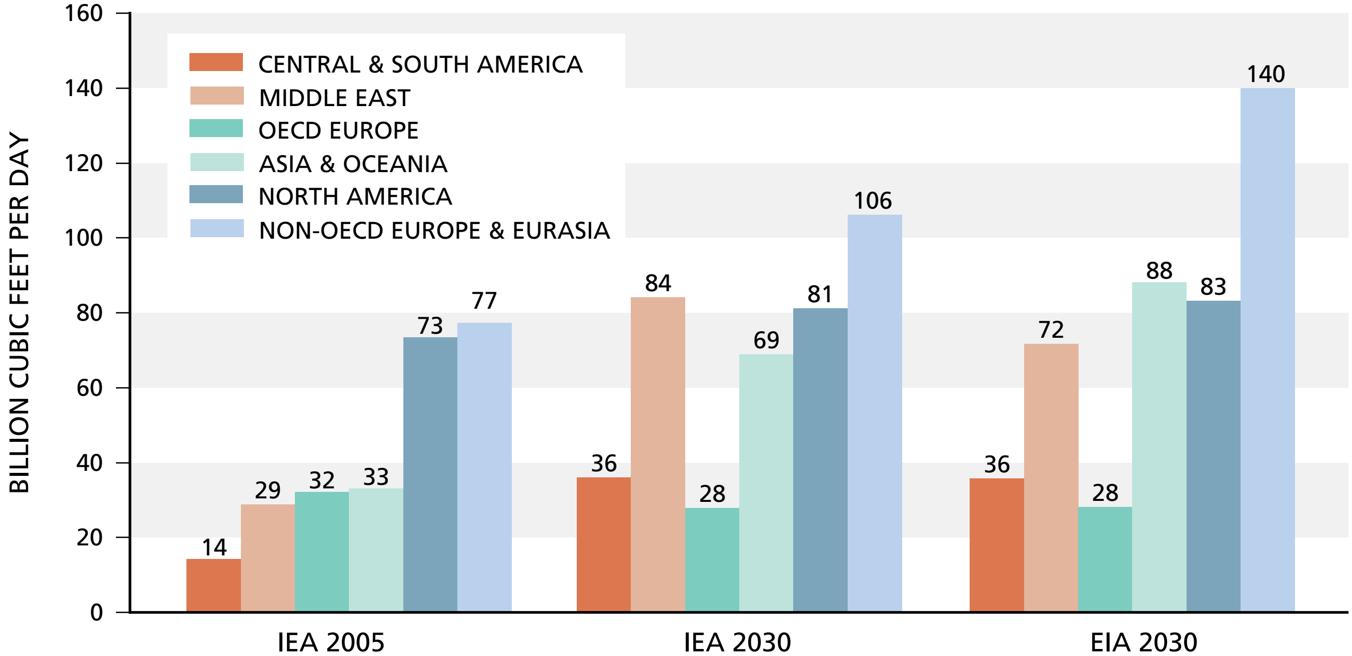
Figures 2-50, 2-51, and 2-52 show the increasing importance of imports in the main OECD demand regions that were traditionally supplied from indigenous sources. Domestic supply in North America is expected to decline and then, possibly, to reach a plateau as unconventional resources (e.g., tight gas, coalbed methane, and shale gas) supplement domestic conventional gas production. Most forecasts assume that pipeline supplies from Alaska and the Mackenzie Delta will reach North American markets in the study time frame. However, projected demand growth will ultimately be met by increasing LNG imports.

Domestic production in Europe is expected to be flat or declining, with pipeline imports increasing dramatically, primarily from Russia and the Caspian region. LNG imports will also play a growing and more significant role in meeting Europe's gas requirements.

Unlike other major consuming areas, Asia Pacific is expected to see a significant increase in domestic production of natural gas. Much of this growth will be traded between producing countries such as Indonesia and Australia and consuming countries such as Japan and China. The region will also need greater supplies of LNG to meet about 30 percent of projected regional demand. Long-distance gas pipelines to Russian, Caspian, and Middle East supplies are also a potential option.

North American Gas Production

Natural gas production in the United States has been relatively flat over the past 35 years, while



Sources: International Energy Agency (IEA), *World Energy Outlook 2006;* and Energy Information Administration (EIA), *International Energy Outlook 2006*.

FIGURE 2-49. *Projected Regional Natural Gas Production (Regional Data)*

demand has been growing over most of that period (Figure 2-53). Since the mid-1980s, most of the growing gap between domestic production and consumption has been filled by increased gas pipeline imports from Canada. Since 2003, LNG imports from several other countries have also grown, making a small but increasingly important contribution to U.S. gas supply.

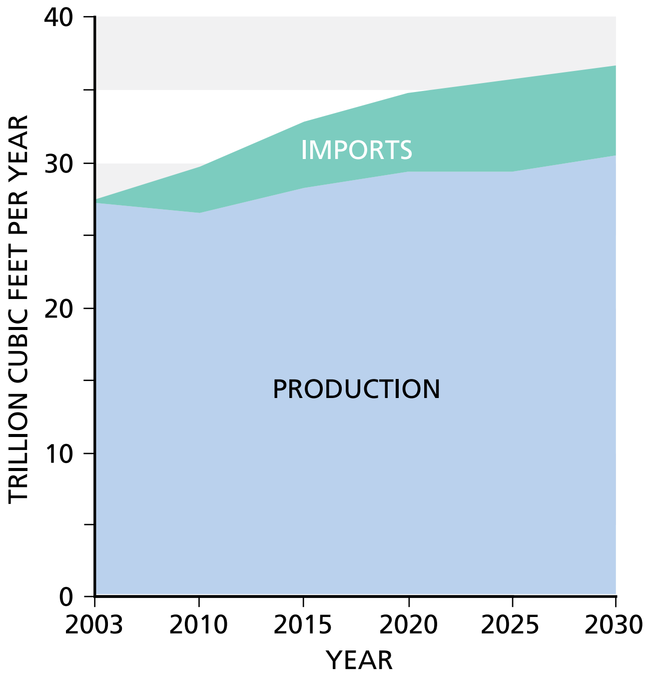
For North America as a whole, natural gas production has been largely sufficient to meet demand over the past 35 years (Figure 2-54). Growing integration of the pipeline systems of Canada, the United States and Mexico has allowed regional trade flows to develop and balance the gas markets in each of the countries. Beginning in 2004, the region has imported larger quantities of LNG, with the LNG contribution reaching about 2 percent of North American supply by 2006.

EIA projections show some potential for maintaining a slow growth rate in North American natural gas production (Figure 2-55). The IEA concurs with this outlook, also projecting a North American natural gas production growth of about 0.4 percent per year. Both forecasts assume growing success in exploiting unconventional natural gas resources in North America and completion of two major pipelines to bring Arctic gas to market centers from Alaska and the Mackenzie Delta. The risks and challenges associated with these potential supply sources are discussed below.

Over the next 25 years, it will be an increasing challenge to avoid declining conventional gas production rates in the United States. The 2003 NPC natural gas study identified such contributing factors as accelerating decline rates, decreasing size of new conventional discoveries, and higher finding and development costs for deeper and more technically challenging gas accumulations.

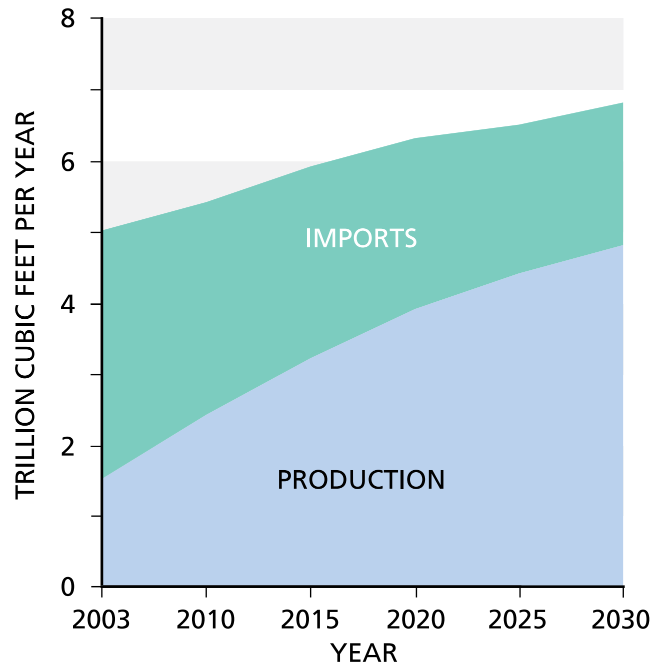
The forecasts analyzed for the current study largely agree that domestic conventional gas production will decline over the forecast period, assuming that restricted onshore and offshore areas will not be developed. The balance of natural gas supply to the United States over the next 25 years is generally expected to be met by a combination of three elements:

- Increased domestic production of unconventional gas (basin-centered gas, tight gas, shale gas, coalbed methane)



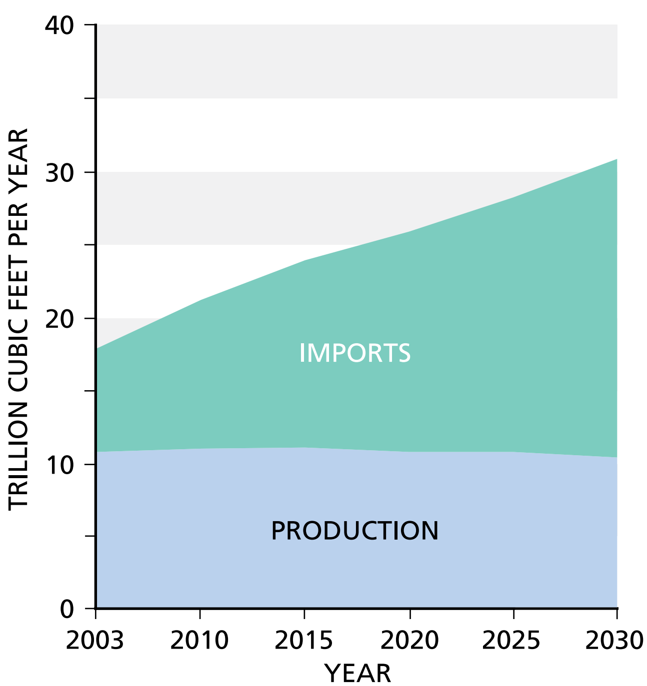
Source: Energy Information Administration, *International Energy Outlook 2006*.

FIGURE 2-50. *North American Natural Gas Production and Imports*



Source: Energy Information Administration, *International Energy Outlook 2006*.

FIGURE 2-52. *OECD Asia Natural Gas Production and Imports*



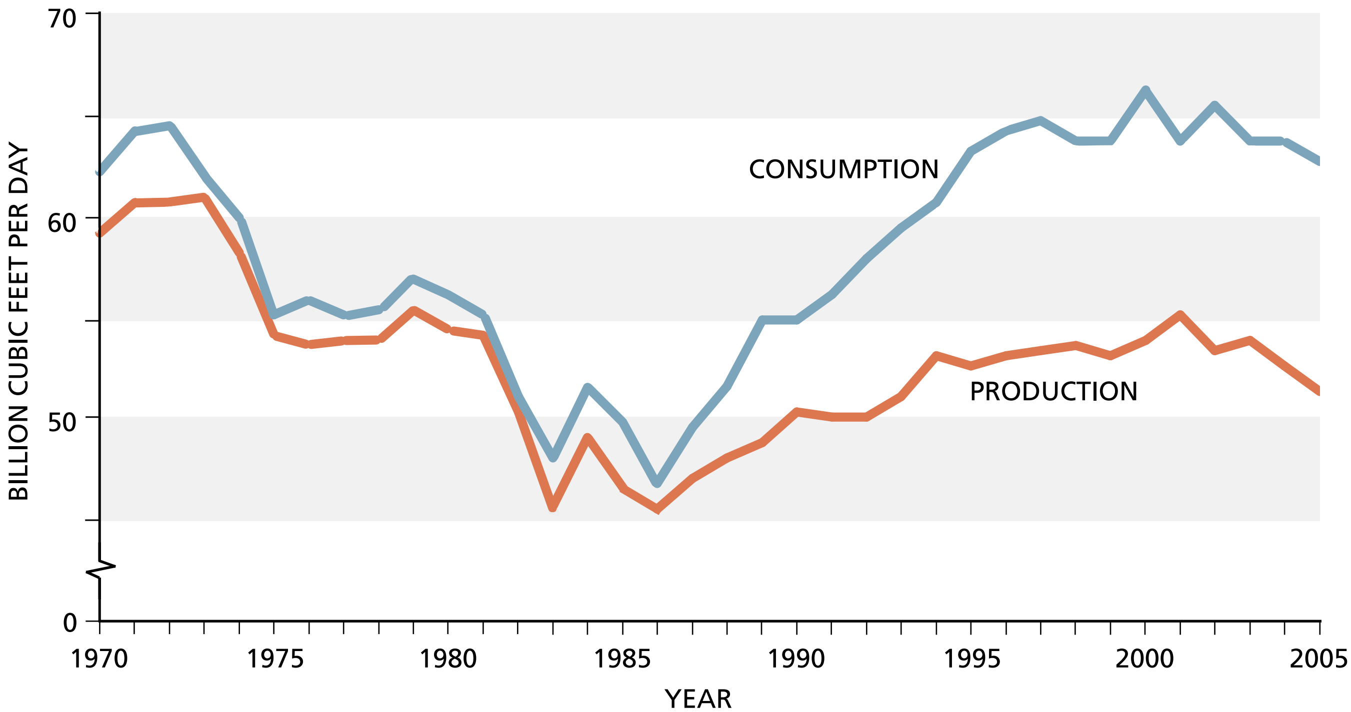
Source: Energy Information Administration, *International Energy Outlook 2006*.

FIGURE 2-51. *OECD Europe Natural Gas Production and Imports*

- Arctic gas resources from Alaska and the Canadian Mackenzie Delta, both of which require development and massive new infrastructure to bring gas to market
- Increased LNG imports.

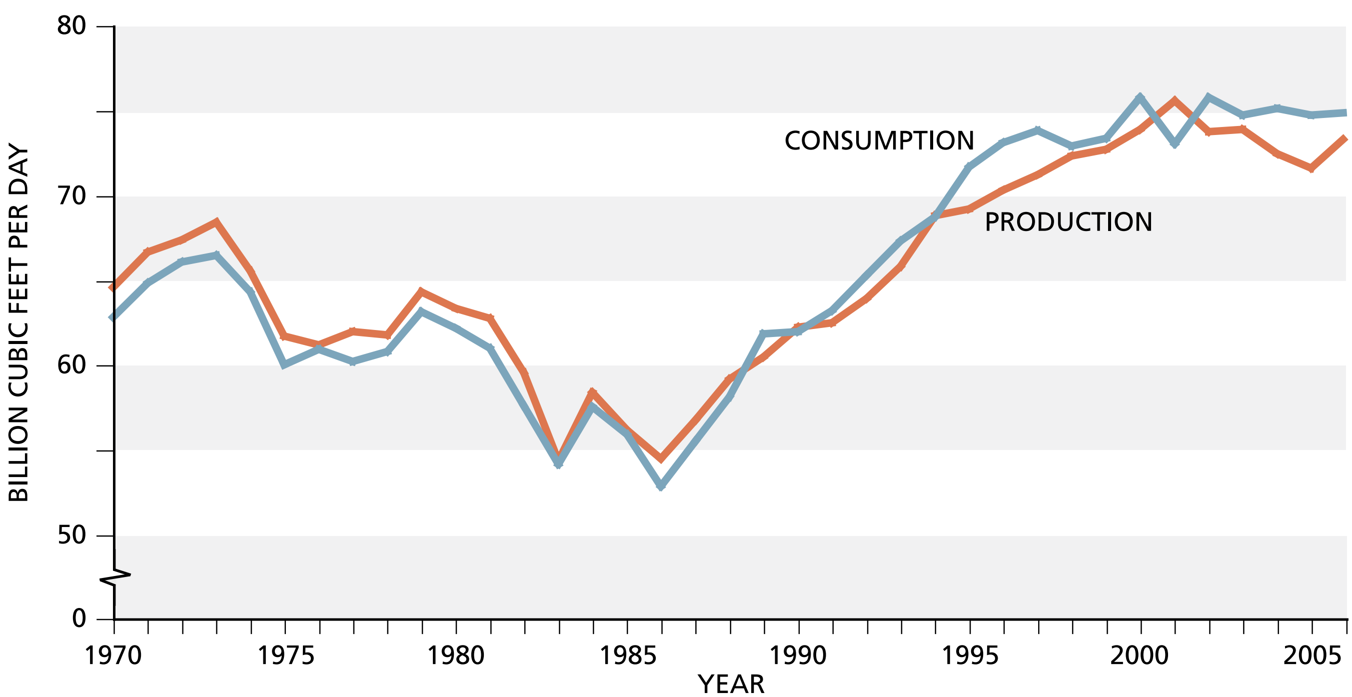
Each of these elements may be subject to risks that make development slower or less significant than the forecasts assume.

Unconventional gas typically costs more to develop than conventional gas, requires different production technologies, has a different environmental impact, and produces at lower rates. Therefore, maintaining or increasing investment in unconventional gas will be essential to growing supply. In addition, many unconventional gas resource basins are located in areas at some distance from demand centers. For example, the Rocky Mountain and San Juan basin regions contain very significant resources of tight gas, coalbed methane, and basin-centered gas. Growth in production capacity in these regions proportionate to the resource size will require new pipeline capacity to bring the gas to markets in the Midwest, Northeast, and West Coast.



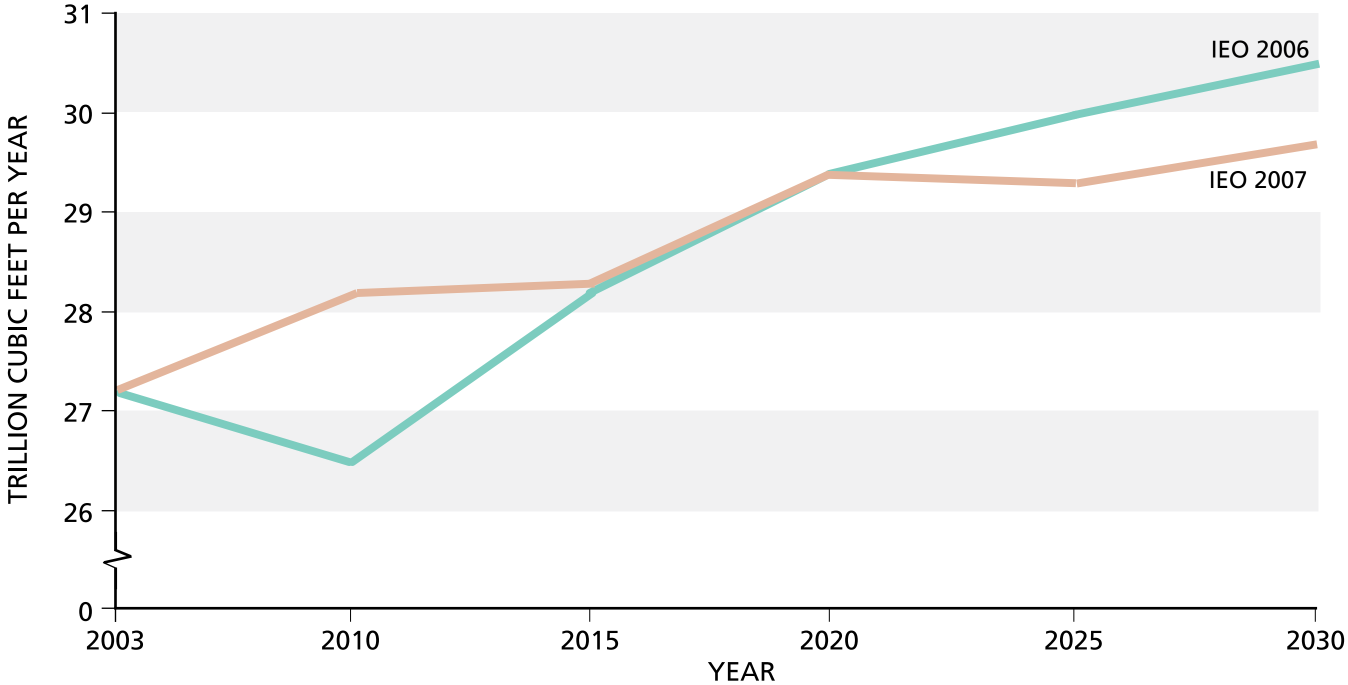
Source: *BP Statistical Review of World Energy 2006.*

FIGURE 2-53. *U.S. Natural Gas Production and Consumption, 1970-2005*



Source: *BP Statistical Review of World Energy 2006.*

FIGURE 2-54. *North American Natural Gas Production and Consumption, 1970-2005*



Source: Energy Information Administration, *International Energy Outlook 2006* and *2007.*

FIGURE 2-55. *Projected North American Natural Gas Production*

Most forecasts assume that Arctic gas from the United States and Canada will contribute significant volumes to North American supply, perhaps 6 to 8 billion cubic feet per day by around 2020. Huge stranded gas resources exist in the Arctic regions, but bringing gas to markets will require construction of new high-capacity, long-distance pipelines through Arctic terrain. Companies and agencies involved in proposed development of these pipelines have thus far not resolved complex issues involving regulatory frameworks, fiscal regimes, local communities, and environmental impacts. The investment required for these pipeline projects is huge, amounting to tens of billions of dollars. If the issues cannot be resolved, there is a significant risk that the investments may not be made in the timeframe of this study. If Arctic gas is not developed, North America and the United States would require significantly higher LNG imports.

Gas Supply Challenges

Considerable uncertainty surrounds the growth of natural gas production from mature areas as well as the timing of new projects in specific countries and regions. Table 2-6 summarizes various challenges that may constrain gas production. They include restricted access to resources; uncertain investment and fiscal frameworks; requirements for high-capacity, long-distance infrastructure; shortages of skilled people; escalating costs and possible shortages of vital equipment; geopolitical tensions; development policies of major gas resource holders; and the time required to develop and deploy new technology. The challenges are dynamic and will have different combinations in time and place over the time frame of the study.

Considering investment alone, the IEA WEO 2006 Reference Case estimates that the required investment in natural gas supply will amount to $3.9 trillion over the next 25 years. This figure includes large capital investments in Russia, Qatar, Iran, Nigeria, and Australia to increase exports.

Russia, the largest regional supplier to Europe, will be challenged to meet European demand growth while initiating exports to Asia and supplying its large and growing domestic market. The IEA projects that the Middle East and Africa will provide more than two-thirds of global inter-regional exports. At the same time, the Middle East will see increased

		Access	Investment	Infra-structure	People and Equipment	Geopolitics
Large Producers	*Current Production (Billion Cubic Feet per Day)*					
Russia	~100	X		X		X
United States	~ 50	X	X	X		
Indonesia	~ 10		X			
Production Growth	*2005-2030 Expected Growth (Billion Cubic Feet per Day)*					
Russia	+ 30	X		X		X
Qatar	+ 15				X	
Iran	+ 15	X	X	X	X	X
Nigeria	+ 10		X			
Australia	+ 10		X			

Note: An X in any column means that the matter is problematic or open to question.

Source: NPC Survey of Outlooks.

TABLE 2-6. *Natural Gas Supply Challenges*

domestic demand. It will also need natural gas to maintain pressure or enhance recovery in its oil fields.

Liquefied Natural Gas (LNG)

Key Observations—LNG

- *LNG trade is projected to grow faster than historical or future global gas and energy demand.*
- *The natural gas reserve base can support the projected expansion of LNG supply over the next 25 years.*
- *The global LNG market has many new entrants.*
- *Major uncertainties surround the scope and pace of liquefaction development in key supply countries.*

This section summarizes a full discussion in the LNG Topic Paper included on the CD distributed with this study.

Liquefied natural gas is a means of delivering natural gas from the wellhead to the market. Cooling the gas to such low temperatures that it converts to liquid reduces its volume, making it economical for transport over long distances by specialized ship. Since natural gas is in many cases too far from markets to be economically or practically transported by pipeline, liquefaction provides a way to link remote gas to markets.

Despite its rapid growth in recent years, LNG remains a relatively small contributor to total internationally traded gas. It comprises about 22 percent of the total gas trade and supplies only 7 percent of global gas demand. Pipeline gas still dominates international trade, notably supply to Western Europe from Russia, North Africa and Norway, and supply to the United States from Canada. By region, LNG trade in the Pacific Basin and Asian markets is almost double the size of Atlantic Basin and Mediterranean markets. However, the Atlantic Basin market has grown much faster than the Pacific market over the past ten years, growing by 12 percent per year compared to 5.5 percent per year in the Pacific market.

Global LNG Forecasts

All forecasts agree that global LNG growth is very likely to accelerate over the next 25 years. In the IEA WEO 2006 Reference Case, LNG trade grows by 6.6 percent per year between 2004 and 2030, from around 9 billion cubic feet per day to 46 billion cubic feet per day. The expected LNG contribution grows more than three times faster than a projected 2 percent per year increase in world natural gas demand. The IEA also projects that LNG will account for 70 percent of the increase in gas trade by 2030. LNG would then comprise half the internationally traded gas by 2030, compared to around 22 percent in 2004. The IEA identified key trends in the changing pattern of LNG supply:

- The Middle East and Africa account for over 70 percent of the increase in gas exports by 2030, mainly to supply Europe and North America.
- Russia will begin supplying gas to Asian markets by LNG.
- Australia and the Middle East will supply LNG to China.
- Venezuela is projected to emerge as an important supplier to North America and Europe.

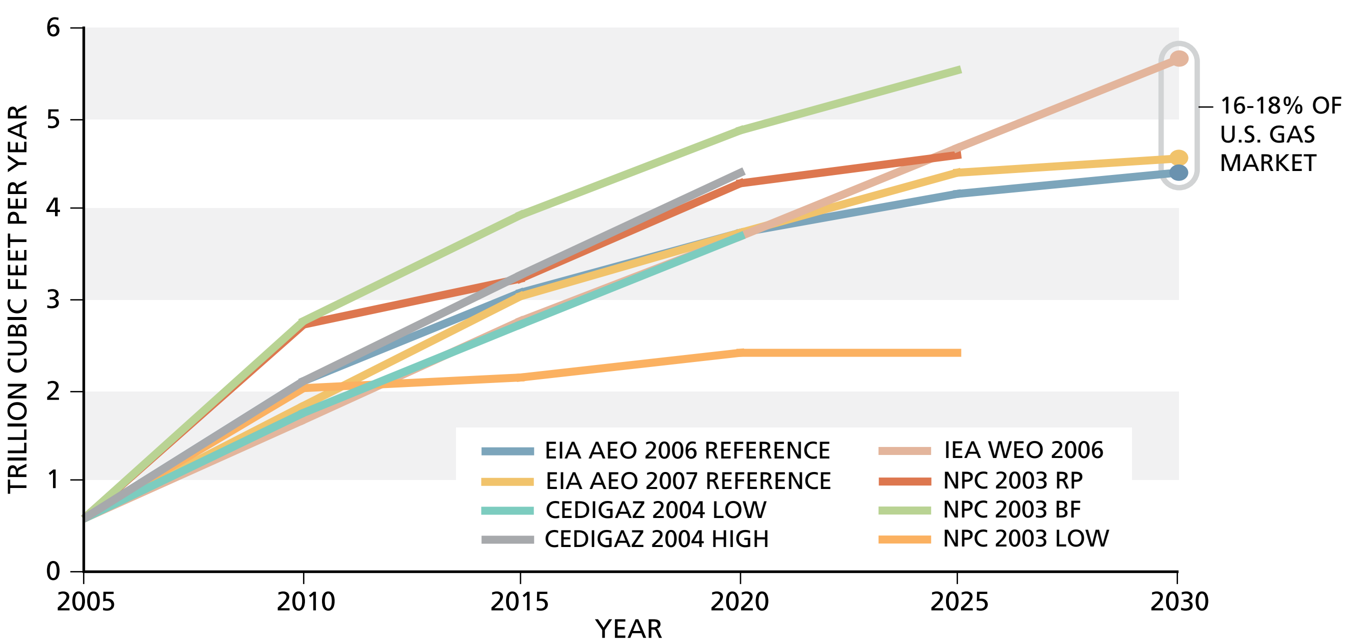
The EIA IEO 2006 provides a less detailed view of LNG developments to 2030. Discussion of LNG and gas trade developments in this outlook includes the following main points:

- Increasing concentration of natural gas reserves in Russia and the Middle East make these regions the most likely sources of supply growth.
- African natural gas production is expected to grow strongly through 2030, mainly for exports.
- Central and South America will have a surplus of gas, with Peru and Venezuela potentially joining Trinidad as LNG exporters.
- Russia, Norway, Equatorial Guinea, and Peru are likely to be new LNG exporting countries over this period.
- China, Canada, Mexico, Germany, Poland, Croatia, Singapore, and Chile are potential new LNG importing countries.
- The reliance of OECD countries on gas supplies from other regions will increase from 22 percent in 2003 to over 33 percent in 2030.

U.S. LNG Forecasts

Figure 2-56 shows projected LNG imports to the United States over the next 25 years. Depending on the forecast, LNG grows from about 2.5 percent of U.S. supply to 16 to 18 percent by 2030.

The EIA Annual Energy Outlooks provide a detailed look at factors specific to the U.S. gas market that may drive growth. The 2006 and 2007 Reference Case projections for LNG imports to the United States are similar. The main difference between the forecasts is that the



Note: RP = Reactive Path scenario; BF = Balanced Future scenario.
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2006* and *2007*; Cedigaz, *LNG Trade and Infrastructures*, February 2004; International Energy Agency (IEA), *World Energy Outlook 2006*; and National Petroleum Council (NPC), *Balancing Natural Gas Policy*, September 2003.

FIGURE 2-56. *Projected U.S. LNG Imports*

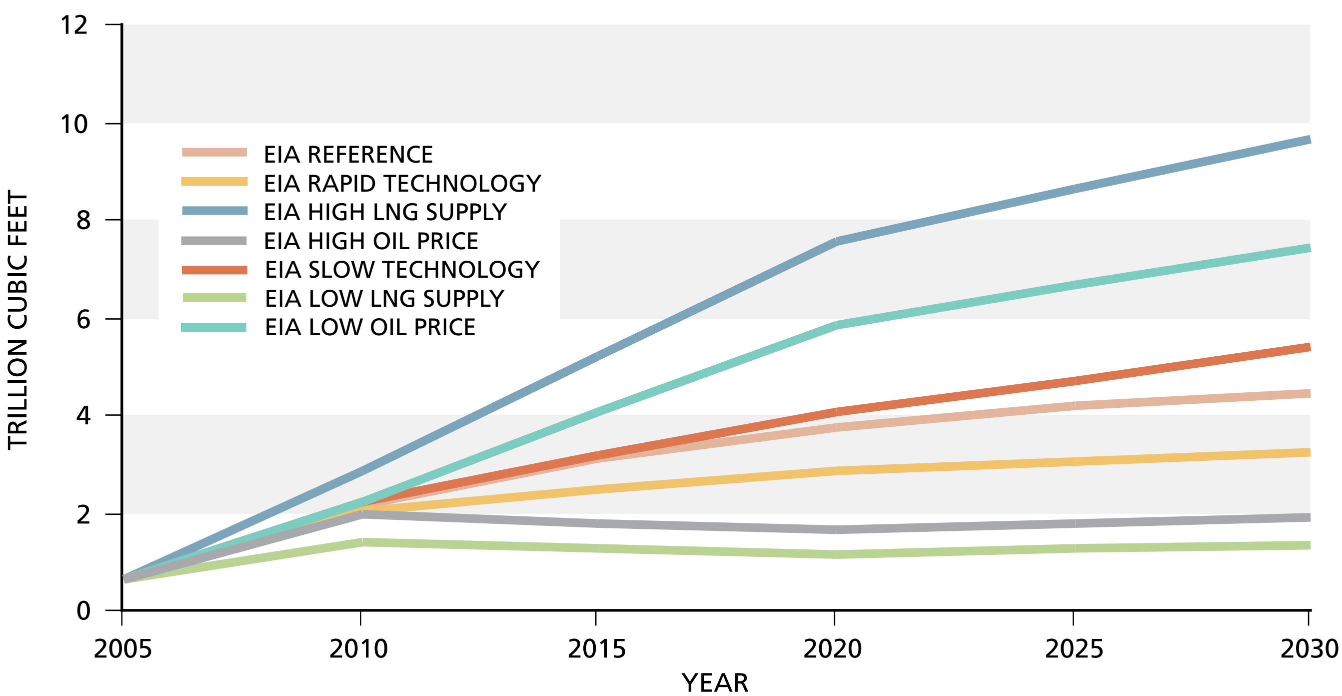
2007 update is slightly lower in the early years, because of slower development of upstream LNG projects, and slightly higher in the later years, especially after 2020.

The EIA AEO 2006 Reference Case projects that U.S. LNG imports will grow by 8 percent per year to 2030. Two factors drive the rapid increase: (1) a domestic gas production profile that begins to decline after 2020 and only increases by 0.5 percent per year over the entire period to 2030; and (2) pipeline imports from Canada. A high rate of LNG imports is needed to balance the market, despite slow demand growth of 0.7 percent per year. The Reference Case assumes that high natural gas prices in the United States and the availability of import infrastructure will attract LNG to the U.S. market. However, LNG imports may be affected after 2015, as world natural gas prices rise, attracting LNG to other markets. It should be noted that this projection does not integrate U.S. requirements for LNG into a global market balance where LNG competes against indigenous gas to find the best economic opportunities.

The AEO 2006 includes several sensitivity cases built around: high or low oil price paths; high or low adoption of new technology favoring indigenous gas production and lowering gas prices; and high or low LNG supply based on the uncertainty of upstream developments in the LNG supply chain. Figure 2-57 shows the range of outcomes from these cases, which by 2030 range from more than double to only 30 percent of the Reference Case. The range between the various high and low cases is close to 23 billion cubic feet per day of natural gas delivered to the U.S. market, indicating the scope of very different outcomes according to the assumptions made.

LNG Trade and Infrastructure

Global natural gas supply patterns are shifting, as domestic production in major demand centers of North America and Western Europe fails to keep pace with growing demand. The growing LNG trade is expected to play a pivotal role in meeting this increasing demand. In North America, for example, LNG imports are expected to grow to around 20 percent or more of gas supply by 2030, compared to about 2 to 2.5 percent in recent years. The natural gas resource and reserve base in current and potential LNG exporting countries appears more than adequate to support a high growth rate. However, such growth will require a much stronger LNG supply and delivery infrastructure than currently available.



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2006.*

FIGURE 2-57. *Projected U.S. LNG Imports — Alternative Cases*

LNG terminal and distribution infrastructure in the key markets of North America, Western Europe, East Asia, and South Asia is being developed at a scale that will support the expected increase in LNG imports. Uncertainty and risk are now more concentrated in upstream export projects. Less than expected or slower development of export projects could lead to tighter global supply, higher prices, and potential shortages, perhaps for extended periods.

Coal

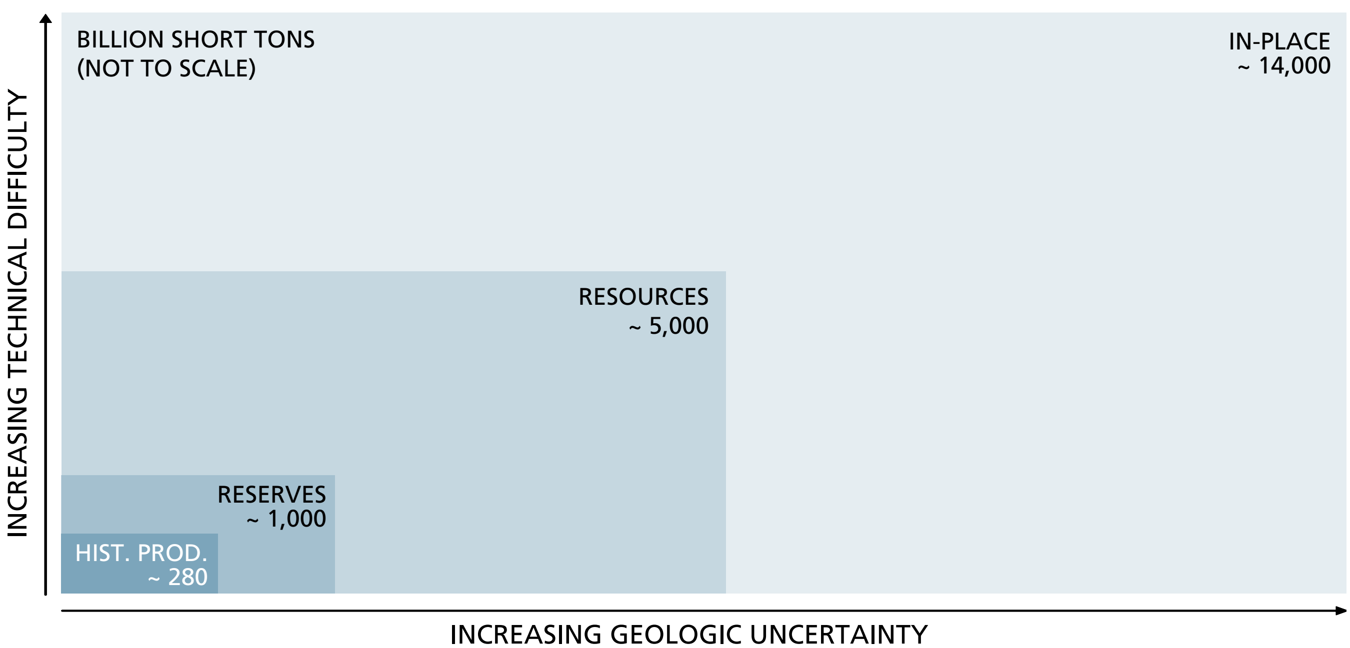
Key Observations—Coal

- *The global coal endowment is large (Figure 2-58) but national and local issues such as infrastructure limitations, environmental regulation, energy security, and coal conversion activities will determine how extensively coal is used in future global, regional, and national energy markets.*
- *Most business-as-usual energy forecasts expect an increasing demand for coal.*
- *Coal is the major feedstock for power generation growth. Future regulation of carbon dioxide emissions or carbon capture and sequestration will affect the direction of growth.*
- *China, India, and the United States have significant indigenous resources and are the largest coal consumers during the study time frame.*
- *International and U.S. coal transportation infrastructure will need additional capacity in order to meet projected demand.*

Global Coal Endowment & Resources

There are few independent estimates of the global coal endowment and resources. Almost all forecasts evaluated in this study use a World Energy Council assessment of the global coal resource base. World Energy Council assessments are based on self-reported, individual-country submissions that vary widely in quality. U.S. information on coal reserves and resources is extensive but outdated, since it is based on a Bureau of Mines 1974 study that used pre-1971 geological assessments and technology assumptions.[8]

8 U.S. Bureau of Mines, Compiled by U.S. Geological Survey, "Coal Resources of the United States," 1974.



Sources: (1) 1800 to 1980: Bernardo F. Grossling, "World Coal Resources," Financial Times Businesss Information, London, 1981; 1981 to 2005: Energy Information Administration, *International Energy Annual*. (2) World Energy Council, "Survey of Energy Resources," 2004. (3) Rogner, H-H., "Annual Review – Energy Environment," Institute for Integrated Energy Systems, 1997.

FIGURE 2-58. *Global Coal Endowment*

About 280 billion short tons of coal have been produced globally to date, a small portion of the total coal resource base of approximately 5,000 billion short tons.[9] While coal resource estimates clearly suggest many years of supply, resources are not equally distributed among consuming centers, which may create significant trade and regional supply issues.

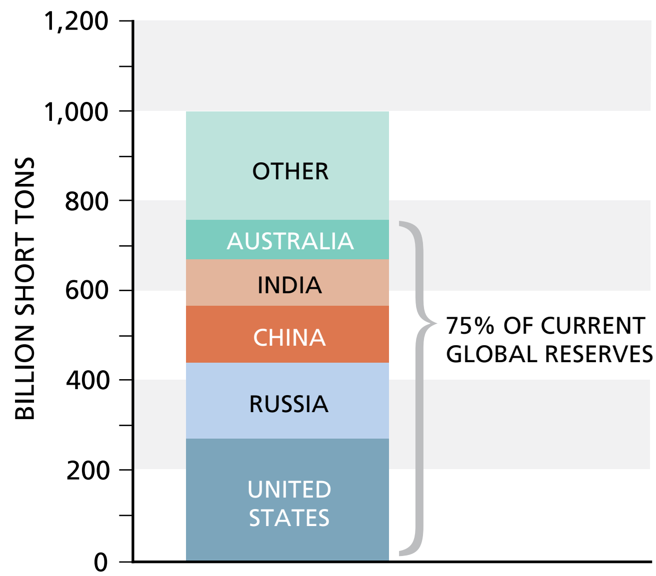
Global proved coal reserves are approximately 1,000 billion short tons.[10] This figure suggests a reserves-to-production ratio of about 150 years, making coal much more abundant in these terms than oil or gas. Given potential risks and constraints on other fossil fuel resources, countries with substantial indigenous coal resources such as China, India, and the United States, can see benefits to increasing coal use in their domestic energy mix (Figure 2-59).

Table 2-7 shows the five countries that hold over 75 percent of global proved coal reserves. The United States holds 27 percent of these reserves, the Russian Federation 17 percent, China 12.6 percent, India 10.2 percent, and Australia 8.7 percent.

Coal varies by chemical and physical properties that reflect its maturity from peat to anthracite. These properties are described by referring to the coal's rank. Low rank coals such as lignite and subbituminous have high moisture levels and low carbon content, resulting in low energy content. Higher rank coals such as bituminous and anthracite are characterized by less moisture and higher carbon and energy content. Lignite is at the bottom and anthracite is at the top of the coal rank scale. The quality of indigenous coal supplies varies between countries (Figure 2-60). This variation will affect end uses and environmental impacts. Global reserves are about evenly split between anthracite/bituminous coal and lignite/subbituminous coal.

9 Grossling, B.F., "World Coal Resources", 2nd Edition, Financial Times Business Information, London, England, 1981; and Rogner, H-H., "Annual Review – Energy Environment," Institute for Integrated Energy Systems, University of Victoria, 1997.

10 World Energy Council, "2004 Survey of Energy Resources."



Note: Global coal reserves are approximately 1.0 trillion short tons. Reserves data are available from limited sources and are generally self-reported by individual countries. Quality and vintage of estimates will vary.

Source: World Energy Council, 2004 Survey of Energy Resources.

FIGURE 2-59. *Estimated Global Coal Reserves*

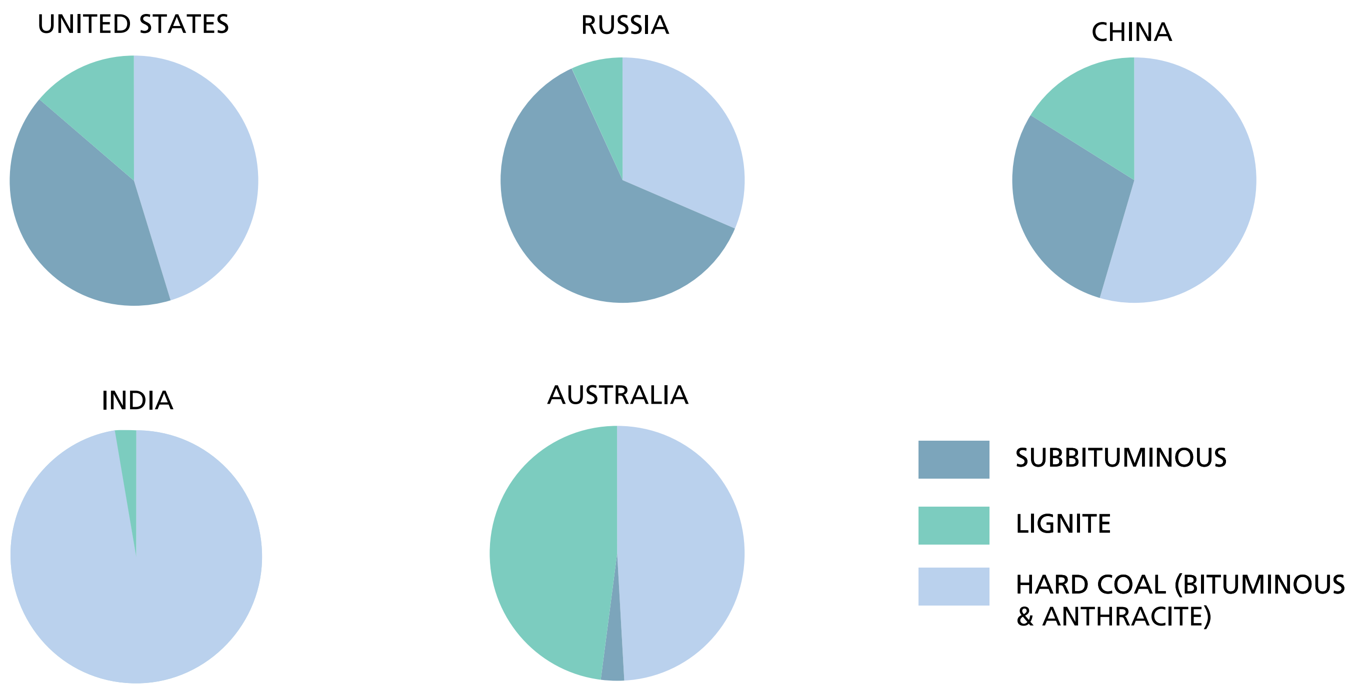
U.S. Coal Resource Base

Coal is the most abundant fossil energy source in the United States. Figures 2-61 and 2-62 show regional

	United States	Russia	China	India	Australia
Estimated Coal in Place	3,968	6,600	5,572		
Identified Resources	1,731			279	479
Proved Amount in Place	493	220	1,110	132	118
Proved Recoverable Reserves	**271**	**173**	**126**	**106**	**87**

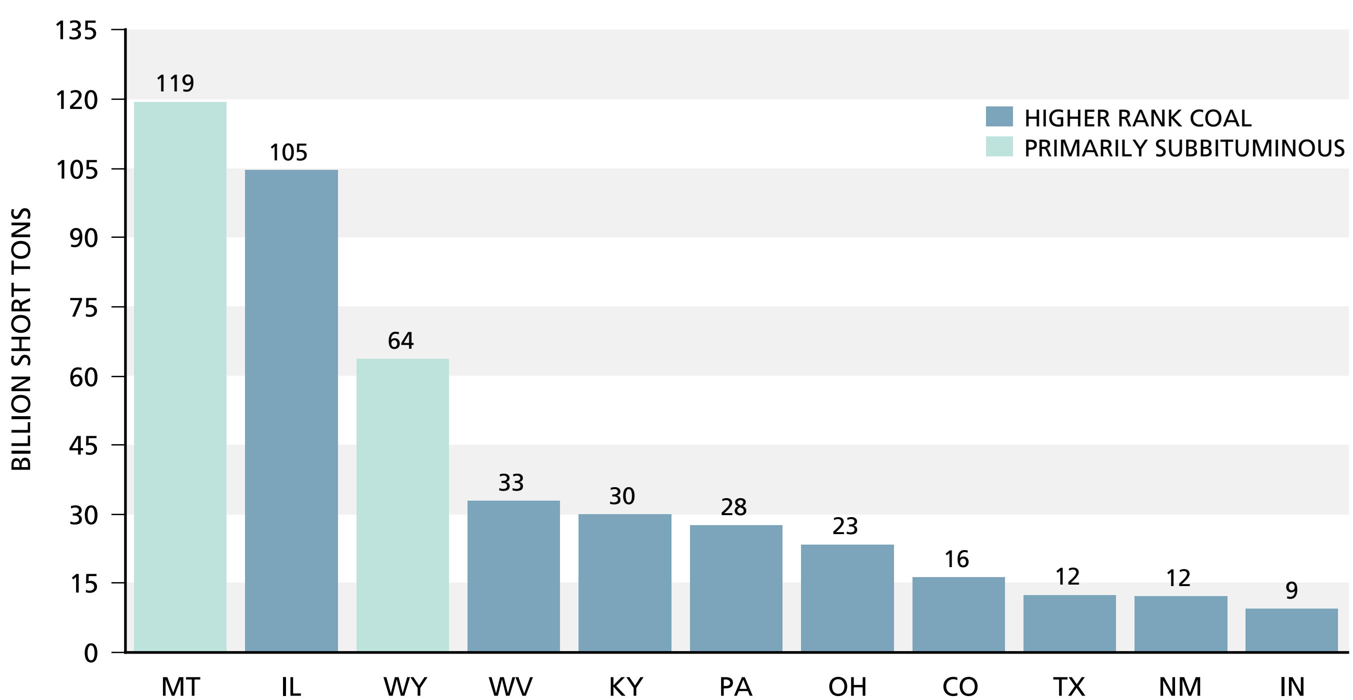
Sources: EIA, *Annual Energy Review 2006*; IEA, "Russia Energy Survey," 2002; Cui Mingxuan (ed.), "China Energy Development Report 2006," 2006; India, Ministry of Coal, 2006; Geoscience Australia, "Australia's Identified Mineral Resources," 2007.

TABLE 2-7. *Major Coal Resource Owners (Billion Short Tons)*



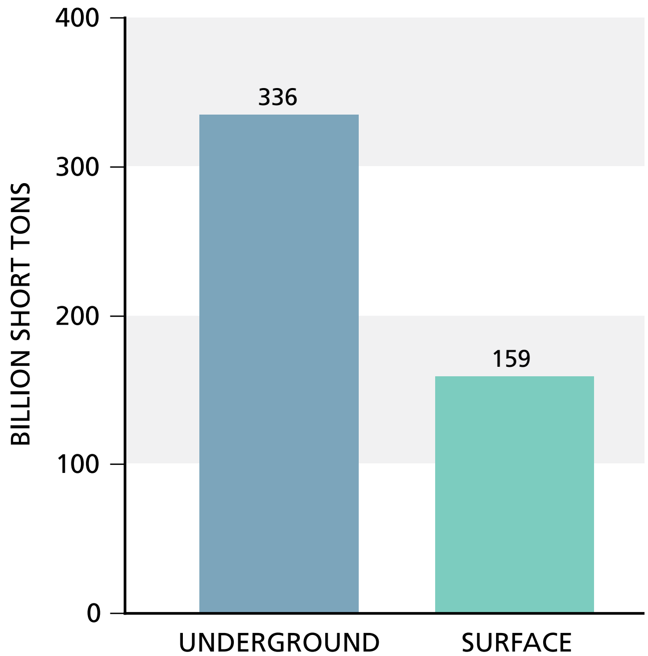
Source: World Energy Council, 2004 Survey of Energy Resources.

FIGURE 2-60. *Coal Rank Distribution in Large Resource Countries*



Source: Energy Information Administration, *Annual Energy Review 2005.*

FIGURE 2-61. *U.S. Coal Demonstrated Reserve Base by Key State*



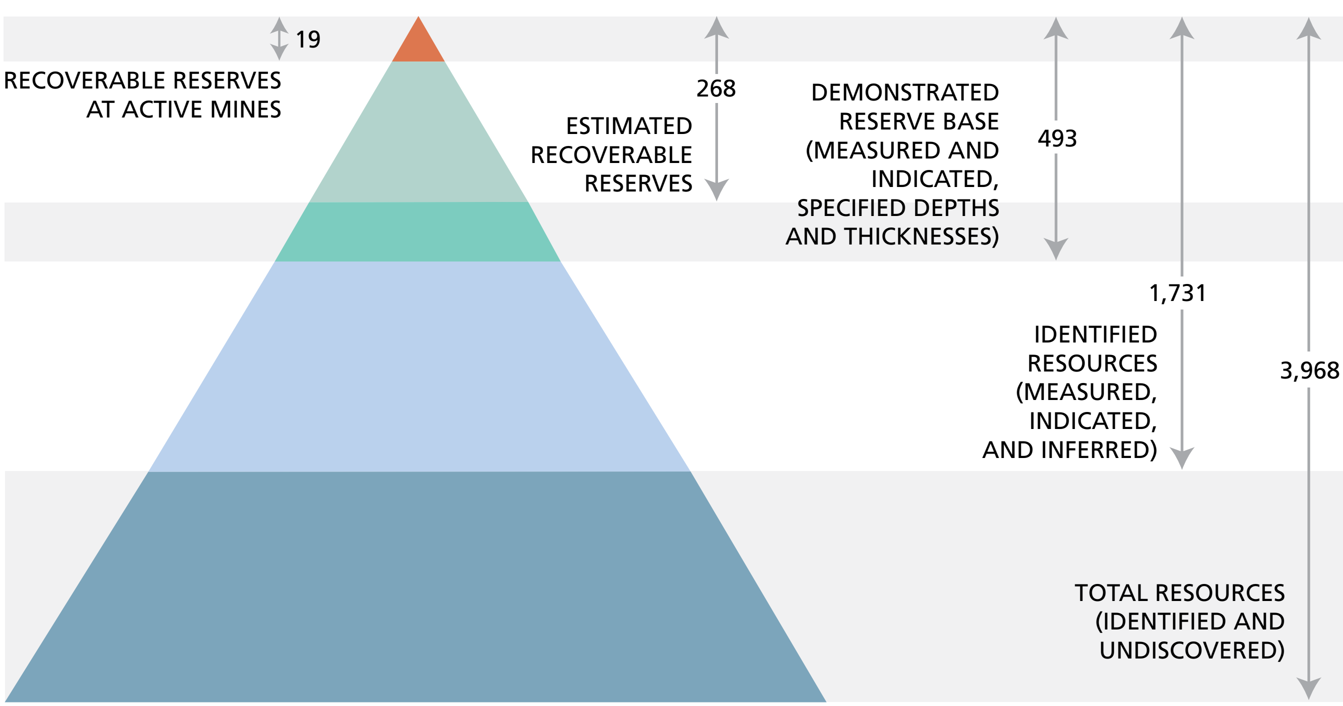
Source: Energy Information Administration, *Annual Energy Review 2005.*

FIGURE 2-62. *U.S. Coal Demonstrated Reserve Base by Mining Method*

distribution, rank, and extraction methods for U.S. coal resources. The EIA Annual Energy Review 2005 indicates that demonstrated U.S. coal reserves, equivalent to proved amount in place, amount to 493 billion short tons. Figure 2-63 shows the U.S. coal resource pyramid, which identifies known and estimated coal resources.

The EIA reports three mining regions: Appalachian, Interior, and Western. The Western region contains 47 percent of the reserve base, followed by Interior with 32 percent, and Appalachian with 21 percent. Of the 234.5 billion tons of Western reserves, about 77 percent are subbituminous coal; 13 percent are lignite; the remaining 10 percent are bituminous coal. The Western region contains all U.S. subbituminous reserves and 68 percent of U.S. lignite reserves, primarily in Montana and North Dakota. The bituminous coal is dispersed through the western states, with the largest reserves, in descending order, in Colorado, Utah, Wyoming, and New Mexico.

Approximately 92 percent of the Interior region's 158 billion short tons of reserves are bituminous coal, while the remainder is lignite. About 40 percent of the bituminous reserves are located in Illinois. The lignite reserves are located primarily in Texas, Louisiana,



Sources: Energy Information Administration 2004; and United States Geological Survey 1974.

FIGURE 2-63. *U.S. Coal Resources and Reserves Pyramid (Billion Short Tons)* and Mississippi. In the Appalachian region, 92 percent of the reserves are bituminous coal and 7 percent are anthracite. Nearly all the anthracite is located in Pennsylvania.

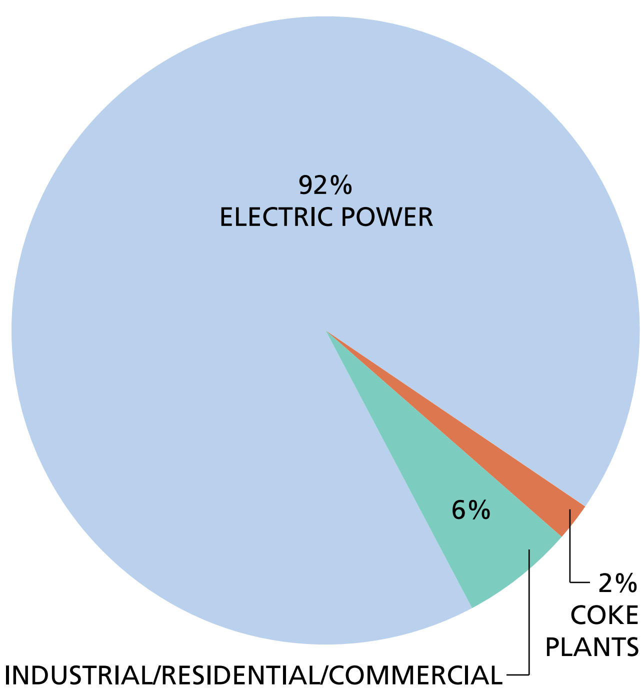
Coal is critical to future energy security in the United States. The foundation for coal resource estimates is more than 30 years old and should be updated to account for new technologies, better subsurface information, and improved understanding of recovery efficiencies. The U.S. National Academies has found that current U.S. reserve estimates may be overstated and recommends that USGS undertake a new assessment of domestic coal reserves and resources.[11]

Total U.S. Coal Production and Disposition

The United States is self-sufficient in coal production, virtually matching estimated consumption through the study time frame. EIA forecasts total U.S. coal production to increase an average of 1.6 percent per year from 2005 through 2030, in order to meet increasing domestic demand. The primary consumer of coal in the United States is the power industry, using 92 percent of the 1.128 billion short tons burned in 2005. The EIA AEO 2007 forecasts that power generation will decrease to 89 percent of coal consumption by 2030, although total volume is increasing significantly (Figures 2-64 and 2-65). If implemented at scale, new energy applications, such as CTL and coal-to-gas (CTG) would consume an increasing share of coal production later in the study time frame, although this is likely to remain small relative to total consumption.

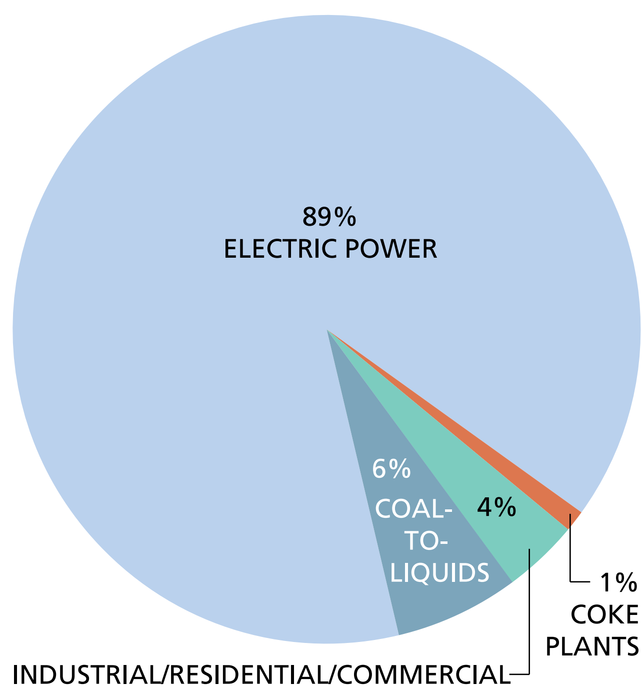
Most forecasts received by the study project relatively low CTL production volumes in the United States (Figure 2-66). Forecasting organizations such as the EIA may make widely varying estimates of U.S. coal consumption for CTL and CTG conversion, depending on the date of their forecast. Between the 2006 and 2007 Annual Energy Outlooks, the EIA decreased its forecast for CTL and CTG coal consumption from 190 million to 112 million short tons per year in 2030 (Figure 2-67). The variation in forecasts is even more dramatic between organizations. The Southern

11 U.S. National Academies – Board on Earth Sciences and Resources (BESR), "Coal: Research and Development to Support National Energy Policy," 2007.



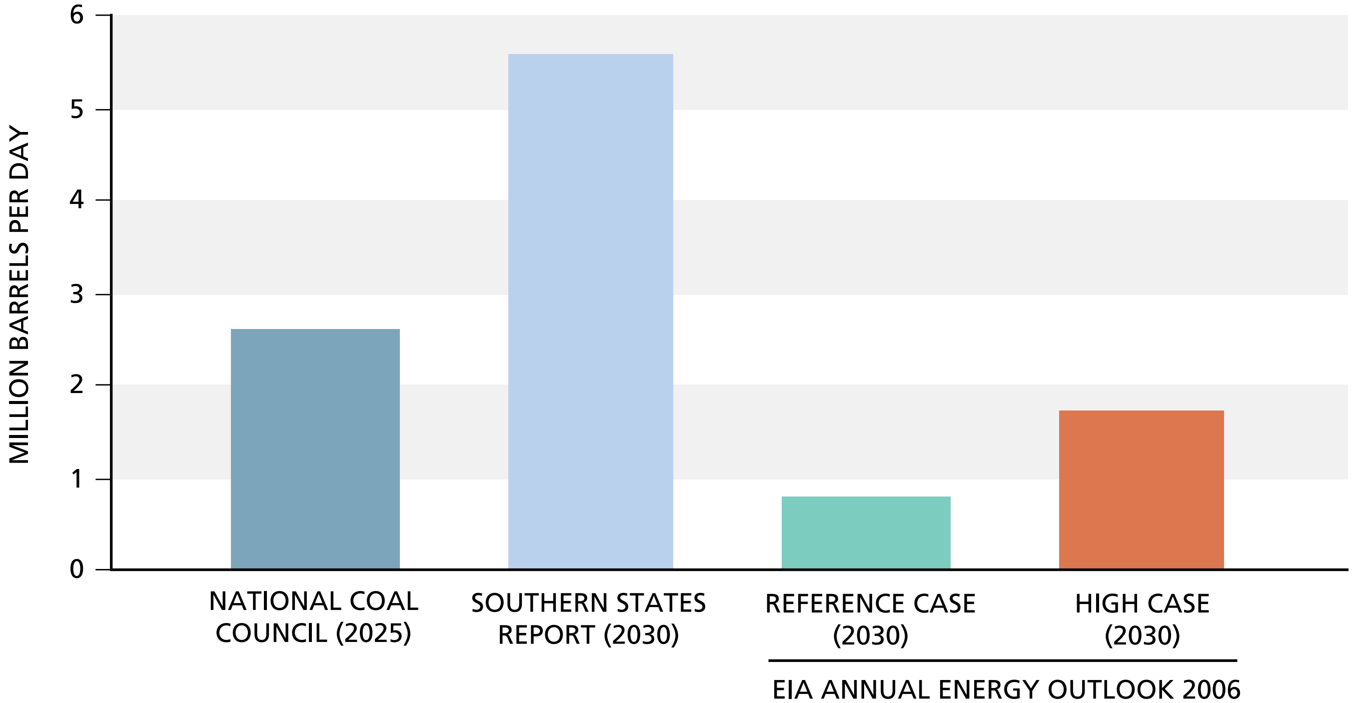
Source: Energy Information Administration, *Annual Energy Outlook 2007.*

FIGURE 2-64. *U.S. Coal Consumption by Sector in 2005 (1.128 billion short tons)*



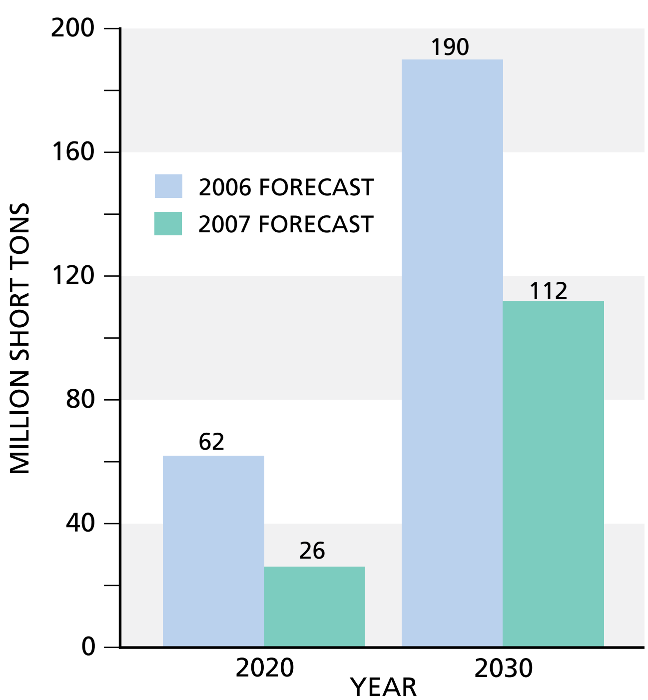
Source: Energy Information Administration, *Annual Energy Outlook 2007.*

FIGURE 2-65. *U.S. Coal Consumption by Sector in 2030 (1.772 billion short tons)*



Source: NPC Survey of Outlooks.

FIGURE 2-66. *Projected U.S. Coal-to-Liquids Production*



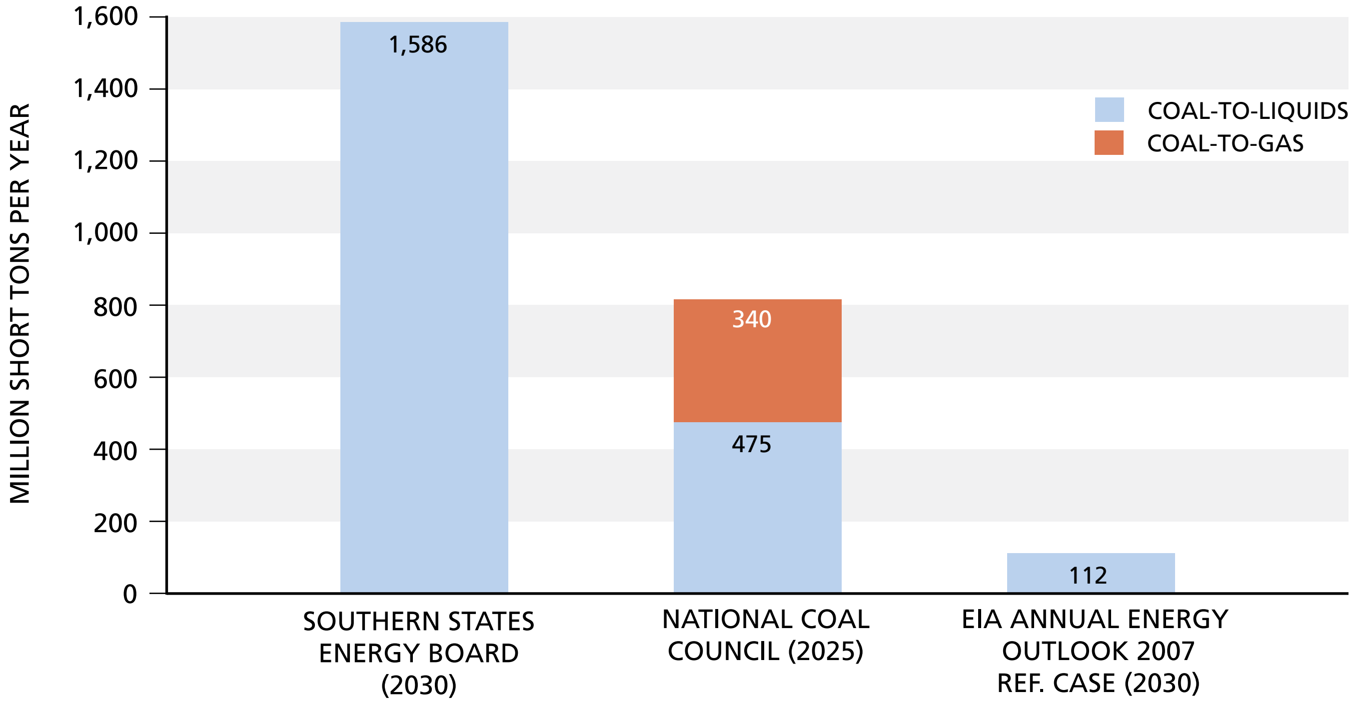
Source: Energy Information Administration, *Annual Energy Outlook 2006* and *2007*.

FIGURE 2-67. *One-Year Change in EIA Reference Case Forecast of U.S. Coal-to-Liquids Coal Consumption*

States Energy Board and the National Coal Council also produced forecasts for converting coal to liquids and to gas in order to increase U.S. energy security and displace oil imports (Figure 2-68).[12] The Southern States Self-Sufficiency case projects U.S. CTL production reaching at least 20 percent of U.S. oil demand in 2030. This projection is an order of magnitude greater than the most recent EIA forecast.

Globally, China's relatively low-cost coal may allow economical production of CTL. In the IEA WEO 2006 Reference Case, CTL production will be less than 1 MB/D by 2030, primarily in China. Elsewhere, higher coal costs, capital costs, and significant CO_2 emission concerns are likely to constrain CTL production between now and 2030. The EIA IEO 2007 Reference Case projects global CTL production of 2.4 MB/D in 2030, while production reaches 3.9 MB/D in the High Price Case, or about 4 percent of global oil demand. For a full discussion of CTL technology, see the Coal-to-Liquids Topic Paper included on the CD distributed with the study.

12 Southern States Energy Board, "The American Energy Security Study," 2006; and The National Coal Council, "Coal: America's Energy Future," 2006.



Source: NPC Survey of Outlooks.

FIGURE 2-68. *Projected U.S. Coal-to-Liquids and Coal-to-Gas Coal Consumption*

Infrastructure

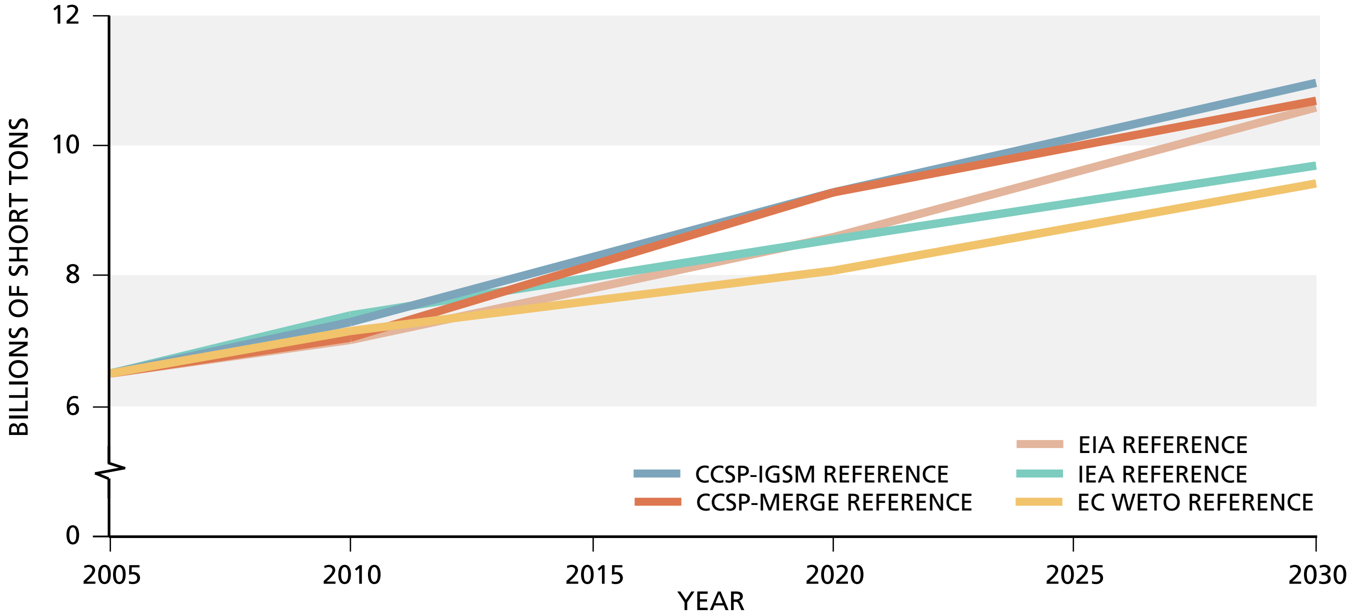
The extent to which coal contributes to U.S. energy requirements will depend heavily on the capacity of coal transportation infrastructure. Railroads, barges, and trucks are all critical modes of transport for coal. Each mode faces challenges, some of which are unique to it and others that are common to all modes. For each mode, having adequate capacity to meet growing demand is perhaps the most pressing need. Roads and waterways depend on publicly owned and maintained infrastructure. Waterway infrastructure is generally in need of significant maintenance and improvement. Railroads, on the other hand, rely overwhelmingly on privately owned, maintained, and operated infrastructure. They will need a balanced regulatory and legislative environment to ensure sufficient private capital is invested to provide the additional capacity required by energy forecasts.

Global Coal Production and Disposition

Global coal production is projected to increase substantially, primarily to meet demand for electricity and, to a smaller extent, for CTL and CTG conversion. Most Reference Cases project a 50 to 60 percent increase in coal production between 2005 and 2030. Global production is currently 6.5 billion short tons per year and is forecast to increase to between 9.5 and 11.0 billion short tons by 2030. Figure 2-69 shows Reference Case supply forecasts for EIA, IEA, the European Commission, and the U.S. Climate Change Science Program (CCSP).[13] The Reference Cases are generally based on business-as-usual assumptions for economic and population growth, without significant environmental constraints. IEA forecasts that global coal demand will increase by an average annual rate of 1.7 percent per year from 2004 to 2030. EIA projects 2.0 percent annual growth.

Much of the world's coal is consumed in the country where it is produced. In 2004, 68 percent of global primary coal consumption was used to generate electric power and heat. Industry used 18 percent. This pattern of consumption is expected to remain quite stable over the study timeframe, although the higher efficiency of new generating plants will mitigate consumption growth. In 2030, coal for power and heat generation is projected at 73 percent of total primary coal consumption, while

13 European Commission, "World Energy Technology Outlook – WETO H2," 2006; and Climate Change Science Program, "CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations," 2006.



Note: All Forecasts Normalized to 6.5 Billion Short Tons In 2005.
Sources: Climate Change Science Program (CCSP); Energy Information Administration (EIA), *International Energy Outlook 2006*; International Energy Agency (IEA), *World Energy Outlook 2006;* and European Commission, *World Energy Technology Outlook 2050* (EC WETO), 2006.

FIGURE 2-69. *Global Coal Production Reference Cases*

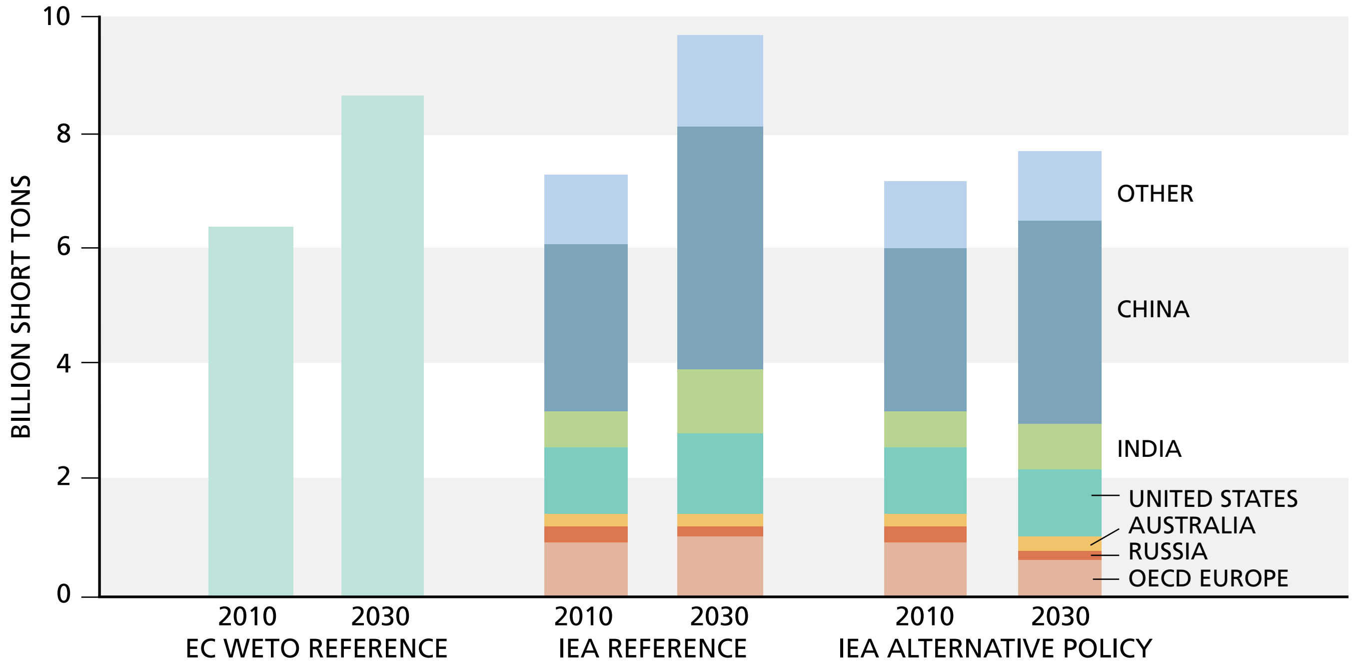
industry remains at 18 percent. Electricity generation remains the primary driver of coal consumption. IEA projects the share of coal in global power generation as increasing from 40 percent in 2004 to 44 percent in 2030.

Most growth in coal production will occur in rapidly expanding economies. Coal consumption in developing Asia is projected to rise from 2.9 billion short tons in 2004 to 4.5 billion short tons in 2015 and 6.1 billion short tons in 2030, a growth rate over the period of 2.7 percent per year. China and India heavily dominate coal consumption in the region (Figure 2-70) accounting for nearly 80 percent of annual incremental demand through 2030. They also account for 71 percent of the projected 6 billion kilowatt-hour increase in coal-based electricity generation.

Coal consumption in OECD Europe is projected to grow only slightly in Reference Cases, increasing from 761 million short tons to 778 million short tons per year from 2005 to 2030. In this case, gains in power generation are offset by losses in industry. The coal share of power generation is projected to decrease from 29 percent to 27 percent to the benefit of natural gas. Coal inputs to power generation are projected to fall in the period to 2020 and then increase between 2020 and 2030 as nuclear power plants are retired and the assumed competitiveness of coal improves relative to natural gas. OECD-Europe coal production is projected to decline from 467 million short tons in 2005 to 324 million short tons in 2030. Given that consumption is projected to rise, this suggests an increase in net imports from 293 million short tons to 454 million short tons over the period.

Coal consumption in Russia and other countries of the former Soviet Union is projected to rise by an annual average of 1.1 percent between 2004 and 2015, then decline to the 2004 level by 2030. Industrial use of coal is projected to increase throughout the period while coal consumption in power generation is projected to fall. Coal-fired power generation capacity is forecast to decline throughout the period as natural gas replaces aging coal-fired plants. Coal's share of power generation is projected to fall significantly from 21 percent in 2015 to 15 percent in 2030. Latin America, the Middle East, and Africa are expected to be relatively minor consumers of coal.

Demand increases for coal vary geographically, and the remaining resource estimates vary widely for the five largest resource owners. While India has sufficient



Sources: European Commission, *World Energy Technology Outlook 2050* (EC WETO), 2006; and International Energy Agency (IEA), *World Energy Outlook 2006*.

FIGURE 2-70. *Projected Regional Coal Consumption (2010 vs. 2030)*

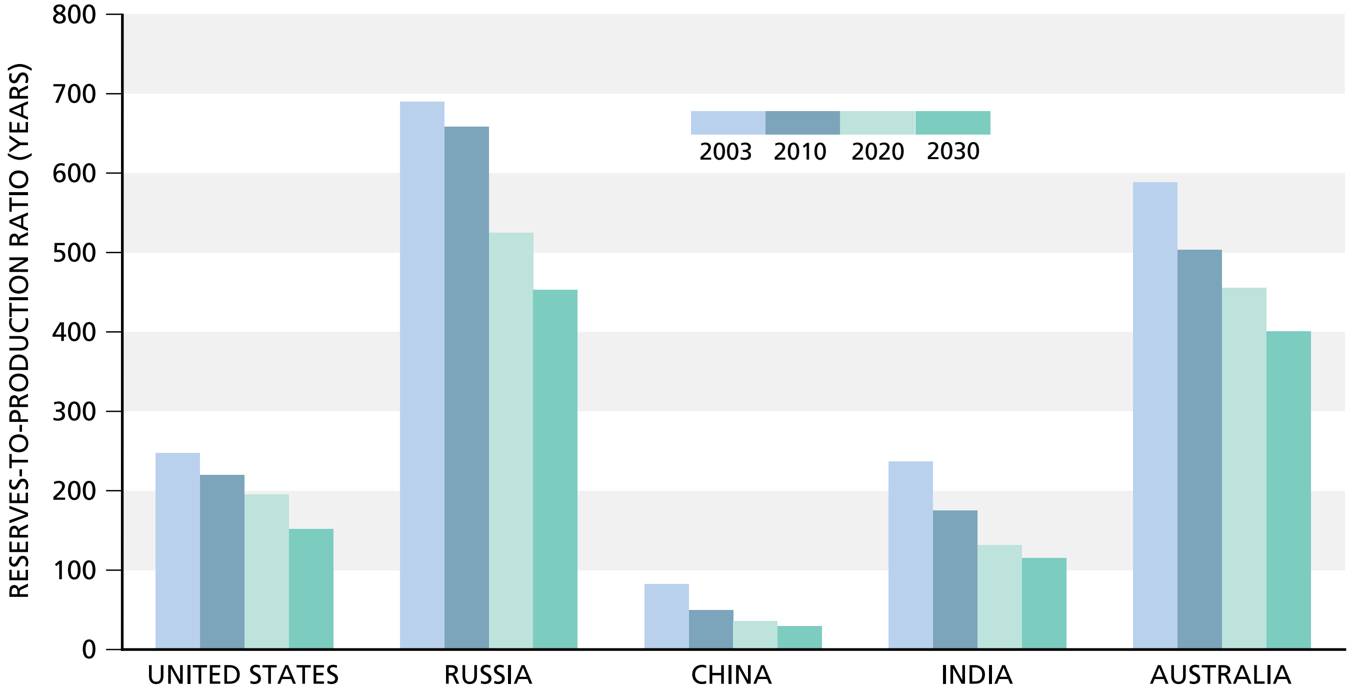
coal reserves for more than 200 years of consumption at 2005 levels, China has coal reserves for only 52 years (Figure 2-71) at 2005 levels. China's planned coal production capacity in 2010 is 2.1 billion short tons. Restructuring of township coal mines is expected reduce production capacity to 1.65 billion short tons in 2020. When compared to many consumption forecasts, the reduction suggests that China may rely increasingly on coal imports or may need to develop new domestic reserves. With Chinese industrial demand growing significantly, especially for steel making, China will require not only coal in quantity, but the right type of coal. Restructuring plans should be viewed in this light.

China and India will be the fastest growing markets for coal exporters. Regions well situated to serve those markets are likely to experience the greatest growth. Russia has a large coal resource base and could supply foreign markets such as China. Australia is projected to increase exports from 257 million short tons in 2005 to 435 million short tons in 2025. Indonesia is expected to increase exports from 138 million short tons to 203 million short tons. This suggests that Australia and Indonesia will represent 70 percent of the increase in coal exports between 2005 and 2025, rising from 46 percent of global coal exports in 2005 to 53 percent in 2025.

Infrastructure is unlikely to present a long-run constraint on Australian coal exports, although Indonesia may prove to be more problematic. Although Indonesian coal resources are substantial, a significant proportion is located some distance from the coast and dedicated port terminals. Currently, a substantial portion of Indonesia's coal exports is transported by barge and later transshipped. Investment needed to provide the infrastructure for interior coal deposits is also likely to be significant.

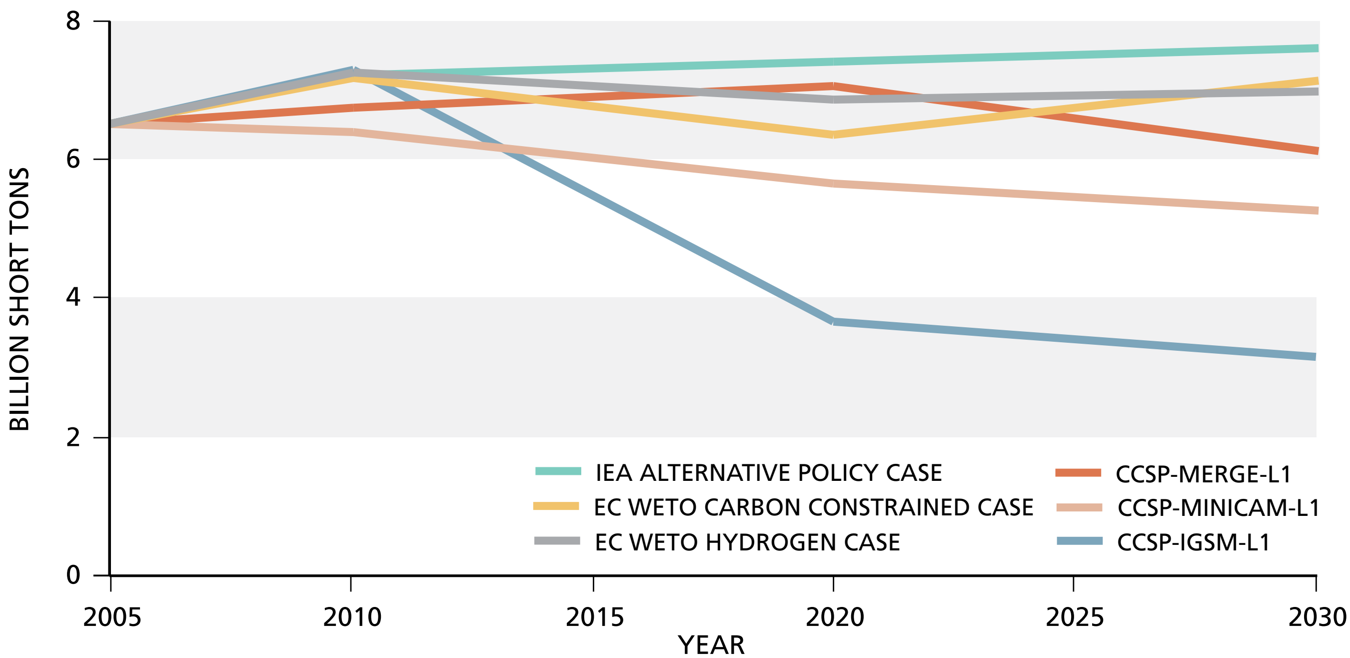
Carbon Constraints

Carbon-constrained cases generally show flat-to-declining global coal production as energy demand is met by fuels with lower carbon content, including renewable sources (Figure 2-72). Total coal production continues to increase in the IEA Alternative Policy Case, but is approximately 20 percent less than coal production in the IEA Reference Case. Most of the reduction in coal demand results from fuel switching and energy savings in the power sector. The European Commission's *World Energy Technology Outlook 2050* (WETO) carbon-constrained case represents ambitious policies for long-term stabilization of atmospheric carbon



Sources: World Energy Council 2006; and Energy Information Administration, *International Energy Outlook 2006.*

***FIGURE 2-71.** Reserves-to-Production Ratios in Major Coal-Producing Countries*



Note: All forecasts normalized to 6.5 billion short tons in 2005.
Sources: International Energy Agency (IEA), *World Energy Outlook 2006;* European Commission, *World Energy Technology Outlook 2050,* (EC WETO) 2006; and Climate Change Science Program (CCSP).

***FIGURE 2-72.** Projected Carbon-Constrained Coal Production* dioxide concentrations at 500 parts per million by volume (ppmv) by 2050.

Technology development is critical in shaping a future carbon-constrained energy system. WETO envisages incremental improvements in large-scale power generation and renewable technologies. The WETO-H2 scenario incorporates new technology to decrease total energy consumption and increase the use of hydrogen, which may be produced from lower carbon energy sources. The CCSP cases designated L-1 are based on stabilizing atmospheric carbon dioxide at 450 ppmv by 2100. Three integrated assessment models from MIT (IGSM), Stanford (Merge), and Joint Global Climate Change Research Institute (MiniCam) forecast climate change based on input assumptions, with each addressing the carbon issue for different energy inputs.

In a carbon-constrained world, CCS is one of the technology and policy prerequisites for maintaining coal's significant role in the energy system. For a full discussion of carbon management and carbon capture and sequestration, see the Carbon Capture and Sequestration Topic Paper included on the CD distributed with this report.

Coal Supply Challenges

Many challenges faced by the coal industry (Table 2-8) are common to other carbon-based fuels. The requirement for affordable energy must be balanced with environmental and other policy issues, while maintaining infrastructure to transport resources from supply to demand regions. Permitting new facilities takes longer, costs more, and is subject to more scrutiny than in the past. Construction, labor, equipment, and supply costs have escalated significantly in recent years and are more volatile than in the past, contributing to higher, less predictable production costs. Carbon management is likely to become a factor in future coal use as carbon policies develop in the United States and globally. Land owners and various interest groups are vocal in their objections to new surface mines, often delaying the permitting process and increasing development costs. Local, state, and federal regulations that place land use restrictions on private lands, such as populated areas, also limit mining access. Table 2-8 summarizes the coal supply challenges that will apply in different combinations and places over the study time frame.

Biomass

Key Observations—Biomass

- *Energy from Biomass can be converted to electricity, heat, and biofuels; forecasts show considerable growth potential while meeting the world's need for food.*
- *The cellulosic biomass resource is substantial, but technology does not currently exist to convert it to large volumes of liquid fuels at competitive economics.*

		Access	Investment	Infra-structure	People and Equipment	Environment
Large Producers	*Current Annual Production (Billion Short Tons)*					
China	~ 3		X	X		X
United States	~ 1	X	X	X	X	X
OECD Europe	~ 1					X
Production Growth	*2005-2030 Expected Growth (Billion Short Tons)*					
China	+ 1		X	X		X
India	~ 0.5		X	X		X

Note: An X in any column means that the matter is problematic or open to question.

Source: NPC Survey of Outlooks.

TABLE 2-8. *Coal Production Challenges*

- *In a carbon-constrained environment, biomass-fired power generation will be an attractive use of biomass.*
- *Biomass resources will continue to be converted to biofuels as a supplemental contributor to the U.S. transportation fuel mix, with public policy as a factor in overall market penetration.*

Biomass was the primary source of energy before the industrial age developed through intense use of coal, petroleum, and natural gas. Like coal and natural gas, biomass is a local energy source that could provide significant additional supply, although it constitutes only a small fraction of current primary energy supply. Like many unconventional and alternative energy sources, biomass presents new demands on other resources such as land and water. Since biomass is renewable, it is expected to have a lower carbon footprint than other widely available energy sources.

Biomass can be burned, gasified, fermented, or otherwise processed to provide energy as electricity, heat, and biofuels. However, the infrastructure developed for coal, petroleum, natural gas, and other energy sources may not have the capability to support biomass as the main source of primary energy. Where possible, biomass has been incorporated economically into the value chains that link energy sources to products and markets. For example, biomass has been co-fired with coal in power plants; ethanol produced from corn or sugarcane has been blended with gasoline; biodiesel has been produced from palm and soy. In each case, incorporating biomass in the corresponding value energy chains required only minor modifications to existing infrastructure.

The biomass energy value chain has many characteristics similar to those of oil, coal, and natural gas. However, since the underlying source is solar energy, biomass is characterized by low energy density and production over large areas. Land use, transportation logistics, harvesting, storage, and processing of biomass feedstocks and products are key hurdles to widespread production. The sources of energy used to convert biomass to products and the energy balance of the conversion processes are also significant considerations for biomass use. For example, coal is an important source of heat for some biorefineries in the United States. Significantly reducing the carbon footprint and improving the energy balance of these refineries would require developing and using processes that incorporate more biomass energy.

Biomass Forecasts

Most business-as-usual forecasts show continued growth of the energy supplied from biomass.[14] Great care must be taken when analyzing these forecasts, however, because they sometimes distinguish between commercial biomass and existing biomass use and incorporate energy conversion efficiencies of biomass into final fuels such as ethanol, and thus do not refer to real primary energy. The EIA Reference Case, for example, shows biomass growing at small rates. By comparison, the IEA Reference Case projects biomass use in 2030 at more than four times higher than 2005. Business-as-usual cases typically forecast biomass penetration as biofuels for transportation. These forecasts project up to 5 MB/D of biofuels in the year 2030, representing almost 5 percent of total liquids supplied. This projected volume is still a small fraction of the total energy mix.

Forecasts that are not business as usual project dramatic increases in biomass as an energy source based on policy objectives. Stabilizing atmospheric carbon dioxide, increasing the efficiency of energy consumption, or reducing carbon impact are typical policy objectives assumed in these forecasts. For example, a scenario that accelerates stabilization of carbon dioxide concentrations includes policies that impose carbon-neutral primary energy production in the coming decades. The policies result in rapidly increasing biomass use; rapid growth of new nuclear-based electricity generation; and widespread use of CCS for all fossil fuel based power plants. This case reduces total global liquids demand to 98 MB/D by 2030, of which biofuels supply more than 23 MB/D, or almost 25 percent.[15]

As with all resources, biomass needs to be produced, converted, and delivered in a useful form for consumers. Current processing technologies for corn and sugarcane seek to balance biomass use for food, feed, and fuel production. This delicate balance is subject to intense study. Many technology developments target the balanced and adequately supplied food, feed, and fuel markets. The use of co-products of ethanol processing,

14 Business-as-usual forecasts do not incorporate policies, taxes, or incentives that are not currently in force or would preclude direct economic competition between sources of energy within the established framework.

15 U.S. CCSP Level 1 Stabilization Scenario, IGSM Model. This scenario imposes a very high penalty on carbon-related emissions in order to achieve such an accelerated transition away from non-carbon neutral fuels. The model also constrains the growth in nuclear energy. The economic impacts of such carbon constraints can affect economic growth.

such as distiller's dry grains used in livestock feed, contribute to the balance by allowing the same corn crop to serve as a source of both fuel and feed.

Studies that estimate the annual potential for biomass production are balanced by forecasted future global demand for food and feed. Any surplus, in the absence of cross-competition, could be available to supply energy. Forecasts usually consider such factors as available arable land, water resources, and changes in land use. Assuming widespread use of recent advances in biotechnology and modern land management techniques, the potential energy available from biomass is estimated to be approximately 952 quadrillion Btu, or on the order of annual human energy consumption. The efficiency of converting potential biomass energy into forms suitable for widespread consumption is a matter of considerable interest.

Biotechnology is expected to play a significant role in expanding global biomass production, with crop yields in the next few decades increasing at a faster rate than historically. For example, marker-assisted plant breeding can increase trait development by a ten-fold rate over conventional breeding. The ability to engineer specific new traits into crops may bring about remarkable changes in crop production and crop adaptability to different growing conditions. New technologies could potentially increase U.S. corn production to 25 billion bushels by 2030. Using conventional conversion methods, a crop of this size could potentially yield 54 billion gallons of ethanol by 2030, or 3.5 MB/D. This forecast contrasts with both the carbon-constrained case, which shows volumes above 20 MB/D and with the more conservative EIA IEO 2007 Reference Case, which forecasts about 1.5 MB/D.

Ethanol

Ethanol is an alcohol that can be used directly as an alternative fuel or blended with gasoline. It is made by fermenting sugars from many agricultural products and food wastes, including cellulose. The technology for producing ethanol from corn (90 percent of U.S. ethanol) and sugarcane (Brazil) is well established. Current technologies such as direct combustion and the production of ethanol or biodiesel have made wood, dung, cereals, sugar crops, and oilseeds the current leaders in bioenergy crops. Global production of ethanol has more than doubled over the last five years, to about 9 billion gallons in 2005 or 0.6 MB/D.

As mentioned above, conventional conversion methods in a business-as-usual case may produce up to 3.5 MB/D of ethanol in the United States by 2030. Large additional increases would require technology development to convert lignin and cellulose more efficiently into useful fuel. Technologies that use non-foodstuff biomass could potentially augment energy crop use for fuel production by increasing (1) overall process efficiency and (2) the biomass resource available for conversion.

Infrastructure

Several steps are necessary to increase the use of biomass as an energy source: bioenergy crops, preferably perennial, must be developed for excess agricultural land and marginally arable land; systems are required to harvest, collect, and store energy crops; efficient conversion and delivery systems must be developed. Widespread adoption of agricultural best practices could enable development of better food crops and better use of arable land now in production. Much of the infrastructure needed to increase biomass use does not exist today, limiting the growth rate of biomass, much as with any new energy source. Development of the sugarcane-based ethanol industry in Brazil is an example of how public policy can guide development of a biomass energy source.

Biomass Resource Potential

The growing use of certain biomass feedstocks as an energy source raises concerns about the availability of biomass for foodstuffs. The multiple uses of land compete and increase the value (and cost) of land. However, forecasts show that available land could produce enough biomass to provide food, feed, and fuel. The United Nations Food and Agriculture Organization (FAO) confirms this expectation in its recent estimate of population, food needs, and agricultural development from 2015 to 2030. According to the FAO, agricultural production of food and feed will continue to expand to meet global needs through 2030. Second-generation or cellulosic ethanol would reduce the potential for competition between food crops and energy crops by using plant waste and a specific energy crop such as switchgrass. However, second-generation biomass conversion technologies are currently in the research and early demonstration phases. The timing of their transition to commercial operation at scale remains uncertain.

Various studies over the past 20 years have assessed the potential of agriculture to produce both energy and food for the world. While conclusions from these studies differ, the annual resource potential could reach approximately 238 to 476 quadrillion Btu of biomass

Biomass Category	Main Assumptions and Remarks	Potential 2050 (EJ/yr) [1]	Potential as Cellulosic Ethanol (Quads)/BOE [5]	Potential as Pyrolysis Bio-Oil (Quads)/BOE [6]	Potential as Methanol (Quads)/BOE [7]	Potential as Methane via Anaerobic Digestion (Quads) [8]
Energy farming on current agricultural land	Potential land surplus: 0-4 Gha (more average: 1-2 Gha). On average higher yields are likely because of better soil quality: 8-12 dry t/ha/yr is assumed if intensive agricultural practices are used. [2]	0-700 (100-300)	0-305 Quads 0-52 billion BOE	0-464 Quads 0-80 billion BOE	0-398 Quads 0-68 billion BOE	0-199 Quads 0-34 billion BOE
Biomass production on marginal lands	On a global scale a maximum land surface of 1.7 Gha could be involved. Low productivity of 2-5 dry t/ha/yr. [2]	0-150 (60-150)	0-65 Quads 0-11 billion BOE	0-99 Quads 0-17 billion BOE	0-85 Quads 0-15 billion BOE	0-43 Quads 0-7 billion BOE
Bio-materials	Range of land required to meet the additional demand for bio-materials: 0.2-0.8 Gha (average productivity: 5 dry t/ha/yr.	0-150 (40-150) [3]	0-65 Quads 0-11 billion BOE	0-99 Quads 0-17 billion BOE	0-85 Quads 0-15 billion BOE	0-43 Quads 0-7 billion BOE
Residues from agriculture	Estimates from various studies. Potential depends on yield/product ratios and the total agricultural land area and type of production system.	15-70	6.5-30 Quads 1.1-5.1 billion BOE	9.9-46 Quads 1.7-7.9 billion BOE	8.5-40 Quads 1.5-7 billion BOE	4.3-20 Quads 0.7-3.3 billion BOE
Forest residues	The (sustainable) energy potential of the world's forests is unclear. Part is natural forest (reserves). Range is based on literature data.	0-150 (30-150)	0-65 Quads 0-11 billion BOE	0-99 Quads 0-17 billion BOE	0-85 Quads 0-15 billion BOE	0-43 Quads 0-7 billion BOE
Dung and Organic waste	Use of dried dung. Low estimate based on global current use. High estimate: technical potential. Utilization (collection) in longer term is uncertain.	5-105 [4]	2.2-46 Quads 0.37-7.8 billion BOE	3.3-69 Quads 0.57- 11.9 BOE	2.8-59 Quads 0.5-10.3 billion BOE	1.4-30 Quads .23- 6.1 billion BOE
Total	Most pessimistic scenario: no land available for energy farming; only utilization of residues. Most optimistic scenarios: intensive agriculture concentrated on the better quality soils.	40-1100 (250-500)	17.4-489 Quads 3 – 84 billion BOE	26.5-729 Quads 4.6-125 billion BOE	22.7-625 Quads 108 billion BOE	11.3-312 Quads 54 billion BOE

Notes

1 Bio-Energy supply, where two ranges are given, numbers between brackets give the range of average potential in a world aiming for large-scale utilization of biomass. A lower limit of zero implies that potential availability could be zero, e.g. if we fail to modernize agriculture so that more land is needed to feed the world.

2 Heating value: 19 GJ/t dry matter.

3 This value could even be negative: the potential biomass demand for producing bio-materials (such as bio-plastics or construction materials). These markets can represent a large demand for biomass that will reduce the availability of biomass for energy. However, the more bio-materials are used, the more organic waste (eventually) will become available for energy. Such use of biomass results in a "double" GHG benefit as well through avoided emissions in manufacturing materials with fossil fuels and by producing energy from the waste. Thus, calculating the potential biomass availability for energy is not straightforward adding the figures of the different rows. More details are given in [Hoogwijk et al., 2003].

4 The energy supply of bio-materials ending up as waste can vary between 20 and 55 EJ (or 1100-2900 Mt dry matter) per year. This range excludes cascading and does not take into account the time delay between production of the material and "release" as (organic) waste.

5 Future cellulosic ethanol yield ~ 46% on an energy basis (C. Hamelinck/ Dissertation, Outlook for Advanced Biofuels/Utrecht: Universiteit Utrecht, Faculteit Scheikunde, Proefschrift Universiteit Utrecht. Met literatuuropgave en samenvatting in het Nederlands. ISBN: 90-393-3691-1)

6 Future pyrolysis oil yield 70% on an energy basis (A.P.C. Faaij / Energy Policy 34 (2006) 322–342).

7 Future methanol yield 60% via syngas on an energy basis (C. Hamelinck/ Dissertation, Outlook for Advanced Biofuels/Utrecht: Universiteit Utrecht, Faculteit Scheikunde, Proefschrift Universiteit Utrecht. Met literatuuropgave en samenvatting in het Nederlands. ISBN: 90-393-3691-1).

8 Future anaerobic digestion yield of 30% on an energy basis (T. Bridgwater J Sci Food Agric 86:1755–1768 (2006).

Source: Faaij APC, et al: *Energy for Sustainable Development,* Volume X, number 1 (March 2006).

***TABLE 2-9**. Biomass Categories and Energy Potentials* energy, produced while still feeding a growing global population (Table 2-9). The higher estimate is equivalent to about 68 percent of projected global energy needs in 2030. However, various factors will influence the potential penetration of biomass as an energy source, the most important being the availability of conversion technology and infrastructure, and competing delivered energy costs. Business-as-usual forecasts project biomass as supplying approximately 10 percent of global energy needs by 2030. Forecasts that incorporate strong carbon-management policies see biomass energy growing considerably, to 15 percent of total global energy demand by 2030 and 30 percent by 2100.[16] Specifically, with targeted policies and restraints on carbon dioxide emission, the U.S. CCSP Level 1 Stabilization Scenario, IGSM Model, forecasts that bio-fuels will reach nearly 25 percent of liquid fuels on a volumetric basis in 2030 (Figure 2-73).

In summary, production of biofuels and energy from the large potential biomass resource is projected to grow over the study time frame. Policies to stabilize carbon dioxide concentrations are forecast to strongly stimulate growth in biomass use, though possibly with significant economic impact. There will be tradeoffs between different lower carbon alternatives depending on the type of carbon constraint. Ethanol from biomass is commercially produced today and is part of the energy supply. In order to reach its potential market penetration, energy from biomass requires considerable investment and supportive public policies. These requirements apply particularly to associated infrastructure and the development and demonstration of new fuel conversion technologies for biomass not intended for food or feed. For a full discussion of Biomass as a potential energy source, see the Biomass Topic Paper on the CD included with this report.

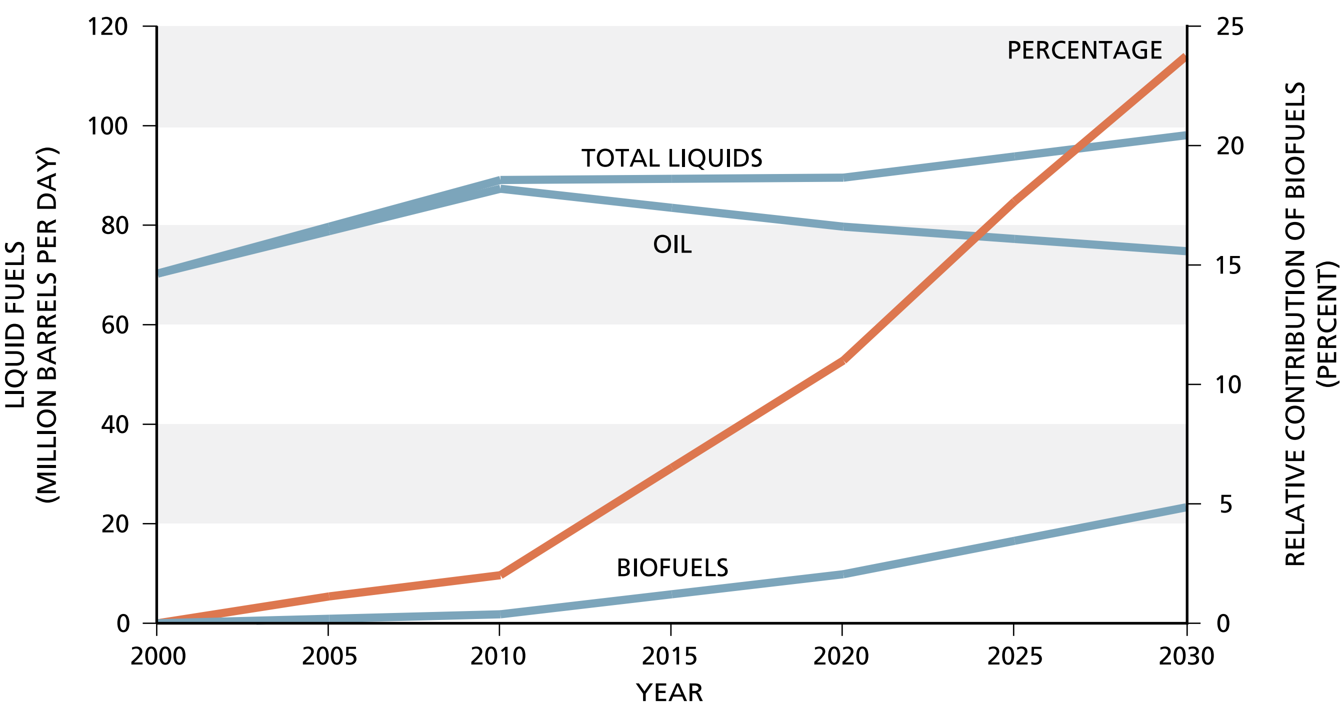
16 Energy demand in these highly carbon constrained scenarios is only marginally greater in 2100 than it is today. The carbon constraint greatly impacts economic activity.

Non-Bio Alternative Energy Sources

Key Observations—Non-Bio Alternatives

- *Forecasts for the possible role of nuclear energy vary from limited growth to cases where nuclear power is employed for power generation as a replacement for fossil fuels with a higher carbon footprint.*

- *The diversity of views about nuclear energy's future reflects conflicting positions and perceptions about*



Source: U.S. Climate Change Science Program, Level 1 Stabilization Scenario, IGSM Model.

FIGURE 2-73. *Accelerated Global Biofuels Production under Considerable Carbon Dioxide Emission Constraints* *safety, waste, nuclear proliferation, and the nuclear fuel cycle.*

- *Some alternative sources of energy, much like unconventional fossil fuels, have secondary resource impacts (water, land, fuel, etc.) that are not completely understood and may be significant as they reach new scales of supply.*

This section summarizes discussions of alternative energy sources in the Renewables and the Hydrogen Topic Papers on the CD distributed with this report.

Hydropower and Ocean

Historically, hydroelectricity has dominated non-biomass alternative energy sources. Dams have been developed globally to provide vast supplies of electricity at very low marginal production costs. Industrialized nations have already developed most of their hydroelectric resources. Additional, limited opportunities to increase hydroelectric production may exist in industrializing and economically developing nations, subject to growing questions about their environmental and social impact. Ocean and small-scale hydroelectric technologies currently being developed and deployed may also provide additional distributed and localized power with reduced environmental footprint.

Wind

Energy from wind has grown significantly in recent decades and is forecast to grow several times faster than overall energy demand, thus increasing its share of the supply mix. Given infrastructure requirements and a current share of less than 2 percent of energy supply, it will be some time before wind supplies a significant portion of global energy requirements. One of the main challenges faced by wind and other intermittent sources of energy is the need to maintain ready reserve power capacity. Incentives and tax credits have made wind power an attractive option in many markets. Additional technology development could eliminate the need for incentives.

Solar

Concentrated solar power (CSP) technology is being deployed globally. CSP costs are not yet competitive with large-scale electricity production from fossil fuels, but may be attractive for smaller and remote applications. Research in new materials for photovoltaic electricity generation (PV) continues to reduce its costs. PV technology has niche applications, but does not make significant global contributions to energy supply.

Geothermal

Conventional geothermal is competitive as a base-load power source in areas with readily accessible, naturally occurring, and plentiful underground steam. As with large-scale hydroelectric dams, conventional geothermal energy presents limited opportunities for new supplies. However, enhanced geothermal systems (EGS) that harvest heat by introducing water into an underground heat source to produce steam may have future potential growth. EGS technology significantly leverages existing oil and natural gas related technologies.

Nuclear

Despite its considerable growth in previous decades, nuclear power represents only 5 to 6 percent of the total global energy supply mix and less than 20 percent of global electricity generation. Regions and countries, however, can vary significantly from the global average. Countries such as France that have made progress in developing nuclear power tend to show contributions that are much larger than average.

Views about nuclear energy's future role are diverse. Most forecasts that stipulate business as usual show only limited changes in the contribution of nuclear energy to the energy supply mix. These forecasts refer to difficulties in siting, financing, and operating nuclear facilities, as well as in disposing of nuclear waste given environmental and non-proliferation concerns in industrialized nations.

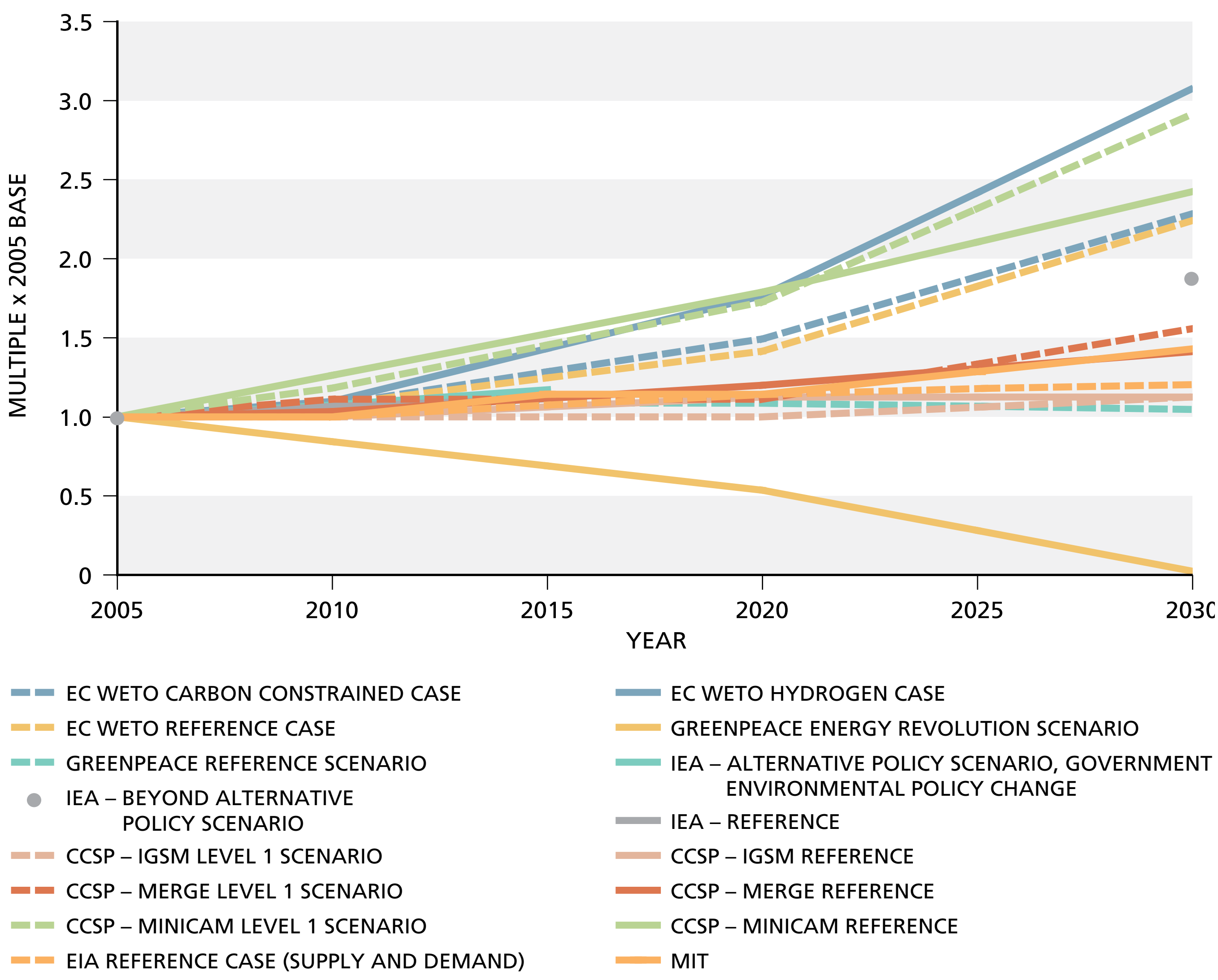
Nuclear power is forecast to grow in industrializing nations, particularly China, which have the greatest need for new sources of abundant energy. The forecasts reviewed in this study usually do not include constraints in the uranium fuel value chain, but do incorporate concerns about the fuel cycle and proliferation. Moreover, recent developments of futures contracts for uranium allow for risk mitigation. These forecasts show an increasing role for nuclear power in the latter part of the century, parallel with growth in coal-fired power plants.

As with biomass, nuclear energy becomes an important energy source in forecasts that include policy objectives to stabilize atmospheric carbon dioxide, promote efficient energy use, or reduce its carbon impact. The resulting forecasted growth is a function of the policies implemented and the technologies available. For example, if carbon capture and sequestration is delayed or never widely deployed for coal-fired power plants, nuclear power may grow considerably, perhaps to 25 percent of total global energy demand by 2100. On the other hand, if carbon capture and sequestration is successful and widespread, the projected growth of nuclear power remains significant but more moderate.

The greatest projected growth of nuclear power generation by 2030 results in an increase of more than 200 percent from current levels (Figure 2-74). By comparison, forecasts that show a significant decrease in the share of nuclear energy show a marked increase in fossil fuel use. Or, they assume revolutionary gains in efficient energy use, resulting in only marginal demand growth.

Hydrogen

Hydrogen is being considered as a future energy carrier/fuel, given that its combustion emits only water. However, hydrogen's low molecular weight and energy density, as well as its production, handling, and storage, are very important hurdles to its widespread use. Hydrogen is an intermediate product, manufactured from a primary energy source and then used to move



Source: NPC Survey of Outlooks.

FIGURE 2-74. *Projected Nuclear Power Generation Relative to 2005* energy from the source to a demand center. Currently, natural gas reforming is the main source of hydrogen. Integrated gasification combined cycle (IGCC) power plants could make coal an important source of hydrogen. Or, nuclear power could generate electricity to produce hydrogen via electrolysis or an alternative process.

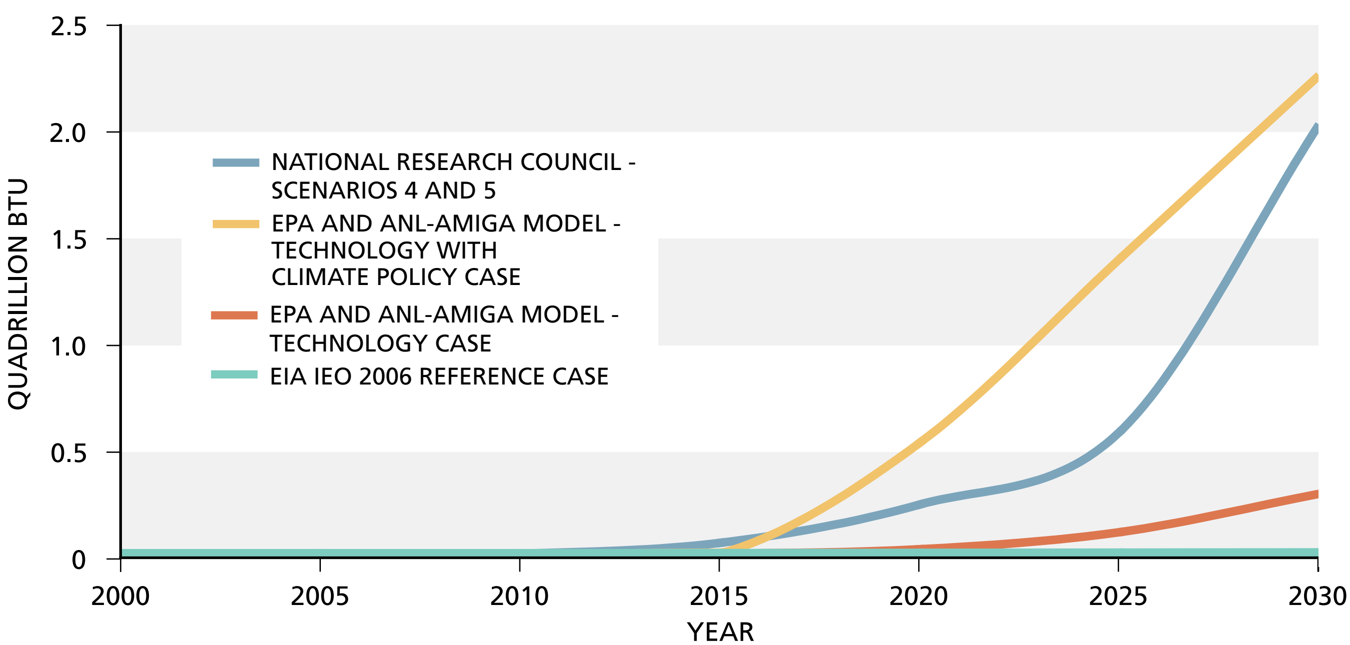
Clearly, many primary energy sources can be used to produce hydrogen. If hydrogen became the transportation fuel of choice, it could provide convergence between all sources of energy and remove the end-fuel issue from carbon policy discussions. Policy discussions might then focus on the primary sources of hydrogen, which, given its centralized nature, could more easily fit with carbon capture and sequestration.

Forecasts for hydrogen use (Figure 2-75) are usually limited to the United States. Business-as-usual forecasts, such as the EIA Reference Case, do not show significant growth in hydrogen use for transportation. By comparison, forecasts that incorporate rapid technology development and targeted carbon constraints show considerable growth in the U.S. market. However, even in this growth case, hydrogen does not displace petroleum-based transportation fuels during the study time frame.

Energy Conversion and Delivery Infrastructure

Key Observations—Energy Infrastructure

- *Energy forecasts generally do not explicitly account for specific energy infrastructure requirements, such as capital requirements, return expectations, construction schedules, resources, and permitting processes.*
- *Uncertainty relating to energy demand outlooks may restrict or delay infrastructure investment.*
- *Data collection and analysis of energy transportation infrastructure is inadequate for evaluating infrastructure capacity, throughput, and future needs.*
- *A significant realignment in the global refining system is underway, following forecast demand growth in China and India.*
- *Infrastructure requirements of many alternative energy sources at scale are not well understood and may be significant.*
- *Complex permitting processes lengthen infrastructure construction times and reflect social, environmental, and land-use constraints on infrastructure development.*



Sources: National Research Council, *Implications of a Transition to Hydrogen in Vehicles for the U.S. Energy System Scenarios*, 2004; Argonne National Laboratory, *AMIGA U.S. Technology Case Projections*, 2005; and Energy Information Administration, *International Energy Outlook 2006*.

FIGURE 2-75. *Projected U.S. Hydrogen Use for Transportation*

- *Implementing widespread carbon capture and sequestration will require significant new infrastructure.*

This section summarizes discussions in the Infrastructure and the Refining & Manufacturing Topic Papers on the CD distributed with this report.

The energy forecasts reviewed in this study do not show significant infrastructure development constraints other than those associated with siting and permitting nuclear power generation. Based on historical experience, forecasts generally assume that if sufficient economic incentive exists, new infrastructure will be developed or existing infrastructure expanded.

As with independent supply forecasts, a limited set of forecasts are available to assess new infrastructure requirements over a given period and supply-demand balance. These forecasts usually include capital and resource requirements, but focus on global or national scales that do not allow analysis of regional infrastructure development and requirements. In addition, considerably more infrastructure data are available for the United States than for the rest of the world, which increases the uncertainty of projections.

Growing international trade in natural gas and petroleum liquids will require the development of new infrastructure. For natural gas, the LNG supply chain will need considerable capital investment, from upstream development and natural gas liquefaction to LNG tankers and regasification facilities. Not all natural gas will be transported via LNG, so significant investments will also be required in long-haul natural gas pipelines. Similarly, the growing international trade in petroleum liquids will require considerable investment in oil pipelines and ocean tankers.

The evolving concentration of energy demand and energy production in different regions around the world will create new trade flows and associated infrastructure requirements. Limited infrastructure and energy trade routes that run through a few international choke points raise increasingly serious security risks (Figure 2-76).

Time and scale are significant considerations for energy infrastructure. The large, global infrastructure projects associated with forecast demand growth have long lead times. Building spare infrastructure capacity to deliver energy may not meet conventional economic thresholds. Therefore, potential project delays and lack of spare capacity increase the risk of temporary supply constraints.

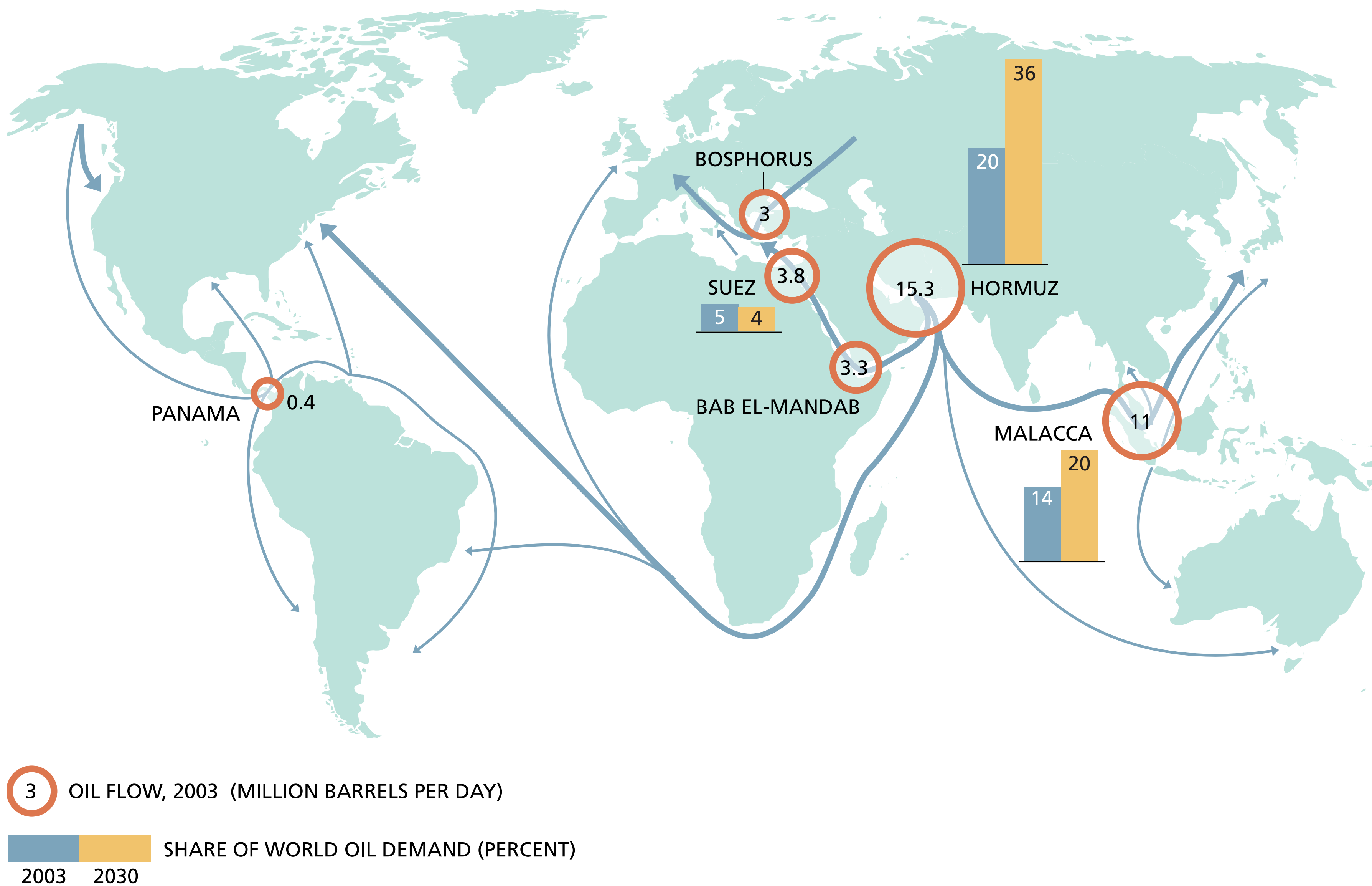
Transportation infrastructure is a highly complex, robust network that delivers energy and other commodities from resource locations to manufacturing plants and ultimately to consumption centers. The transportation system is an immense network of pipelines, railways, waterways, and roads that has been in continuous development for the past two centuries. Safe, reliable infrastructure has been, and will continue to be, a prerequisite for economic growth. Figure 2-77 suggests the complexity of the energy supply system.

In 2002, for example, more than 19 billion tons of freight was delivered across the transportation system. Energy commodities—coal, natural gas, crude oil, ethanol, and petroleum products—comprise nearly one-third (by weight) of the freight shipped in the United States. Freight shipments are expected to grow 72 percent to nearly 33 billion tons by 2030, while shipments of energy commodities are expected to total 11.4 billion tons. Pipelines, tankers/barges, and railways are the main transport modes for energy commodities. Roads are the primary delivery routes for transportation fuels from blending facilities to consumer filling stations.

A reliable, economic, and flexible energy transportation infrastructure is essential to national security and economic prosperity. Demands on current and anticipated infrastructure are heavy and growing, both to supply conventional forms of energy and enable diversification to new sources.

Refining and Manufacturing

Petroleum refining capacity in the United States has changed significantly over the past 35 years. The rapid increase in capacity in the 1970s resulted from the combination of many factors, including incentives for small refiners (Figure 2-78). Coupled with reduced demand for products after the oil price shock in 1979, the incentives led to over-investment in small, inefficient refineries and poor margins for these investments. The last three decades have seen a rationalization of this inefficient capacity, while refinery outputs have increased at the same time. The number of refineries in the United States fell from more than 300 to 150 while the average capacity per refinery steadily increased, through efficiency gains and plant expansions. U.S. refinery output has



Source: International Energy Agency, *World Energy Outlook 2004.*

FIGURE 2-76. *Oil Flows and Geographic Choke Points, 2003*

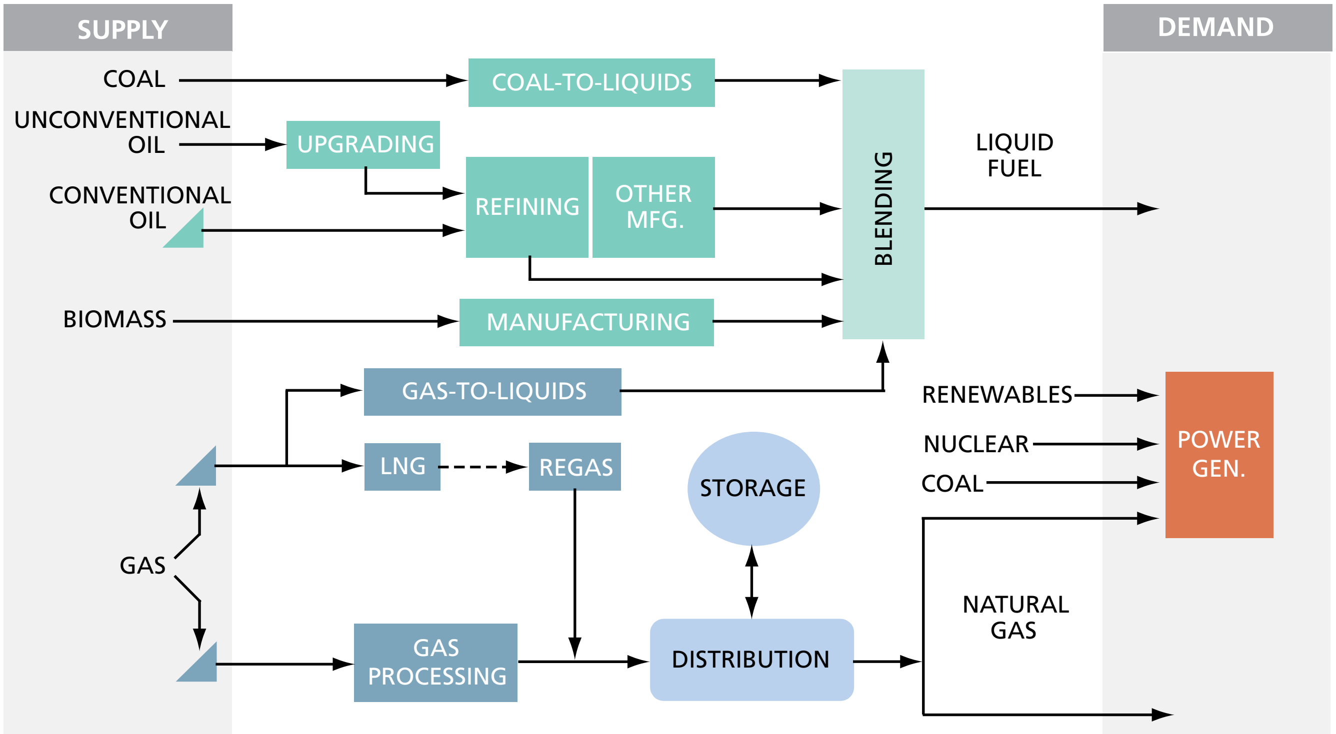
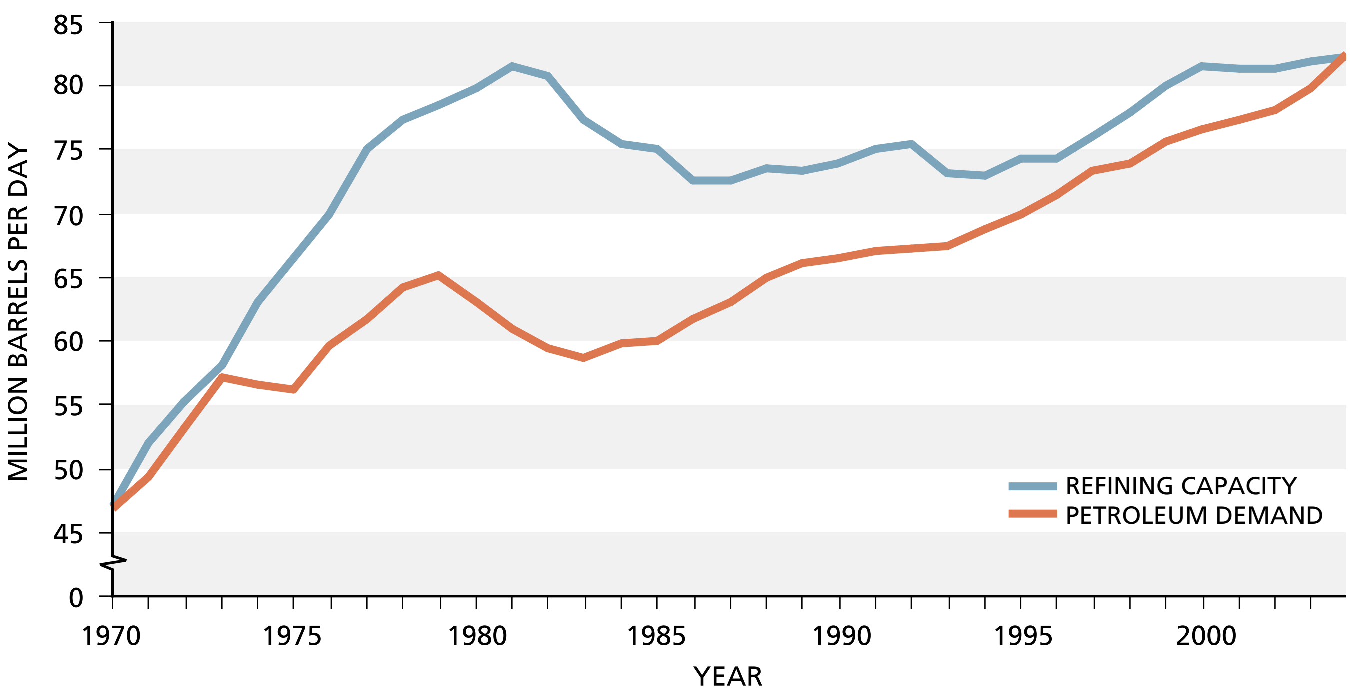


FIGURE 2-77. *Simplified Infrastructure Diagram for Energy Production, Conversion, and Delivery*



Sources: Refining Capacity: eia.doe.gov/international/iealf/table36.xls; Petroleum Demand: eia.doe.gov/emeu/ipsr/t46.xls.

FIGURE 2-78. *Global Historical Refining Capacity* increased continuously since 1985, while capacity increased by 11.7 percent between 1996 and 2005.[17] However, domestic refining capacity has not been able to keep up with product demand, resulting in increased U.S. imports of finished product and blendstock.

The study focused on four key questions to assess and understand global refining capacity projections over the next 25 years:

- What new refining capacity will be built over the next 25 years to process the projected crude oil demands?
- Where will the new capacity be located?
- What new technologies need to be developed to increase the capacity to process unconventional oil?
- What policies or regulatory barriers exist today that may inhibit development of new refining capacity?

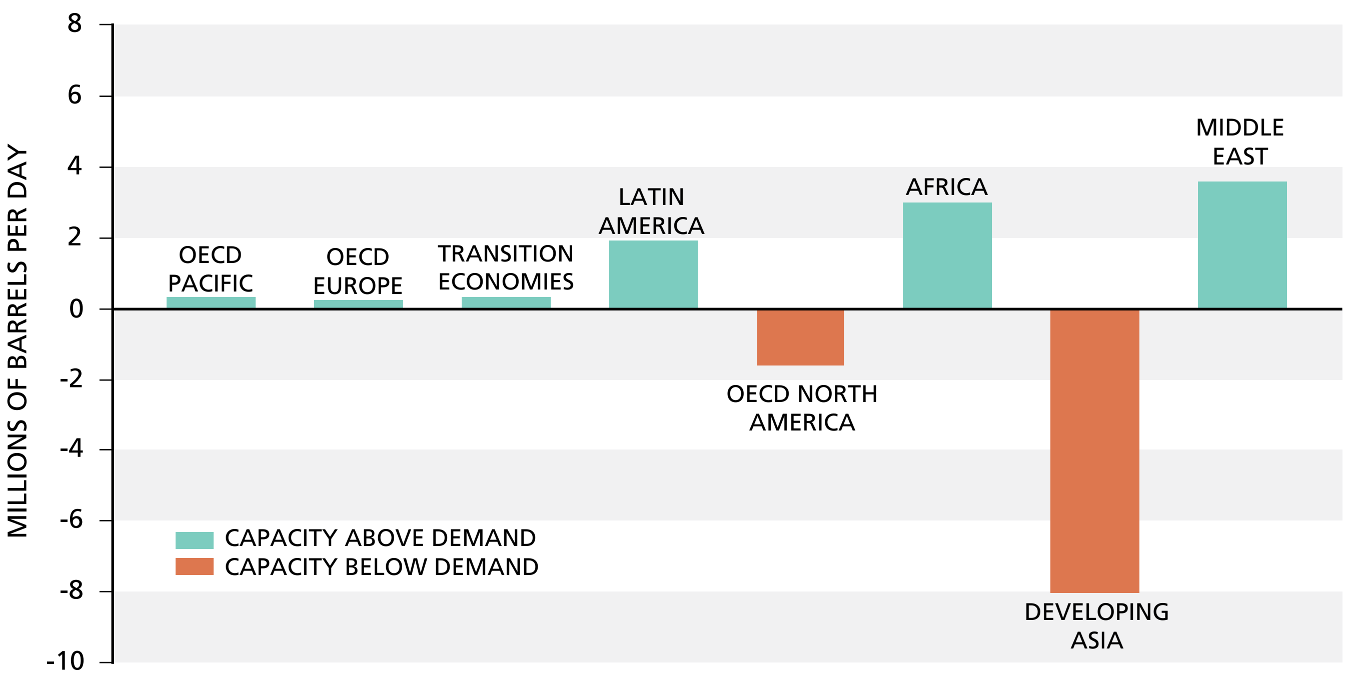
Analysis of Refining Forecasts

Ten forecasts comprising 18 scenarios contained 27 direct or inferred projections for refining capacity.

17 Federal Trade Commission Report, *Investigation of Gasoline Price Manipulation and Post-Katrina Price Increases*, Spring 2006.

The primary integrated studies from the IEA and EIA were the context for assessing the refining capacity data from the other studies. Based on the IEA and EIA Reference Cases, global refining capacity must grow by 32 MB/D over the next 25 years to meet projected oil demand. The studies and cases reviewed in this study provide various projections based on different assumptions. However, *all* cases with a projection for 2015 show primary oil demand exceeding projected 2015 refining capacity, even assuming that all announced capacity expansion projects in the latest *Oil & Gas Journal Worldwide Construction Survey* are executed. The gap is consistent with the delicate balance between forecasted infrastructure demand and the uncertainty that governs it. Resolving the uncertainty around this projected imbalance can create incentives for additional projects to increase capacity.

Figure 2-79 is one projection of the balance between regional refining capacity and demand in 2030. Based on the IEA and EIA data, growing oil demand in the United States will continue to outpace rising refinery output, requiring continued imports of blending components and finished products. Europe, the Middle East, and Africa will



Source: Calculated from data in *Oil & Gas Journal 2005* and EIA *World Energy Outlook 2006.*

FIGURE 2-79. *Projected Balance between Regional Refining Capacity and Demand in 2030* increase refining capacity above their oil demand, allowing export of finished products. Asia is projected to move from a balance between oil demand and refining capacity to an imbalance similar to the U.S. situation, with product imports needed to bridge the supply gap.

Increased unconventional oil production, primarily from Canada, is unlikely to require new technology development for the refining industry. Existing residual oil conversion technologies, including coking and solvent de-asphalting, should be sufficient to process the heavy oil into finished products. The unconventional oil-to-products value chain is tightly integrated because unconventional oil is generally less fungible than lighter conventional oil. Refineries that make the investments required to process heavy crude oil will become increasingly complex, as they add capacity to convert residual heavy oil, supply additional hydrogen, and provide hydrotreating.

The increasing integration of biofuels into the refined products distribution system can complicate distribution logistics, increase transportation costs, and reduce supply reliability. The requirements for transporting biofuels have led to large shipments by rail and truck from bio-refineries to product distribution terminals. This represents a shift in the fuels transportation system from large, cost-efficient, bulk shipments by reliable and dedicated pipelines, barges, and ships to small, less cost efficient shipments by non-dedicated railroads. The shift may reduce supply reliability while increasing transportation costs. Efforts to incorporate biofuels into existing pipelines or construct new, dedicated pipelines for biofuels at significant cost are directed at overcoming such hurdles.

ACCESS TO RESOURCES

Governments around the world have restricted access to oil and natural gas resources for various reasons, including to preserve wildlife habitat or fragile ecosystems or to further domestic economic and energy security. Recent studies in the United States have identified over 20 billion barrels onshore and nearly 19 billion barrels offshore of technically recoverable oil resources that are under access restrictions which prevent their development. This section summarizes restrictions in the United States and globally.

United States Onshore

A recent comprehensive review of U.S. oil and natural gas resources showed that almost 97 percent, or 20.5 billion barrels, of undiscovered technically recoverable oil resources beneath onshore federal lands are inaccessible or have restrictions beyond standard lease terms[18] (Table 2-10).

Over 60 percent of U.S. technically recoverable oil resources and 66 percent of U.S. technically recoverable

18 Scientific Inventory of Onshore Federal Land's Oil and Gas Resources and the Extent and Nature of Restrictions or Impediments to Their Development (EPCA Inventory), 2006.

Study Area Onshore (including Alaska)	Area: Acres (x1,000)		Undiscovered Technically Recoverable Resources: Oil (Million Barrels)		Natural Gas (Billion Cubic Feet)	
Inaccessible or With Restrictions	75,452	76%	20,473	97%	161,647	87%
Standard Lease Terms	23,751	24%	743	3%	25,210	13%
Total	99,203	100%	21,216	100%	186,857	100%

Sources: U.S. Departments of the Interior, Agriculture, and Energy, 2006.

TABLE 2-10. *U.S. Onshore Oil and Gas Resources with Access Restrictions — Federal Lands* natural gas resources lie beneath state, tribal, and private lands. Over the past several decades, urban growth, competing land uses, and changing public values have placed ever-increasing constraints on existing and new oil and gas development.

Arctic National Wildlife Refuge

The Alaska National Interest Lands Conservation Act of 1980 established the Arctic National Wildlife Refuge (ANWR). In Section 1002 of the Act, Congress deferred a decision regarding management of the 1.5 million acre coastal plain, or 1002 Area, in recognition of its significant potential for oil and natural gas resources as well as its importance as wildlife habitat. Congress continues to debate whether to open this portion of ANWR to oil and gas leasing and exploration and to eventual development if economic oil and gas resources are discovered. Table 2-11 shows potential energy and economic impacts using USGS estimates for mean and high undiscovered crude oil resources in the 1002 Area.[19]

Marginal Wells

In 2005, marginal oil wells provided over 17 percent of oil and 9 percent of natural gas produced onshore in the United States. The nation has over 400,000 marginal oil wells, each producing 10 barrels or less of oil

19 *Potential Federal Royalty and Income Tax Revenues Resulting from the Leasing and Development of the Coastal Plain of the Arctic National Wildlife Refuge*, Advanced Resources International for U.S. DOE, 2006. Also see EIA, *Analysis of Oil and Gas Production in the Arctic National Refuge*, March 2004, SR/OIAF/2004-04. USGS surveys suggest between 5.7 and 16.0 billion barrels of technically recoverable crude oil are in the coastal plain of ANWR, with a mean estimate of 10.4 billion barrels that includes oil resources in Native lands and state waters out to a 3-mile boundary within the coastal plain. The mean estimate for the federal portion of the ANWR coastal plain is 7.7 billion barrels of crude oil. In comparison, the estimated volume of technically recoverable unproven oil in the rest of the United States was 136 billion barrels as of January 1, 2006.

	2020	**2025**	**2030**	**Cumulative by 2030 (Million Barrels)**
Production Rate (1,000 Barrels/Day)*				
ANWR 1002 Mean	539	723	576	3,034
ANWR 1002 High	741	1,175	1,092	4,812
				Cumulative by 2030 (Million 2006 Dollars)
Federal Royalties (Million 2006 Dollars)				
ANWR 1002 Mean	$1,487	$1,993	$1,587	$22,922
ANWR 1002 High	$2,044	$3,240	$3,012	$36,353
Federal Income Taxes (Million 2006 Dollars)				
ANWR 1002 Mean	$1,372	$1,583	$1,346†	$19,014
ANWR 1002 High	$1,987	$2,886	$2,840	$33,801

* These production estimates are lower that some previous estimates, such as those reported by the Energy Information Administration, because they only include development of resources on federal lands in the coastal plain and not potential resources on Native lands or state offshore coastal waters.

† Tax revenues in 2030 are lower than those in 2020, despite higher levels of production, because larger, more profitable fields were assumed to be developed before smaller, less profitable fields.

Source: Advanced Resources International, 2006.

TABLE 2-11. *Estimated Production, Federal Royalties, and Federal Tax Revenues Associated with the Leasing and Development of the Arctic National Wildlife Refuge (ANWR) 1002 Area*

	Undiscovered Technically Recoverable Resources	
	Oil* (Billion Barrels)	Natural Gas (Trillion Cubic Feet)
United States – Federal OCS	**17.84**	**76.47**
Gulf of Mexico	3.65	22.46
Atlantic	3.82	36.99
Pacific	10.37	18.02
United States – Other	**1.38**	**6.78**
Great Lakes	0.43	5.23
State Waters	0.95	1.55
Canada	**10.86**	**51.10**
Northern Canada	0.10	4.00
Nova Scotia	1.06	5.30
British Columbia	9.80	41.80
Total in Moratoria Areas	**30.08**	**134.25**

*Oil includes natural gas liquids. Does not include resources in areas already under lease.

Note: In January 2007, the presidential moratoria were lifted for the entire North Aleutian Basin and a small portion of the Eastern Gulf. Revised resource estimates were released by the Department of the Interior in May 2007 and this table reflects those revised estimates.

Sources: Department of the Interior, Minerals Management Service and U.S. Geological Survey; and Interstate Oil and Gas Compact Commission.

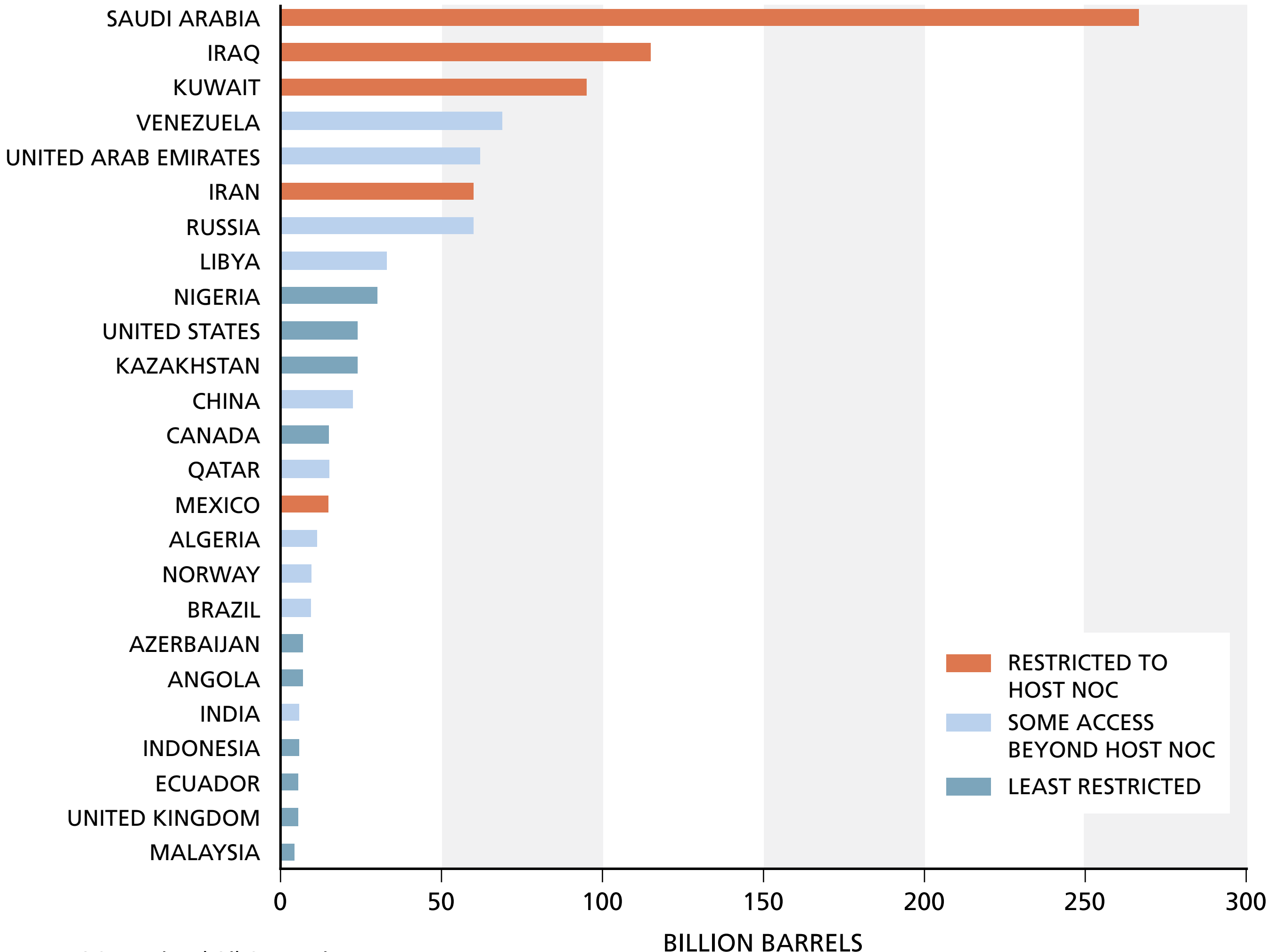
TABLE 2-12. *U.S. and Canadian Offshore Oil and Natural Gas Resources in Moratoria Areas*

Moratoria Area	Incremental Production by 2025		Cumulative Production through 2025		Cumulative Investment to 2025	Value of Avoided Oil Imports to 2025	Cum. Federal Royalties to 2025	Cum. Federal Inc. Taxes to 2025	Max. Direct Jobs	Max. Total Jobs
	Crude Oil (MB/D)	Natural Gas (Bcf/year)	Crude Oil (Million Bbl)	Natural Gas (Bcf)	(Million $)	(Million $)	(Million $)	(Million $)		
Alaska – N. Aleutian Basin	0.02	46	89	601	$2,681	$4,671	$1,642	$1,132	2,221	8,577
Atlantic Offshore	0.17	392	400	2,717	$19,238	$21,095	$7,423	$5,115	25,447	57,860
Eastern Gulf of Mexico	0.20	370	488	2,564	$21,099	$25,736	$7,977	$5,490	40,820	76,039
Central Gulf of Mexico	0.15	286	650	3,786	$18,432	$34,273	$11,149	$7,684	19,020	79,440
Pacific Offshore	0.47	300	1,132	2,078	$36,714	$59,698	$12,937	$8,865	54,561	212,306
All Moratoria Areas	**1.01**	**1,394**	**2,758**	**11,746**	**$98,163**	**$145,473**	**$41,128**	**$28,285**	**130,634**	**328,984**

Note: Assuming MMS *mean* resource estimates and the January 2006 Congressional Budget Office price forecast (all estimates in 2006 dollars).

Source: Advanced Resources International, 2006.

TABLE 2-13. *Estimated Energy Supply and Economic Benefits from OCS Moratoria Areas*



Note: NOC = National Oil Companies.
Source: U.S. Department of Energy.

FIGURE 2-80. *Access to World Proved Oil Resources*

per day for an average 2.2 barrels per day. Without production from marginal wells, it has been estimated that U.S. oil imports would increase by nearly 7 percent.[20] Increasing operational and regulatory costs and diminishing access to markets via pipelines can contribute to the premature abandonment of marginal wells. When wells and fields are abandoned prematurely, the associated oil and gas resources may never be recovered due to economics, lease termination, and related issues.

North America Offshore

Approximately 30 billion barrels of undiscovered technically recoverable oil resources and 134 trillion cubic feet of undiscovered technically recoverable natural gas resources in offshore waters of the U.S. and Canada are in moratoria areas precluded by law or public policy from leasing and development (Table 2-12). Of these resources, about 18 billion barrels of oil and 76 trillion cubic feet of natural gas are currently off limits to leasing and development in the United States. There is significant uncertainty in resource estimates for those areas of the Outer Continental Shelf (OCS) subject to long-standing moratoria or presidential withdrawal. In the north, mid-, and south Atlantic, most of the west coast, and portions of the eastern Gulf of Mexico, the last acquisition of geophysical data and drilling of exploration wells occurred from 25 to 40 years ago. There were a few prospective discoveries at that time and numerous indications for the potential occurrence of oil and gas.

20 Interstate Oil and Gas Compact Commission, *Marginal Wells: Fuel for Economic Growth*, 2006.

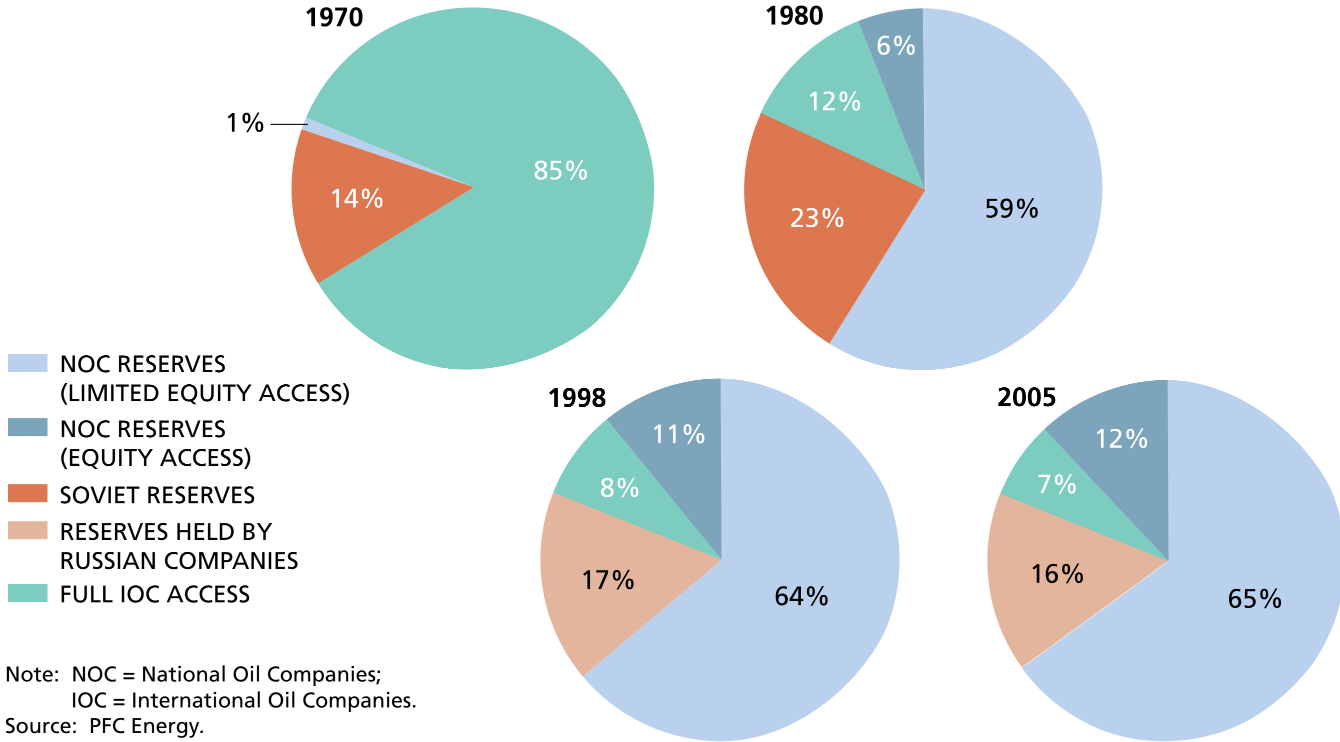


FIGURE 2-81. *Access to Global Oil and Gas Reserves over Time*

Estimates developed in 2006 show that the potential energy and economic benefits of increased access to oil and gas resources in OCS moratoria areas could be substantial (Table 2-13):[21]

- By 2025, U.S. crude oil production could increase by more than 1.0 MB/D.
- Nearly 2.8 billion barrels of crude oil could be produced between now and 2025—production that would not be realized if the existing moratoria were continued.
- Industry would spend $98 billion dollars in the U.S. by 2025 to develop these resources.
- Between now and 2025, the U.S. trade imbalance would be reduced by $145 billion if this domestically produced crude oil were to offset imports on a one-to-one basis.
- The U.S. would collect an additional $41 billion in royalties by 2025 from OCS production.
- An additional $28 billion in federal income taxes would be collected from OCS production between now and 2025.
- The economic activity generated by this development would result in the addition of as many as 130,000 direct domestic, high-paying jobs.

Global Access

Figure 2-80 shows access restrictions for resource holding countries in addition to the United States. Figure 2-81 shows how access to global oil and gas reserves has become increasingly restricted over time. The trend line and the proportion of resources under restricted access raise uncertainties about secure energy supply and potentially diminishing opportunities for equitable access.

21 *Estimate of the Potential Economic Benefits From the Leasing and Development of Oil and Gas Resources in OCS Moratoria Areas*, Advanced Resources International for U.S. Department of Energy, June 6, 2006. Based on mean MMS estimates of undiscovered oil and gas resources in the areas in question.