

Second Wallace E. Pratt Conference  
“Petroleum Provinces of the 21st Century”  
January 12-15, 2000  
San Diego, California

## Discoveries of the 1990s – Were They Significant? <sup>1</sup>

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Oil discoveries of the 1990s, ranging from 4 to 9 billion barrels per year, were significant in location but less so in size. They are smaller in both size and number than in the past and are projected to supply only about 20 percent of consumption in 2005. To meet demand of 28 billion barrels of oil in 1999 and projected demand of 35 billion barrels of oil in 2010, new production must originate not only from recent discoveries but also from other sources, including

- pre-1990s discoveries made economic and accessible with new technology and with political opening, including full development of existing reserves in the Middle East – especially Iraq and Saudi Arabia
- the likelihood of a continuation of the recent trend toward increased annual discovery rates
- development of extra heavy oil in Canada and Venezuela
- growth in gas-related liquids—condensate and natural gas liquids (NGLs), and gas converted to liquids
- continued technological advances to reduce costs and increase recovery rates in mature fields by identifying bypassed reserves.

The outlook for long-term liquid supply shows strong growth from the mid-1990s to 2010 adding 24.2 million barrels per day (mbd) to supply, of which 7.2 mbd will have been added between 1995 and 2000 (see Table 1).

**Table 1.**  
**World Liquid Capacity Outlook**  
(million barrels per day)

1995	2000	2010
73.2	80.4	97.4

Source: Cambridge Energy Research Associates.

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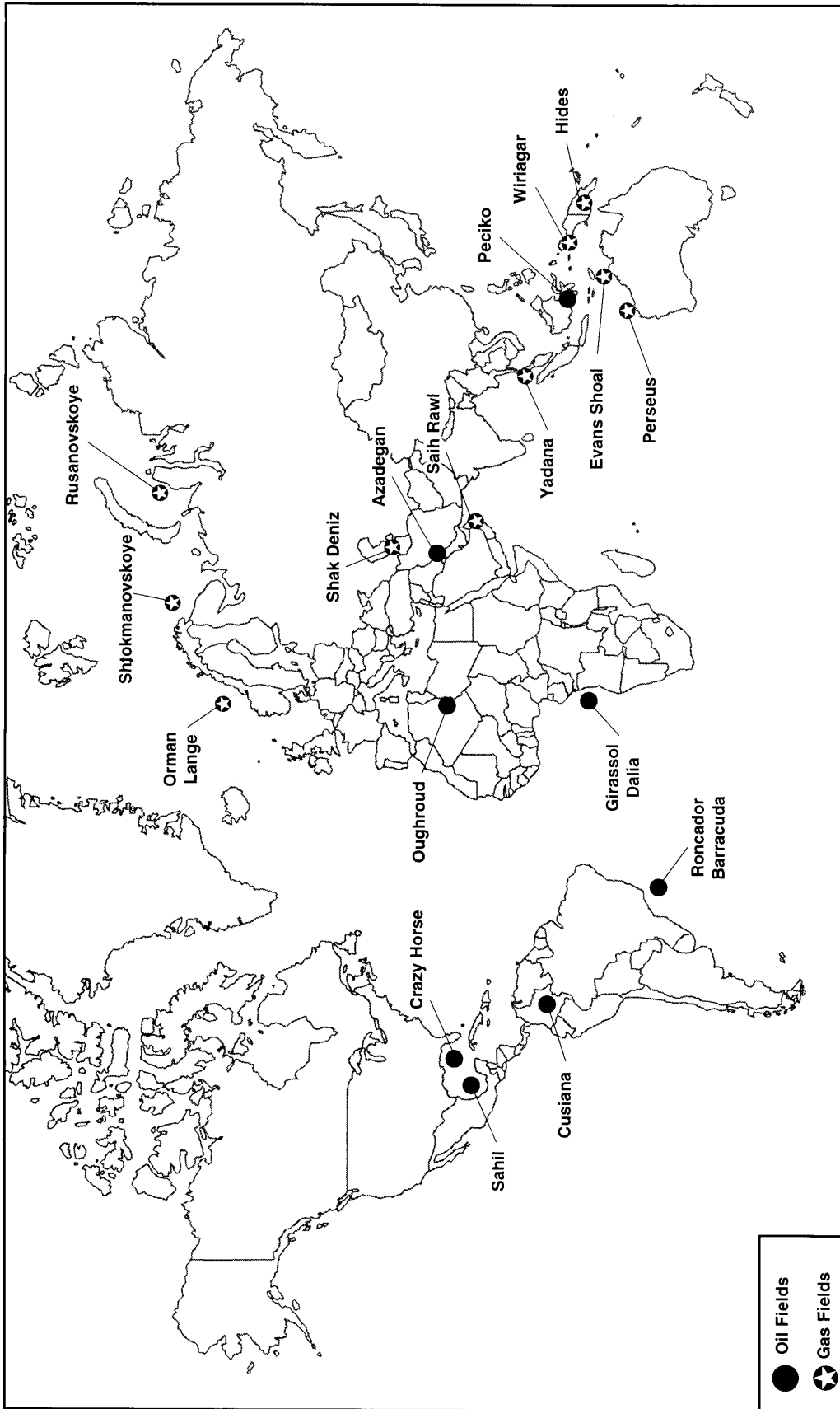
<sup>1</sup> Copyright © 2000 by AAPG. Presented at the 2nd Wallace E. Pratt Conference, San Diego, CA

<sup>2</sup> Cambridge Energy Research Associates, Cambridge, MA 02138

Figure 1

**Giant Discoveries of the 1990s**

(Fields greater than 1 billion barrels or 5 trillion cubic feet)



Source: Cambridge Energy Research Associates.  
October 1999  
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To meet demand in 2020 that could exceed 40 billion barrels, unless oil demand ceases to grow because of the encroachment of natural gas and other energy sources, increased efficiencies, or some new technology, the above sources will be called upon to far exceed the production expectations for 2010. This growth in supply is necessary to overcome significant declines in production, due to resource constraint, projected for the United States and Western Europe and increasing depletion rates in existing production in all areas.

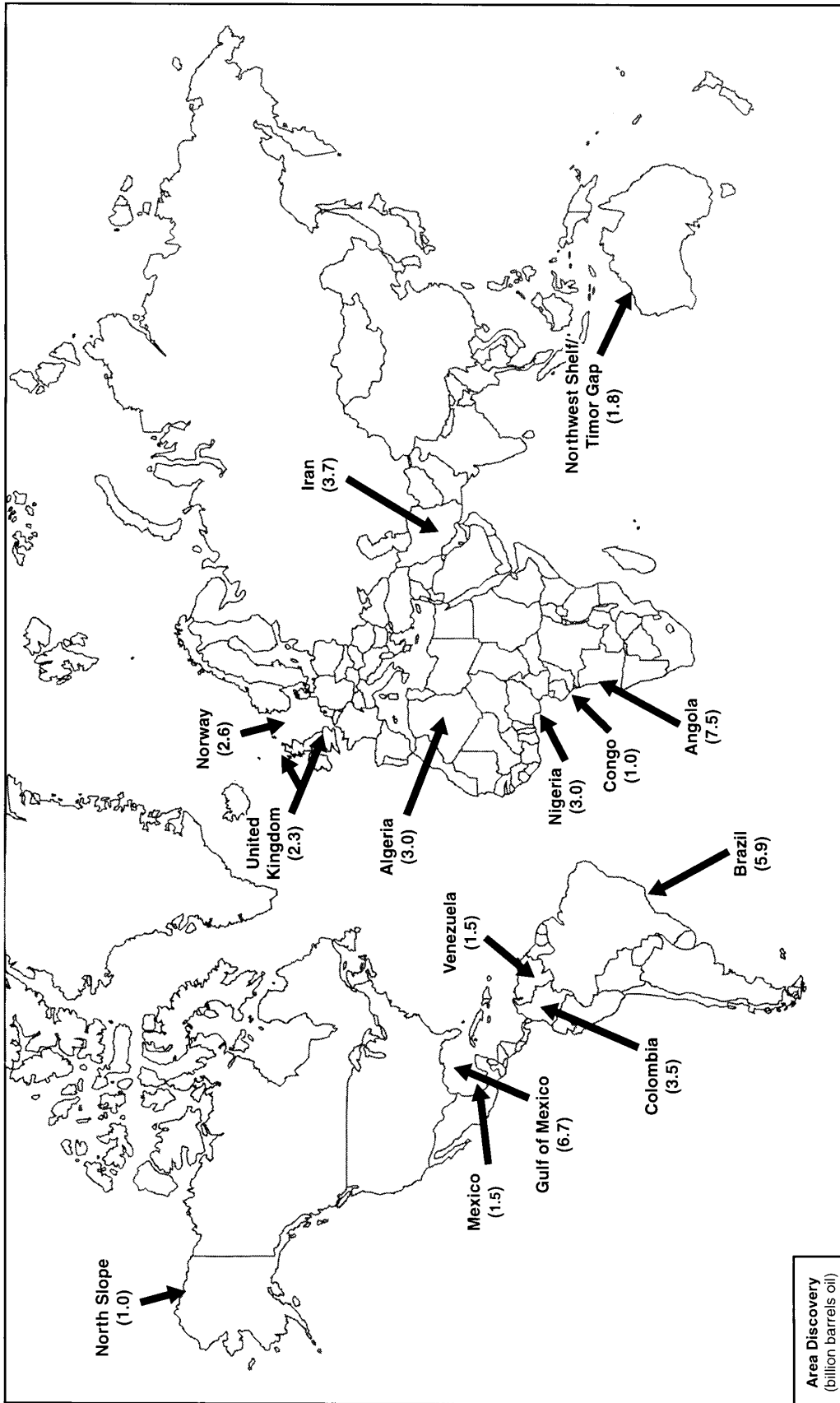
### **Economic Framework of the 1990s**

The 1990s have been characterized by two complete “boom-bust” cycles for E&P. Following the invasion of Kuwait in 1990, companies and some Middle East countries moved to increase their productive capacity, resulting in a rapid increase in surplus capacity and low prices by late 1993 and early 1994. In a reaction to lower prices, companies reduced budgets, increased layoffs, and pulled back to focus on core areas. By the mid-1990s surging demand reversed the decline in prices, and companies renewed activity by moving to prospective regions worldwide to build up supply. This expansion attained boom conditions into late 1997 with large budget increases and was accompanied by fears of rig and personnel shortages. Suddenly, in mid-1997 the collapse of the Asian economy, eliminating over 2 billion barrels per day of previously anticipated demand for 1999, and a record warm winter led to the collapse in oil prices throughout 1998 and into early 1999. This brought about the largest cutback in E&P budgets since the mid-1980s as companies again focused reduced spending levels on core areas and engaged in stepped-up merger activity. However, something was different this time as many companies maintained aggressive E&P activity in the highly prospective deeper water areas—spurred by the increasing availability of deepwater drill ships and rigs and the increasing discovery success rate. In spite of reduced budgets, 1999 will exceed 1997 as the peak year for discoveries in the 1990s.

### **Discovery Characteristics of the 1990s**

The dominant discovery pattern of the 1990s was the evolution of the deep water as the primary new exploration target. This was evident in the Gulf of Mexico, West Africa—especially Angola—and Brazil, and this was made possible by the combination of the surprising individual well productive capability (a reflection of the high reservoir quality) and the large reduction in per-barrel costs resulting from new technology and the decrease in the discovery-to-production time period. Another discovery pattern was the shift in the early 1990s to increased gas exploration, especially in Southeast Asia, resulting in annual discovery rates of 40 to 60 trillion cubic feet (Tcf) of gas and the construction of six grassroots liquefied natural gas (LNG) liquefaction facilities. As a result of the shift of activity to high-potential frontier and newly opened, underexplored areas, the pace and size of the discoveries during the past three years has increased. During the 1990s, nine giant fields with recoverable reserves exceeding one billion barrels of oil each were discovered (see Figure 1). These fields are located in Algeria (Oughroud), Brazil (Barracuda and Roncador), Colombia (Cusiana/Cupiagua), Angola (Girassol and Dahlia), Iran (Azadegan), Mexico (Sahil), and the United States Gulf of Mexico (Crazy Horse). In addition, there were ten discoveries exceeding 0.5 billion barrels each. In the case of gas, 11 fields larger than 5 Tcf each were discovered. These are located in Australia (Perseus, Evans Shoal), Azerbaijan (Shak Deniz), Indonesia (Peciko, Wiriagar), Oman (Saih Rawl), Papua New Guinea (Hides), Myanmar (Yadana), Russia (Shtokmanovskoye, Russanovskoye),

**Figure 2**  
**Major Area Oil Discoveries, 1990-99, Larger than 1 Billion Barrels**



Source: Cambridge Energy Research Associates.  
 October 1, 1999  
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and Norway (Orman Lange).

The most significant areas of discovery in the 1990s consisted of clusters of oil discoveries (see Figure 2) led by Angola, Gulf of Mexico, and Brazil and for gas (see Figure 3) led by the Gulf of Mexico, the Norwegian Sea, and the North West Shelf of Australia and Indonesia (West Irian). It is the clusters of fields that result in large area discoveries that are similar in size to some of the major discoveries of the 1970s.

As for discovery totals for the 1990s, Africa/Middle East exceeds by far all other areas for oil with discoveries of 28 billion barrels of oil (see Figure 4). The Far East leads for gas with discoveries of 180 Tcf, although each individual area had specific years with major discoveries. Examples for 1999 include North America with the discovery of the Crazy Horse field in the Gulf of Mexico; 1996 in Latin America—the Roncador field in Brazil; 1992 in Europe—Foinavon field, located west of the Shetlands, and the Norne field in Norway; and 1994 and 1995 in the Far East—the Laminaria and Bayu Undan discoveries in the Timor Gap area.

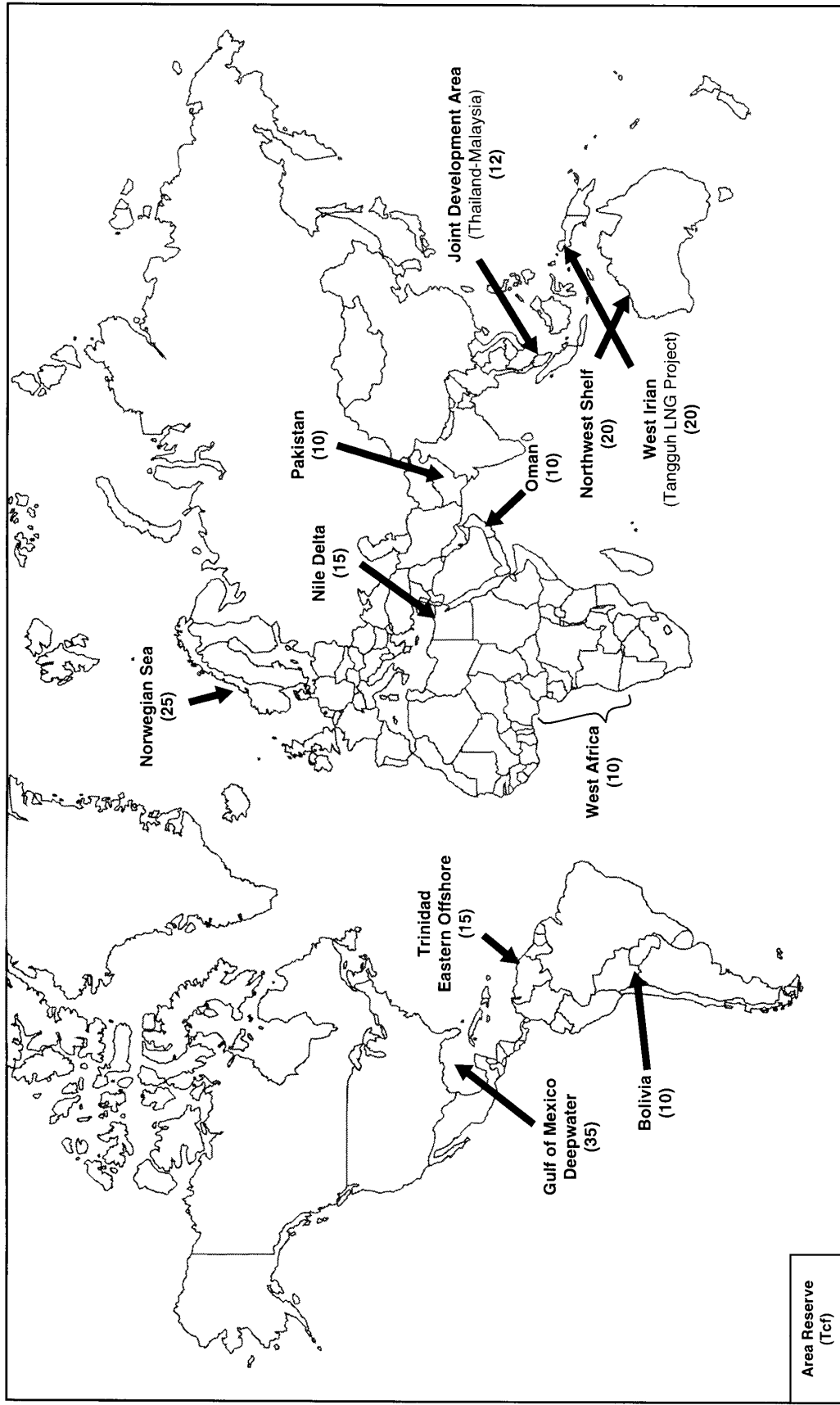
### **Increased Pace and Size of New Discoveries Into the Next Decade**

Emphasis on the high potential E&P “hotspots,” especially the deepwater, has resulted in an increase in the pace and size of new discoveries (see Figure 5). Areas with the largest number of significant discoveries greater than 100 million barrels and 1.0 Tcf during the 1996–1999 time frame include Angola, the Gulf of Mexico, Algeria, Norway, and Egypt. The number of significant discoveries in recent years is increasing, with 1999 likely to exceed the 1998 level of 40 discoveries, up from 32 discoveries in 1996. The increased discovery level is a result of the following:

- There has been growing emphasis on highly prospective ultradeepwater areas, characterized by large structures with high quality reservoirs. These areas include the Gulf of Mexico, West Africa, and Brazil. The majority of the larger discoveries in recent years have been made in water deeper than 3,000 feet.
- The late 1990s has seen a rapid increase in the availability of drilling equipment capable of operating in waters deeper than 5000 feet.
- Countries previously closed to outside investment are opening as a result of political change or the privatization of national oil companies. Besides some of the Middle East countries, examples include the republics of the former Soviet Union, Algeria, Argentina, Venezuela, and, most recently, Brazil.

Because of the high prospectivity of these areas, it's likely that annual discovery rates will continue to increase in the next decade, eventually yielding more production than the discoveries of the earlier 1990s. Thus annual discovery rates in the 7 to 10 billion barrel range are possible in the future, especially when it is recalled that in the 1998–1999 period, the main focus of the newly minted supermajor oil companies was directed toward merger-related factors and away from exploration. Also one very large major company was cutting fundamental investment levels. Thus aggressive exploration and development activity from the largest companies has been constrained since 1997. The slow opening of the major countries of the Middle East to Western investment, leading to the

**Figure 3**  
**Major Area Gas Discoveries, 1990-1999, Larger than 10 Tcf**



Source: Cambridge Energy Research Associates.  
 October 1999

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revival of exploration, will eventually raise the discovery level in an area where exploration has been at a low ebb for almost 20 years. Libya will also be the scene of increased exploration.

## **World Oil and Gas Undiscovered Potential**

Estimates for global oil and gas undiscovered potential are based on work by Masters at the US Geologic Survey in 1993. In certain cases, such as Brazil, Colombia, the Gulf of Mexico, Angola, and Algeria, these estimates have been modified by Cambridge Energy Research Associates to accommodate recent discovery experience (see Figure 6). The interesting observation is the relative similarity of undiscovered conventional oil estimates in the Middle East, Latin America, and Eurasia. North America, Africa, and Australasia are in the second tier. It is actually within this tier that the current spate of the large discoveries are currently being made—the Gulf of Mexico and West Africa. What is most important for the source of new production is the size of the extra heavy unconventional oil resource of 675 billion barrels of oil in Canada and Venezuela, which exceeds the potential undiscovered conventional oil estimate of 610 billion barrels.

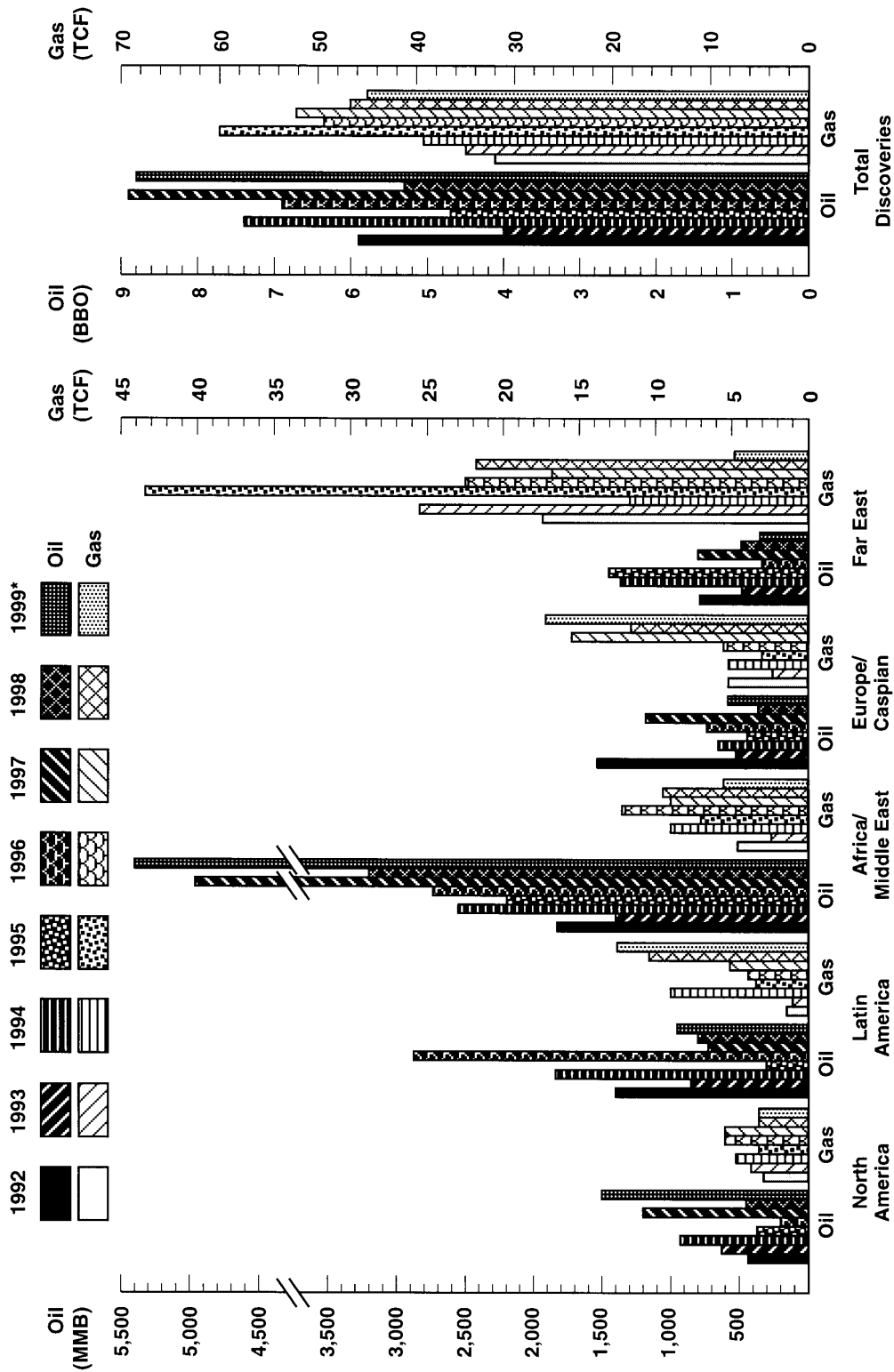
The undiscovered gas potential of Eurasia is 41 percent of the world total of 5,791 Tcf (see Figure 7). This is followed by the Middle East and North America. Interestingly the leading area of the 1990s discoveries—the Far East—rates fourth in potential behind North America.

## **E&P “Hotspots” of the 1990s**

During the 1990s E&P activity has been concentrated on individual company core areas that, collectively, are the global E&P “hotspots” (see Figure 8). Readily apparent is the emphasis in particular areas on oil, oil associated with gas, and nonassociated gas. Other observations regarding the hotspots include

- Deepwater areas of the Gulf of Mexico, Brazil and West Africa lead in E&P activity.
- The Caspian Sea area, especially Azerbaijan and Kazakhstan, continues to retain the high mid-1990s priority of many companies even though the southern Caspian has likely turned out to be gas-condensate-prone, based on recent drilling. The currently drilling Kashagan East test well in the northern Caspian, with the objective of a Tengiz oil field look-alike, will be of prime importance as to the future oil capacity expectations for the Caspian.
- Other areas with strong E&P activity primarily related to oil include the eastern Canadian offshore, portions of the Atlantic Margin west of the Shetlands, the Berkine Basin of East Central Algeria, Central Africa (Sudan and Chad), and Iran.
- Gas-oriented hotspots, to supply increasing demand expectations as pipeline gas and as LNG, include eastern Canada, Bolivia, Nigeria, Qatar, Egypt, Libya, Oman, Pakistan, many countries in Southeast Asia, and the North West Shelf of Australia.
- Unconventional extra heavy oil operations are proceeding with the mineable oil sands in Alberta, Canada, and the Orinoco oil belt in Venezuela. Production from each of these areas is

**Figure 4**  
**World Oil and Gas Discoveries, 1992–1999**



Source: Cambridge Energy Research Associates.  
 \* To October 1999.  
 Updated October-2 1999  
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projected to reach more than 1 mbd by 2010.

- Hotspots of the 1970s and 1980s, which include Mexico, eastern Canada, the North Sea, Brazil, Qatar, Iraq, and the North West Shelf of Australia, remain as hotspots of the 1990s and beyond with some of the areas perpetuated by adding the very deepwater domain.

### **The Current Search for Tomorrow's Hotspots**

In spite of the volatile crude oil prices of 1998 and 1999, the industry has continued its quest for future hotspots, including the movement into deeper water with leasing progressing beyond the 10,000 feet water depth (see Figure 9). Two areas, the Falkland Islands and the Eritrean offshore, were unsuccessfully tested in 1999. In some cases exploration drilling in the future hotspots has occurred, resulting in some discovery and production. Examples include West Newfoundland, Mongolia, and Guatemala. In other areas some larger discoveries have been made, but development efforts have stalled. Examples include the Norwegian portion of the Atlantic Margin, the East African gas play, the Russian Arctic and East Siberia. In 2000 drilling is expected off western Greenland, the Atlantic Margin, and the Faeroe Islands. A similar map of future hotspots, as visualized in 1990, would have shown expectations for future E&P activity in areas with 1990s discoveries such as the Timor Gap/West Irian area, west of the Shetlands, the Egyptian offshore, the Berkine basin in Algeria, the deepwater portions of West Africa, and the Philippines offshore. In the United States many highly prospective areas such as the Arctic National Wildlife Refuge (ANWR) and the entire East and West Coast offshore areas remain off limits for exploration. However, these areas might well appear on a subsequent map of tomorrow's hotspots.

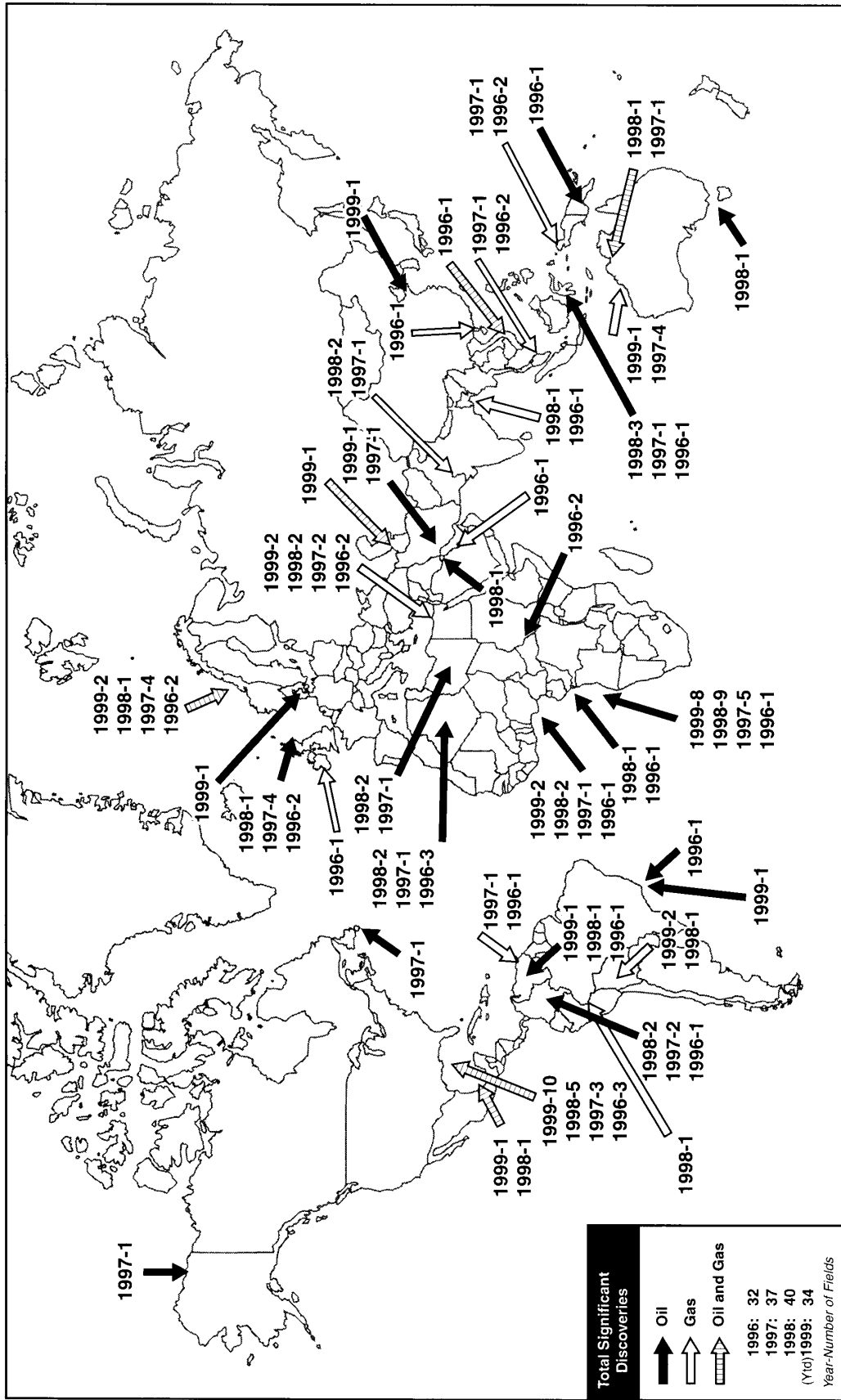
### **Contribution of 1990s Discoveries to Future Production Levels**

Development of the estimated 60 billion barrels of oil discovered in the 1990s is projected to yield over 17 mbd of production, 20 percent of projected 2005 demand of 85 mbd. Of the 17 mbd, 13 mbd will begin initial production in the late 1990s, peaking in the 2005–2007 time frame. Over half of the total capacity additions will emanate from four areas including the Gulf of Mexico (3.2 mbd); and 1.5 mbd each from Angola, Nigeria, and Brazil. The timing of the appearance of much of the new productive capacity, after 2000, is related to the mid-1990s increase in discoveries in deeper water and the additional time required to appraise and develop these discoveries. The increase in deepwater production reflects the increase of the water depth “barrier” to production. In the 1980s the barrier was 1,800 feet with oil production from 1,760 feet. In the 1990s oil production now occurs from 6,079 feet water depth in the Roncador field in Brazil. As of late 1999, water depth production “barriers” are 6,500 feet for oil and 5,500 feet for gas. It is likely the 7,500 foot water depth barrier will be surpassed by 2005 as both the drilling and producing technology and the ability to deal with associated gas will allow production in the 10,000 foot water depth by 2010.

### **Other Sources of Future Production**

In addition to the 1990s discoveries, considerable new production to meet future demand will result from discoveries made prior to the 1990s and from unconventional extra heavy oil and gas-related liquids.

**Figure 5**  
**1996-1999 Significant Discoveries**  
 (larger than 100 million barrels, 1 trillion cubic feet)



## **Pre-1990s Discoveries Made Accessible and Economic**

To supplement the production added by discoveries made in the 1990s, the development of fields discovered in the 1970s and 1980s, with some initiating production in the 1990s, will be required to meet demand. Fields in this category are projected to produce up to 8.0 mbd by 2007 and include undeveloped or partially developed fields in areas such as the Caspian (3.7 mbd), Brazil deepwater (1.0 mbd), and 0.75 mbd each from eastern Canada offshore, Venezuela, and western Canadian bitumen, with lesser amounts of heavy oil from California, the Gulf of Mexico deepwater, the Beaufort Sea of Canada, the North Slope of Alaska, and eventually the Sakhalin area. The major pre-1990s discoveries under development and currently ramping up production include the Caspian with the Tengiz field in Kazakhstan and the Azeri megastructure in Azerbaijan; in Brazil the Marlin and Albacora fields; in eastern Canada the Hibernia and Terra Nova fields; and in the Gulf of Mexico the Mars, Auger, and Brutus fields.

Large existing undeveloped reserves in Saudi Arabia and the backlog of giant, undeveloped 1970s discoveries in Iraq will also be the source of major new production in the years after 2000. Development of new productive capacity in the Middle East will accelerate after 2005 and over 15 mbd of new capacity is projected to be added beyond 2010. In addition, many of the fields in the Middle East have not as yet benefited from modern technology, deep drilling below existing production, infill drilling, and secondary and enhanced oil recovery techniques. An example of deeper drilling in known fields is the Ghawar field in Saudi Arabia, where major reserves have been discovered below the current production. The main producing countries of the Middle East will benefit from Western investment as the major companies seek low-cost areas in which to invest.

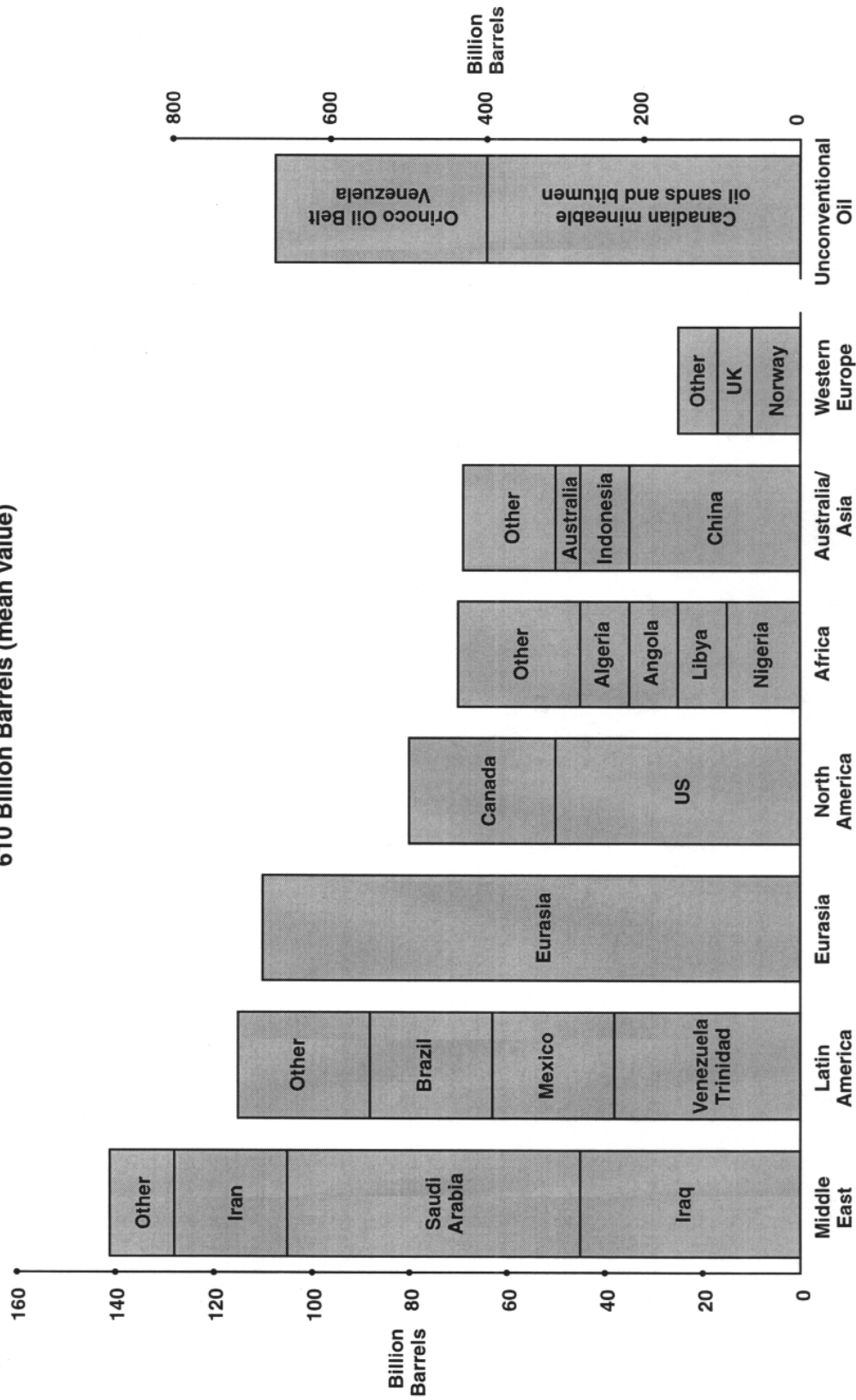
## **Development of Extra Heavy Oil in Canada and Venezuela**

New technology has reduced the cost of development of mineable oil sands in Canada and production from the Orinoco oil belt in Venezuela. Volatile oil prices have resulted in hesitation in some Orinoco projects, but by 2010, production of at least 1.0 mbd is projected. New horizontal drilling technology has increased individual well productivity in the Orinoco oil belt to over 1,000 bd. Development of mineable oil sands expansions in Canada has continued throughout the period of low oil prices. Expansions and new projects will result in production from this source of 0.9 mbd by 2007 and well over 1.0 mbd by 2010 compared to 0.35 mbd in 1999. Expansion of these areas will continue to add large amounts of new capacity in both Canada and Venezuela beyond 2010.

## **Gas-related Liquids-Condensates and NGLs**

The shift in strategy to gas exploration in the early 1990s resulted in the discovery of considerable gas, especially in Southeast Asia. Much of this gas will be delivered as LNG to both Asian markets and as spot supplies elsewhere. Most of this gas is associated with condensate and will be processed to separate the NGLs. The outlook for these liquids is for strong growth throughout the 1990s to 2010, adding 2.7 mbd from 1995 to 2000 and 5.7 mbd between 2000 and 2010 (see Table 2). In addition, the application of gas-to-liquids technology to exploit remote or “stranded” gas resources could eventually add 1 to 2 mbd of products after 2010.

**Figure 6**  
**An Estimate of World Undiscovered Oil Potential**  
**610 Billion Barrels (mean value)**



Source: Cambridge Energy Research Associates  
 Modified from Masters et al, 1994.

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**Table 2**

<b>Global Gas-associated Liquids Outlook</b> (million barrels per day)			
	1995	2000	2010
Condensate	2.9	4.3	7.3
NGLs	5.2	6.5	9.2
<b>Total</b>	<b>8.1</b>	<b>10.8</b>	<b>16.5</b>

Source: Cambridge Energy Research Associates.

### **New Technology and Increased Recovery Rates**

During the 1990s the application of new technology—especially 3-D seismic, geosteering (horizontal drilling), and new well completion techniques—has contributed to the reduction of exploration risk and finding and developing costs. Not only the discovery of hard-to-find fields, such as subsalt discoveries, but also the development of wedge-edge pay zones have been made economic with the advances in technology. Up to 3.0 mbd of oil capacity additions in the 1990s have been made possible with horizontal and extended reach drilling. In the future the technological improvements will center around the second generation of geosteering, extending information from adjacent to the drill bit to information ahead of the drill bit, thus providing an instantaneous correlation of subsurface well data to seismic data. The combination of expected technological improvements and the application of enhanced recovery techniques, including improved reservoir fracturing and stimulation to older fields throughout the world, is projected to continue to raise average recovery rates, thus helping to moderate decline rates.

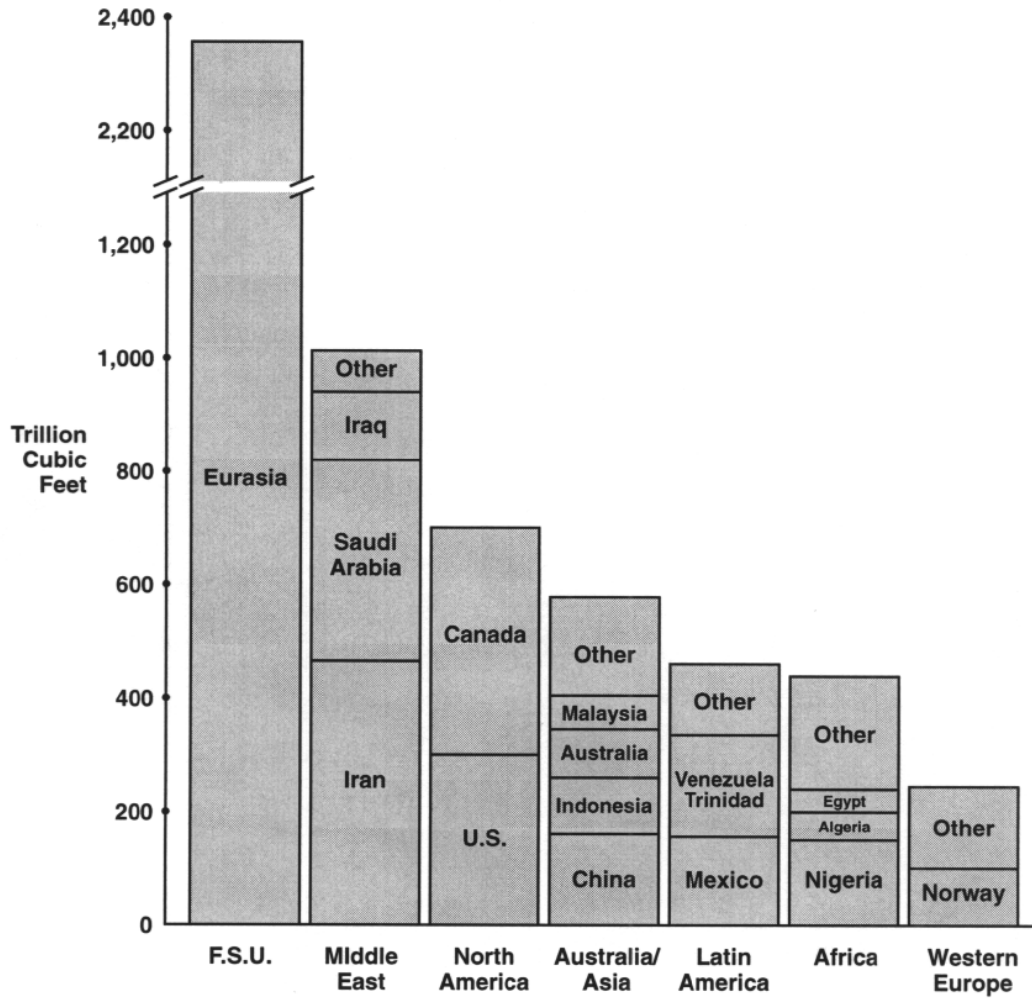
### **Natural Gas**

Continuing the trend started in the 1990s natural gas will provide many of the exploration hotspots of the next century. The discovery of over 450 Tcf in the 1990s is expected to be equaled in the next decade to supplement gas from the development of the 1990s discoveries and other pre-1990s discoveries, such as the North supergiant gas field in Qatar, to meet strong global gas demand growth. Also, the flaring of large amounts of associated gas in a “post-Kyoto” world is likely to become untenable, leading to both initial local consumption and gas-to-liquids projects after initial use in reservoir pressure maintenance operations in both stranded associated and nonassociated gas fields.

The future of LNG, considered lackluster in the mid-1990s, has brightened with the construction of six grassroots liquefaction facilities, two of which have been greatly expanded during the initial construction phase. Because of the expansion of some of the existing producing facilities and new capacity from the North West Shelf of Australia and West Irian, LNG will add to supplies beyond 2005 as demand surges in China, India, and Pakistan.

Gas demand growth is projected to continue to accelerate beyond 2000 as countries convert their energy base to natural gas and demand increases in those countries already utilizing gas. In addition, the struggle to supply sufficient gas to the United States will require increasing imports from Canada and LNG from global sources.

**Figure 7**  
**An Estimate of World Undiscovered Gas Potential:**  
**5,791 Trillion Cubic Feet**  
**(mean value)**



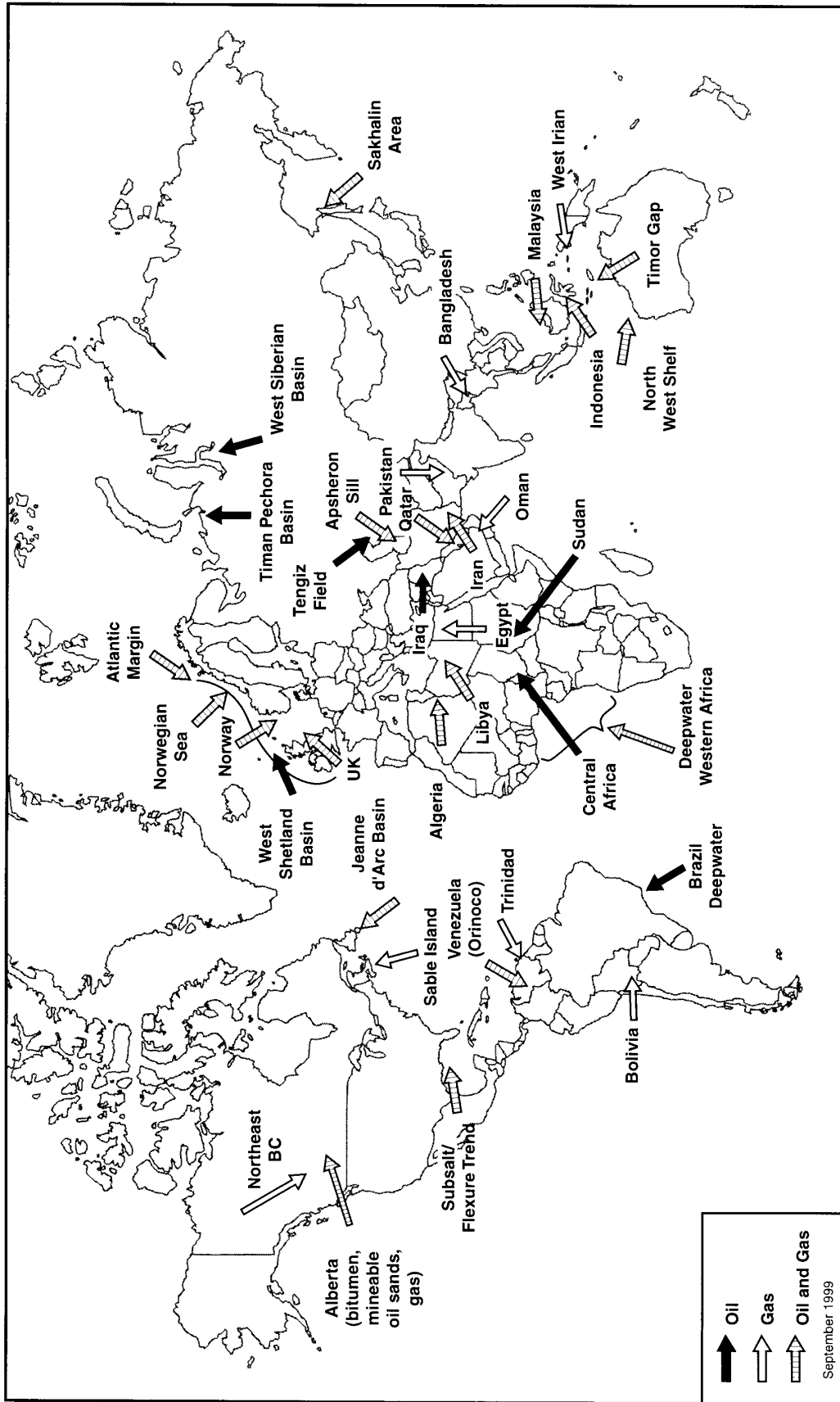
Source: Cambridge Energy Research Associates.  
 Modified from Masters et al. 1994.  
 June 1999  
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## **Conclusion**

The giants of the 1990s were significant in that they traced the opening of the deep water as a primary source of new oil production. In addition, political opening and privatization efforts have provided a second source of new production. A trend toward increased discovery rates in the late 1990s is projected to continue beyond 2000, but future production from this source will only partially meet the growing demand for oil. Continued development of fields discovered before the 1990s and the heavy oil resources of Canada and Venezuela, combined with further technological breakthrough that can raise overall recovery rates, will be required to supply the demand for oil.

The switch to an emphasis on gas in the early 1990s resulted in the discovery of large gas reserves. In spite of the temporary late 1990s weakness in demand for LNG, new liquefaction facilities are under construction, and older facilities are being expanded, utilizing gas from recent discoveries to meet the overall increasing growth in demand for gas.

**Figure 8**  
**Major Exploration and Development Hotspots**



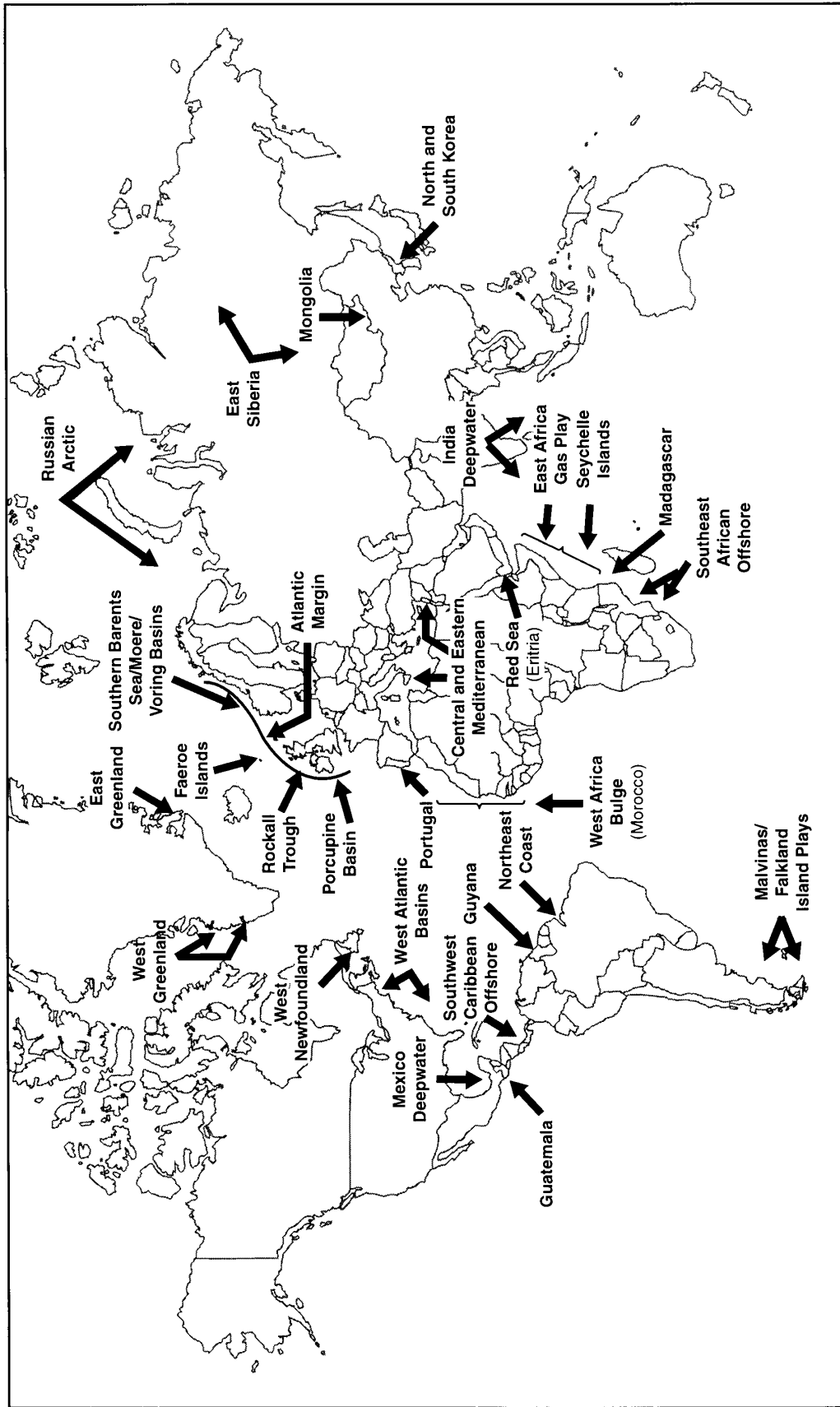
Source: Cambridge Energy Research Associates.

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**Figure 9**  
**The Current Search for Tomorrow's E&P Hotspots**



Source: Cambridge Energy Research Associates,  
 October 1999  
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