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The debate over Hubbert's Peak: a review

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ABSTRACT

The application of various quantitative techniques and assumptions by different authors to forecast the world's conventional crude oil production in the 21st Century results in highly inconsistent predictions. The forecasts attempt to pin-point the peak world oil production year (Hubbert's Peak), peak production rate, and post-peak decline rate, based on estimates of the ultimate recoverable reserves (EURR). These techniques, pioneered by M.K. Hubbert in the mid-1950s, generally consider economic factors, such as the price of oil, as irrelevant in the long run. Some authors support a *Low EURR World Scenario* (about 2.0 trillion barrels, of which half has already been produced) and forecast Hubbert's Peak in this decade. Other authors estimate the EURR at about 3.0 trillion barrels (*Median EURR World Scenario*), and this estimate is the mean EURR assessment of the United States Geological Survey and similar to assessments by several major oil and gas companies. An EURR of 3.0 trillion barrels implies Hubbert's Peak will occur in 2020, or so, at a production rate of about 90–100 million barrels/day (compared to 85 million barrels/day in late 2005). A few authors support a *High EURR World Scenario* (4.0 trillion barrels or more) with Hubbert's Peak in 2030 at a rate of 120 million barrels/day. Sensitivity analysis for Hubbert's Curve suggest that Hubbert's Peak moves by three years for every 200 billion barrels of error in the EURR.

INTRODUCTION

Fifty years ago, M.K. Hubbert (1956a, b) used a quantitative technique (Logistic Growth Curve or Hubbert's Curve) to approximately model the full cycle of production of conventional crude oil in the lower 48 states of the USA. Hubbert used his technique, together with estimates for the reserves and exploration and production history for the USA, to predict that production would peak in the late 1960s or early 1970s and subsequently decline (Heinberg, 2003; Cavallo, 2004). According to Heinberg (2003), at that time most economists, oil companies and government agencies (including the United States Geological Survey, USGS) dismissed the prediction, which later proved correct in 1970. Since then – and more recently because of record high oil prices – many authors have used Hubbert's Curve (Hubbert, 1962, 1966, 1969, 1982) and similar techniques to forecast the peak year (Hubbert's Peak) of crude oil production in different countries and the world.

For example, R. Duncan – six years ago in 2000 – drew the graph in Figure 1 to forecast Hubbert's Peak in 2006 at about 85 million barrels/day, which approximately coincides with world production in late 2005. Duncan's (2000) forecast, however, is but one of many that can be found in articles, books and websites, some of which predicted that Hubbert's Peak should have occurred in the 1990s, while others forecast it in the first half of this century (for a recent review see Heinberg, 2003; Deffeyes, 2005). These contradictory forecasts have generated a heated debate that last peaked in the mid-1990s, but then temporarily abated because of the ensuing oil-price crash of 1998.

Unfortunately, a central issue to the mid-1990s debate remains equally unresolved today; namely: *what are the estimated ultimate recoverable reserves (EURR) for the world?* The EURR of conventional crude oil consist (at any one time) of the sum of cumulative production, plus proved reserves, plus reserve growth in existing reservoirs, plus yet-to-be discovered exploration reserves (i.e undiscovered resources). For the purpose of this article, conventional crude oil does not include NGL, Canadian tar sands, oil shale, very heavy Venezuelan Orinoco oil, etc. In some reports, however, these hydrocarbons are included in the category of oil (e.g. Oil & Gas Journal, 2004; BP, 2005), thus rendering comparisons difficult.

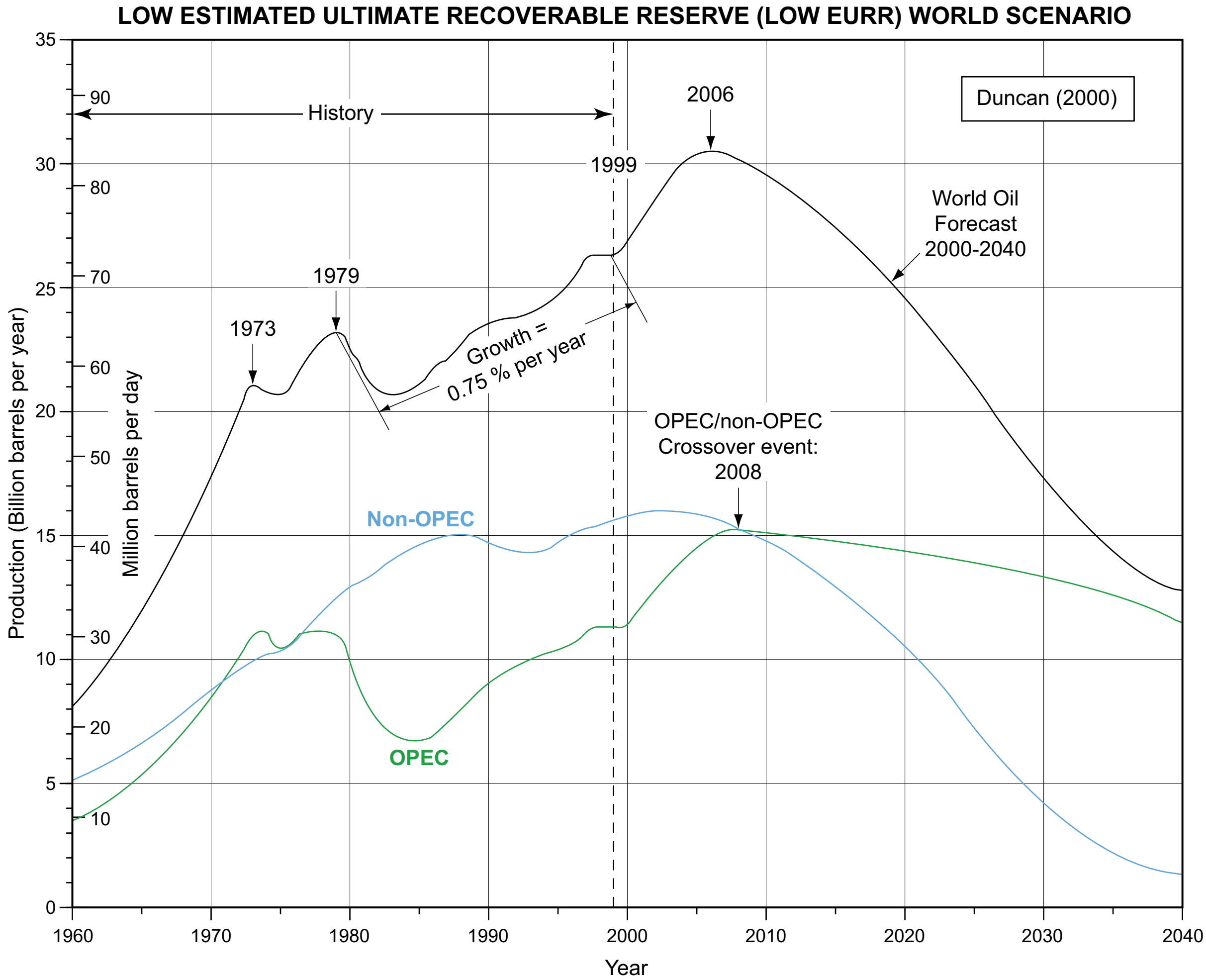

Figure 1: Duncan's (2000) model shows the historical world crude oil production data from 1960 to 1999, and his forecast for 2000 to 2040. He predicted the peak year in 2006 at the current production rate of 85 million barrels/day. He estimated that OPEC production would exceed non-OPEC production in 2008. From the forecast peak in 2006 to year 2040, Duncan predicted that world oil production will fall by about 60% at an average annual decline rate of about 2.45% during those 34 years. Similar Hubbert-style curves (and techniques) adopt a bell-shaped graph (similar to a Gaussian or Normal distribution used in statistical analysis) to approximately model the full cycle of production of a finite non-renewable resource (Hubbert, 1956a,b, 1962, 1966). The curve consists of a period of growth, peaking, and final period of decline. Current forecasts of the peak oil year range from 2006 to the second half of this century (after 2050), and depend on many factors including the estimates of the ultimate recoverable reserves (EURR = area under the curve) that range from about 1,500 to 3,900 billion barrels of oil (see Table 1). Other factors include the price of oil and alternative energy sources, supply and demand growth, etc.

Edwards (1997) summarized the mid-1990s peak-oil debate in a revealing table entitled *World Crude Oil Estimates of Ultimate Recovery and Year of Peak Production*. It shows data that is attributed to 19 authors and has been augmented here with more recent forecasts (Table 1). Table 1 shows how far apart the predictions are: EURR varies between 1,500 and nearly 3,900 billion barrels (i.e. a factor of about 250%), and the peak production year ranges by more than 60 years and falls between 1988 and after 2050. A one-page summary of the debate is available from the USGS website (see Magoon, 2000).

This article reviews some of the world crude oil production scenarios in the literature. To assist the reader in understanding the various positions of the debate it simplifies them into three scenarios: (1) *Low EURR World Scenario* (2.0 trillion barrels); (2) *Median EURR World Scenario* (3.0 trillion barrels);

Table 1
World Crude Oil Estimates of Ultimate Recoverable Reserves (Billion Barrels) and Year of Peak Production (updated from Edwards, 1997)

Year and Reference	Cumulative Production	Proven Reserves	Estimated Ultimate	Peak Year
1969: Hubbert	211	550	2,100	2000
1973: World Oil (*in* Edwards, 1997)	279	595	-	-
1976: American Petroleum Institute (*in* Edwards, 1997)	339	665	2,030	-
1978: Moody	382	-	3,200	2004
1983: Odell and Rosing	488	676	3,000	2025
1985: Energy Information Administration	527	700	-	-
1987: Energy Information Administration	568	753	-	-
1989: Bookout	610	1,000	2,000	2010
1991: Masters et al. (1990 data)	629	1,053	2,171	-
1992: Montadert and Alazard (1991 data)	654	975	2,200	-
1992: British Petroleum	676	970	-	-
1993: Townes	698	1,093	3,000	2010
1993: Masters	698	1,103	2,807	-
1994: Laherrere	720	-	1,750	2000
1995a, b: Campbell (1994 data)	720	722	1,650	1997
1996: Romm and Curtis (1994 Shell data)	720	1,111	-	2030
1997: Edwards (1994 data)	720	1,111	2,836	2020
1996: MacKenzie (1995 data)	743	1,115	2,600	2019
1996: Mabro (1995 data)	752	838	1,800	2000
References added to Table 1 of Edwards (1997)				
1994: Masters et al. (USGS)	-	-	2,300	-
1995: Ivanhoe	-	-	1,500	1988
	-	-	2,000	1996
1996: MacKenzie (not noted in Edwards' table)			1,800	2007
			2,300	2014
			2,600	2019
1997: Ivanhoe	-	-	-	2000-2010
1997: Campbell (1996 data, p. 95)	784	1,016	1,800	1998-2001
1998: International Energy Agency	-	-	-	2010-2020
1998: Campbell and Laherrere	-	-	-	2001-2010
1999: Duncan and Youngquist	-	-	-	2007
2000: Duncan	-	-	-	2006
2000: Bartlett (1995 data)	-	-	2,000	2004
	-	-	3,000	2019
	-	-	4,000	2030
2000: US Geological Survey (1995 data) *resources by 2025	710	891	3,021*	-
2001: Deffeyes	-	-	2,000	2003–2007
2001: Energy Information Administration	-	-	2,248	2021-2045
	-	-	3,003	2030-2075
	-	-	3,896	2037-2112
2004: Campbell, 2004 (2003 data)	919	931	1,850	2005
2003: Oil & Gas Journal	919	1,263	-	-
2003: World Oil (*in* Campbell, 2004)	919	1,003	-	-
2004: Oil & Gas Journal *	-	1,277	-	-
2005: BP (end-2004) *	-	1,187	-	-
2005: Deffeyes	1,006.5	1,006.5	2,013	2005
2005: Energy Information Administration (1995 data)	710	891	3,658	-
2005: ExxonMobil	1,006	-	3,200	-
2005: Zagar and Campbell (2004 data)	940	780	1,850	2010

* ***Note:*** *Quantities in Tables 1–3 generally represent conventional crude oil only; not included are condensates, gas liquids, oil shales, tar sands (Canada), very heavy oils (e.g. Venezuela), etc. Exceptions are the Oil & Gas Journal (2004) and BP (2005).*

and (3) *High EURR World Scenario* (4.0 trillion barrels). The terms low, median and high are used here without implying that any particular EURR is correct. The article, in particular, seeks to highlight the main underlying assumptions that cause such wide predictions for the peak production year. Before reviewing the world scenarios, the article will briefly show how Hubbert's Curve was applied to the USA's crude oil production, and then it will review some production trends in the Middle East and North Africa.

United States Oil Production Peaked in 1970

The peak-oil model originated in 1956 when Hubbert (1956a, b) characterized the crude oil production profile of the lower 48 states of the USA (excluding Alaska) as a bell-shaped curve (Logistic Growth Curve or Hubbert's Curve). He correctly forecast that peak production for the lower-48 states would occur in the late 1960s or early 1970s, based on estimates of the lower-48 USA's EURR of between 150 and 200 billion barrels of oil (Heinberg, 2003; Cavallo, 2004). In 1970, the actual year of peak production in the USA-48, the discovery of Prudhoe Bay field in Alaska and the construction of the Alaska pipeline resulted in a secondary USA peak crude oil production in 1985 at 8.36 million/day (Edwards, 1997).

More recently, Deffeyes (2001, 2005) reviewed the application of Hubbert's Curve to the USA (including Alaska). He used a simple technique that is equivalent to Hubbert's Curve, but which only involves fitting a straight line (Logistic Decline Plot) to the ratio of annual production to cumulative production (P/Q), versus Q. Sandrea (2005) elaborated on the analysis of Deffeyes (2005), and showed that the straight-line fit applies to both individual mature fields (after the initial production phase and when the decline rate has stabilized) and countries (where the decline rate has stabilized and the discovery of new fields is nearly complete).

$$P/Q = A - (A/EURR) \times Q$$

The constant A is the intercept of the line with the vertical axis. The fractions P/Q and A should not be confused with the Annual Decline Rate that measures the year-to-year change in production as a percentage.

For the USA (including Alaska), Deffeyes (2005, Figure 2 reproduced from his figure on p. 38) showed that the straight line fits the data adequately from 1958 onwards (compared to the actual peak in the mid-1970s) and implies A is 0.0536. Sandrea (2005) showed that the USA's P/Q decreased from about 0.045 in 1950 to less than 0.01 in 2004. The P/Q rate of 0.01 includes exploration and production in the deeper waters of the Gulf of Mexico.

The intercept of the straight line with the horizontal axis implies an EURR of about 228 billion barrels (Deffeyes, 2005). Deffeyes noted that his EURR is comparable to Hubbert's (1956) best estimate of 200 billion barrels, and Campbell's (1997) estimate of 210 billion barrels, but is about 135 billion barrels less than the USGS' (2000) estimate of 362 billion barrels. Deffeyes quoted the USA's cumulative oil production in 2004 as about 185 billion barrels, compared to an estimate of 232 billion barrels according to R. Nehring of NRG Associates (T. Ahlbrandt, 2005, written communication). The discrepancy in cumulative production (about 50 billion barrels) suggests that R. Nehring may have included other hydrocarbon liquids such as shale oil, oil sands and NGL.

Deffeyes (2005, p. 38) next converted the straight-line calibration for the entire USA into the equivalent and more familiar bell-shaped Hubbert's Curve shown in Figure 3. It shows the USA's crude oil production dipped to below 2.0 billion barrels per year in 2000. In comparison, Edwards (1997) used the EURR of 329 billion barrels to depict the curve in Figure 4. Edwards forecasted that USA production would be about 2.4 billion barrels per year in 2004, and stay above 2.0 billion barrels per year until about 2030.

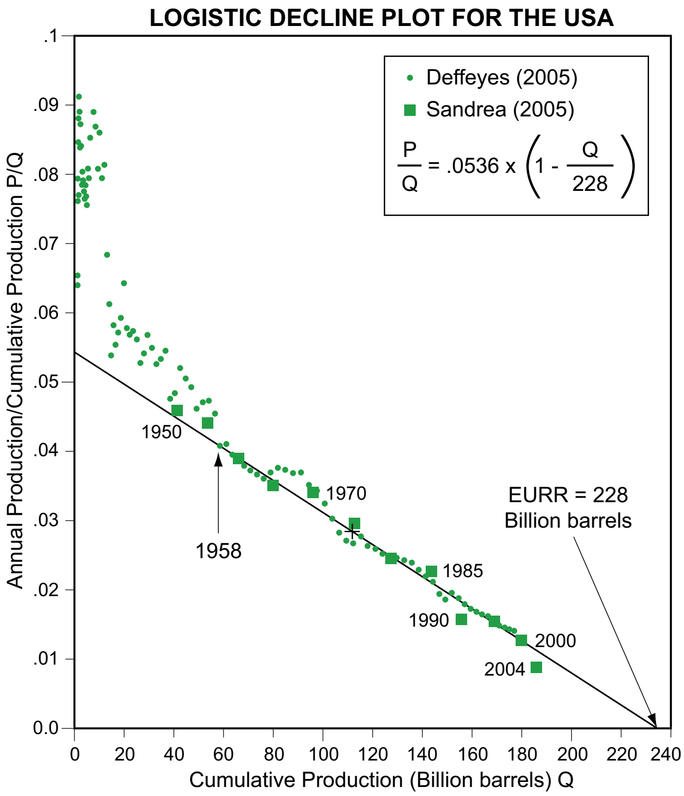

Figure 2: Hubbert's Curve (Logistic Growth Curve) can be represented by an equivalent straight line (Logistic Decline Plot), in which the ratio of annual to cumulative production (y-axis) is plotted against cumulative production (x-axis). Deffeyes (2005, his figure on page 38) used the straight line – reproduced here – to fit the USA's (including Alaska) crude oil production data from 1958 onwards. The years corresponding to decline data are from Sandrea (2005 and attributed to the Oil & Gas Journal). The analysis of Deffeyes (2005) indicates that the USA's EURR is only 228 billion barrels (where the line intercepts the x-axis) compared to 362 billion barrels as assessed by the USGS (2000). Hubbert's Curves for EURRs of 228 and 329 billion barrels are depicted in Figure 3 (Deffeyes, 2001, 2005) and Figure 4 (Edwards, 1997), respectively.

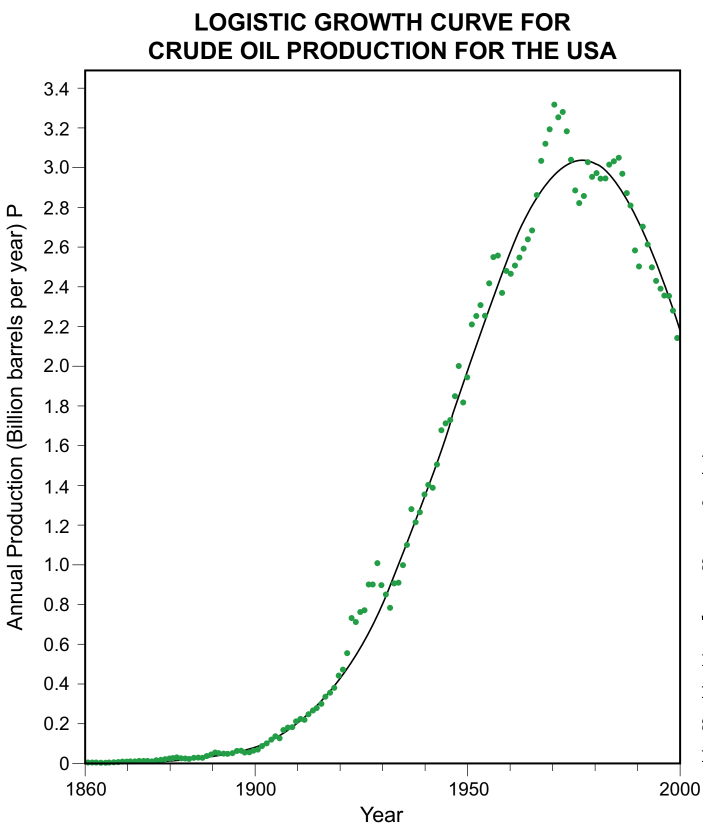

Figure 3: Crude oil production history and Hubbert's Curve for the USA (including Alaska) based on the straight-line fit shown in Figure 3 (Deffeyes, 2005, his figure on page 41). The model graph shows Hubbert's Peak in 1976, about halfway between the maximum production in 1970, and the secondary peak in 1985 due to Alaska's new production.

Cavallo (2004) provided a detailed review of Hubbert's analysis that highlighted why the USA-48 peak year prediction was correct. In his paper, Cavallo (2004) argues that there is no compelling reason for Hubbert's Curve to dictate the production outcome for other countries or the world. Specifically, he noted that Hubbert's Curve applied to the USA because of the following conditions:

- affordable prices for consumers and good profitability for producers;
- stable political and market rules;
- exponential growth in consumption;
- perception of limitless resources by producers and consumers;
- availability of imports;
- reasonable estimates for easily accessible proven, undiscovered and reserve growth for known production costs, profits, and technology development in the forecast period.

As we shall see later, the application of Hubbert's Curve to forecast the production outcome of the world is much more complicated than for the USA. This is because the world's EURR is much more uncertain and, unlike the USA, Hubbert's Peak does not appear to have yet occurred. Before turning to the world, however, we will first review some of the production trends in the Middle East and North Africa.

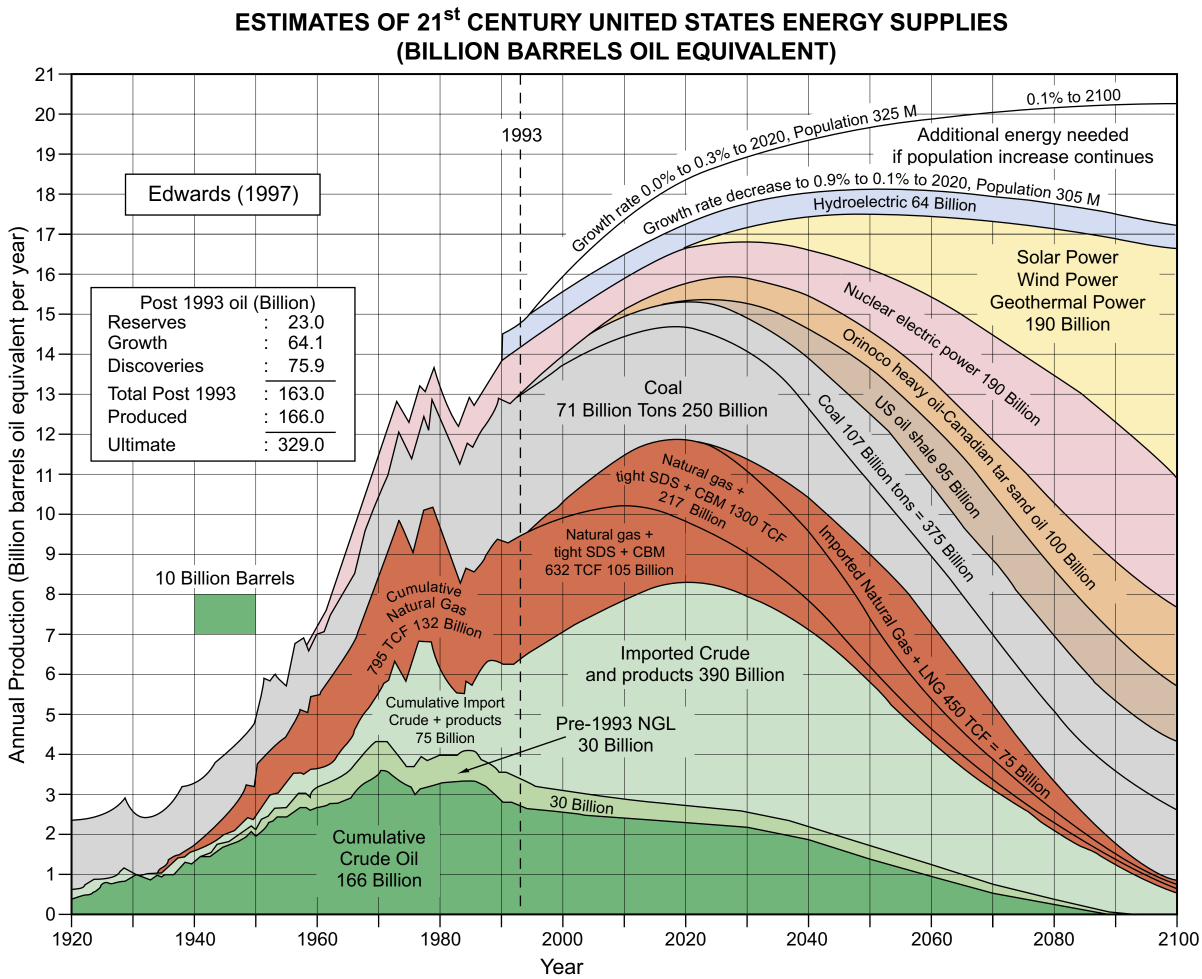

Figure 4: Estimates of 21st Century United States energy supplies by Edwards (1997) based on 1994 data and studies by Carson et al. (1993), Degolyer and MacNaughton (1994), the Energy Information Administration (1994), Masters et al. (1994), the U.S. Geological Survey (1995) and Minerals Management Service (1996). The production of crude oil in the lower 48 states of the USA peaked in 1970 as approximately predicted by Hubbert (1956a, b, 1962 and 1966). The secondary peak in 1985 was due to the discovery of Prudhoe Bay field in Alaska in 1970. Hubbert estimated the USA's EURR between 150 and 200 billion barrels, while Edwards used an estimate of 329 billion barrels. According to R. Nehring of NRG Associates, the USA has produced 232 billion barrels as of 2004 (T. Ahlbrandt, written communication, 2005). Note CBM is coal bed methane, tight SDS is tight gas sandstone.

Crude Oil Production Trends in the Middle East and North Africa

In several Middle East and North Africa countries, crude oil production has peaked and sustained decline has set in (in alphabetical order):

- Production from Bahrain's 75-year-old Awali field peaked in 1970 at 76,640 barrels/day, and declined to 37,550 barrels/day in 2003 (Arab Petroleum Research Center, APRC, 2004).

- Production in Egypt, with end-2004 proved reserves of 3.6–3.7 billion barrels (APRC, 2005; BP, 2005), peaked in 1993 at 910,000 barrels/day (APRC, 2005), and was about 582,000 barrels/day in 2005 (MEES, 2005).

- Oman's oil and condensate production reached a maximum of 961,000 barrels/day in 2000–2001 (BP, 2005). It declined to 782,000 barrel/day in 2004; however, enhanced oil recovery (EOR) techniques are expected to add 190,000 barrels/day (MEES, 2005). Oman's end-2004 proved oil and condensate reserves are estimated at 5.6 billion barrels (BP, 2005).

- Production in Syria, with proved reserves of 3.2 billion barrels, peaked in 1995 at 610,000 barrels/day (APRC, 2005), and was about 450,000 barrels/day in late 2005 (APRC, 2005; MEES, 2005).

- Production in Yemen, with proved reserves of 2.9 billion barrels (BP, 2005) or 4.0 billion barrels (APRC, 2005), peaked in 2001 at 450,000 barrels/day (APRC, 2005), and was 381,000 barrels/day in 2005 (MEES, 2005).

In other Middle East and North Africa countries, the crude oil production history consists of several peaks and valleys (i.e. described as an "undulating plateau" by T. Ahlbrandt, written communication, 2005) that are due to economic and political conditions, such as high and low demand, price variations, OPEC quotas, war, etc. Undulating plateau production is seen in the following countries (in alphabetical order):

- Algeria, with end-2004 proved reserves of 11.8 billion barrels, has since 2001 increased production from about 0.84 to 1.21 million barrels/day (APRC, 2005).

- Iran's production attained a maximum in 1974 at about 6.0 million barrels/day, and then decreased to about 3.2 million barrels/day in 1979 and finally a production valley of 1.3 million barrels/day in 1984 (due to the Iran-Iraq war) (OPEC, 1994). Since then Iran has raised its production steadily reaching 4.08 million barrels/day in 2004 (BP, 2005). Iran's end-2004 proved reserves are reported to be 132.5 billion barrels (BP, 2005). Having recently achieved a production capacity of 4.2 million barrels/day, Iran plans to add a further one million barrels/day of production capacity (MEES, 2005). This new production increment has to offset a high decline rate of about 10% (300,000–400,000 barrels/day) in developed fields (MEES, 2005).

- Iraq with end-2004 proved reserves of 115.0 billion barrels, has produced between 500,000 and 2.6 million barrels/day between 1994 and 2004 (BP, 2005). In 2004 production was 2.0 million barrels/day and plans were to increase production to 2.5 million barrels/day in the future.

- Kuwait, with end-2004 proved reserves of 99.0 billion barrels, produced about 2.1 million barrels/day between 1994 and 2003. In 2004, Kuwait raised production to 2.42 million barrels/day (BP, 2005).

- Libya, with end-2004 proved reserves of 39.1 billion barrels, produced about 1.40 million barrels/day, on average, between 1994 and 2003 (APRC, 2005). In 2004, Libya raised production to 1.61 million barrels/day (BP, 2005).

- Qatar, with end-2004 proved reserves of 15.2 billion barrels, has systematically increased production from 391,000 in 1991 to 780,000 barrels/day in 2004 (APRC, 2005).

- Saudi Arabia's proved reserves at the end of 2004 were 262.7 billion barrels, but this estimate may be dramatically increased. On 24 February 2004, at a forum held by the Center for Strategic International Studies (CSIS) in Washington DC (see GeoArabia, 2005, v. 10, no. 1, p. 152-159), Saudi Aramco Exploration Vice President M. Abdul Baqi, said that Saudi Arabia may discover another 200 billion barrels of oil-in-place as consistent with a USGS (2000) study that predicted the mean undiscovered recoverable oil resources of the Kingdom as 87 billion barrels with a probabilistic range of 29 (95%) to 161 (5%) billion barrels. At the same CSIS forum, Saudi Aramco Manager for Reservoir Managment, N. Saleri, said that the Kingdom may conservatively add another 150 billion barrels (due to both exploration and reserve growth) above the proved reserves of 262.7 billion barrels. These Saudi Aramco predictions were made as a rebuttal to reports by M. Simmons (also at the CSIS forum) that the Kingdom's reserves may be overestimated (Simmons, 2005).

  On September 27, 2005, at the World Petroleum Congress in South Africa, Saudi Arabia's Minister of Petroleum and Minerals, A. Al-Naimi, said that the Kingdom may soon add another 200 billion barrels of oil such that the proved reserves would total about 460 billion barrels. In 2005, the Kingdom embarked on a program to increase the production capacity from 10.5–11.0 to 12.5 million barrels/day by 2009 (MEES, 2005). The "swing producer" role played by the Kingdom is illustrated by the fact that Saudi Arabia had reduced its production from 9.5 million barrels/day in 1981 to 3.0 million barrels/day in 1986.

- The United Arab Emirates, with end-2004 proved reserves of about 97.8 billion barrels of crude oil, has maintained production at a steady level of about 2.5 million barrels/day between 1994 and 2004 (BP, 2005).

WORLD CRUDE OIL PRODUCTION SCENARIOS

The Low Estimated Ultimate Recoverable Reserves (Low EURR) World Scenario

Following his pioneering studies for the USA's peak oil year, Hubbert (1969) turned his attention to forecasting the world's oil production peak. He predicted the world's peak year would occur between 1990 and 2000 based on a *Low EURR World Scenario* of between 1,350 and 2,100 billion barrels. Since Hubbert's death in 1989, the Low EURR Scenario has been advocated by many authors, most notably C. Campbell, the founder for the Association for the Study of Peak Oil (ASPO). Heinberg (2003, on pages 92-102) in his book "The Party's Over" provides a summary of the views and biographies of several of these authors, including C. Campbell, K. Deffeyes, R. Duncan, I. Ivanhoe, L. Magoon, M. Simmons and W. Youngquist. Heinberg's (2003) book then continues (on pages 102-121) to present the views of critics of the Low EURR World Scenario, and to rebut them systematically.

Campbell presented his detailed analysis in his 1997 book "The Coming Oil Crisis" and an article he coauthored with J. Laherrere (1998) in Scientific American. In his book, he argued that the industry has already discovered the majority of the world's giant oil fields in the 1960s (Figure 5) and that reserve growth in existing reservoirs is relatively insignificant and overstated. In a 2004 website report, he went on to show another revealing graph to reiterate that the gap between the rate of all oil discoveries and production continues to grow (Figure 6).

Campbell (1997) assumed an EURR of only 1,800 billion barrels, of which 784 billion was accounted for as cumulative production in 1996, and another 1,016 billion, according to him, remained to be produced and discovered. In his 2004 website update (Figure 7), Campbell considered the world's EURR as only 1,850 billion barrels (Table 2), with *All Future reserves* or *Yet-to-Produce* (i.e. all categories of reserves including exploration discoveries) as 931 billion. His *All Future reserves* estimate is lower than the stated proved reserves (exclusive of reserve growth and exploration discoveries) of 1,003 billion barrels according to World Oil magazine (2003, *in* Campbell, 2004) and 1,263 billion barrels according to the Oil & Gas Journal (2003, *in* Campbell, 2004).

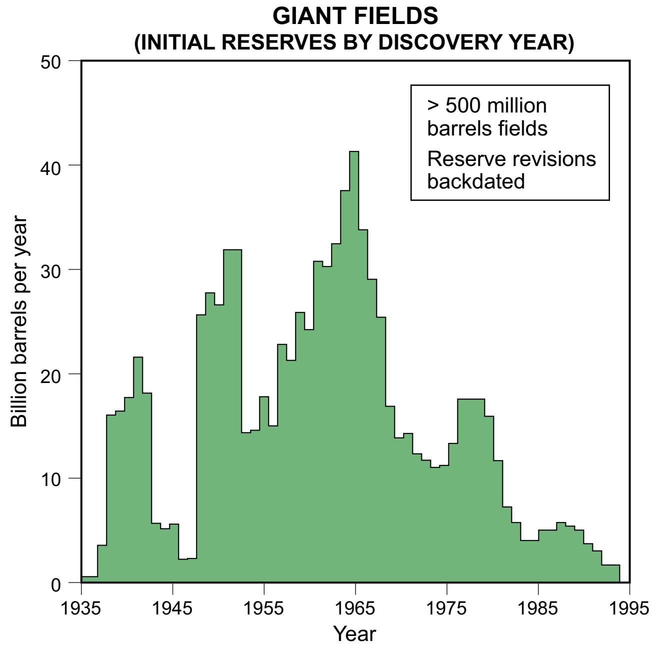

Figure 5: The reserves due to the discovery of giant fields in the world (with more than 500 million barrels of reserves as initially estimated) reached a maximum in 1965 at about 40 billion barrels/year. By the 1990s, much fewer giant fields (less than five billion barrels/year) were discovered, and they are primarily located in remote areas like the deep offshore (Campbell, 1997). Giant fields represent about 60% of the estimated ultimate recoverable reserves (EURR) in the world.

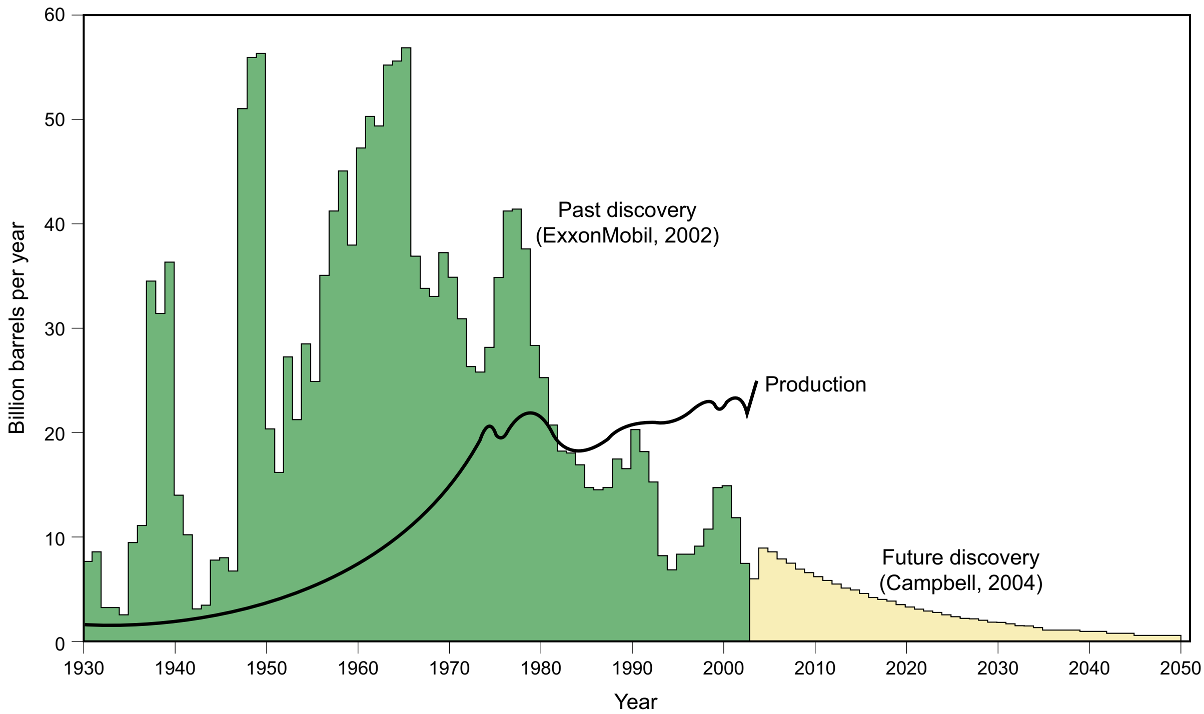

Figure 6: The addition of new world oil reserves by exploration has systematically fallen behind the level of production (Campbell, 2004). The growing gap implies that additional reserves will primarily be achieved by the application of new technology and advanced reservoir management practices (reserve growth). In particular, the largest increments will be achieved in the world's giant fields as they hold some 60% of the proved reserves (EURR).

The stated proved reserves for each country (and the world) can vary in different references, sometimes quite significantly (Tables 2, 4 and 5). For example, the reserves for China for the end of 2003 are cited as 17.1 billion in the BP Statistical Review (2005), 18.3 billion in the Oil & Gas Journal (2003) and 23.7 billion in World Oil magazine (2003). For the world at the end of 2004, the Oil & Gas Journal (2004) cited proved world reserves as 1,277.7 billion barrels which includes all of Canada's tar sands (total Canadian reserves of 178.8 billion barrels). In comparison, the BP Statistical Review (2005) cited the end-2004 proved world reserves as 1,188.6 billion barrels but only included Canada's tar sands that were under development (Canadian reserves of 16.8 billion barrels).

Table 2
Reserves, Production, All Future Reserves, Year of Midpoint Depletion for Various Countries in 2003
(in order shown in Campbell, 1997, his figure 8.1, and 2004 Revision)

Country	Proven Reserves (billion barrels)		Production thousand barrels/day 2003	Campbell (1997)		Campbell (2004)	
	WO (2003)	O&GJ (2003)		All Future Reserves	Midpoint Depletion	All Future Reserves	Midpoint Depletion
Saudi Arabia	259.3	259.4	8,430	223.0	2013	163.0	2013
F.S.U.	-	-		147.0	2000	-	-
Russia	59.7	60.0	8,216	-	-	83.0	1993
Kazakhstan	-	9.0	887	-	-	44.0	2033
Azerbaijan	-	7.0	303	-	-	15.0	2014
Turkmenistan	-	0.6	200	-	-	3.0	1991
Ukraine	-	0.4	83	-	-	1.4	1984
Uzbekistan	-	0.6	150	-	-		
Iraq	115.0	115.0	1,275	92.0	2017	82.0	2028
Iran	100.1	125.8	3,730	74.0	2007	69.0	2007
Kuwait	96.5	96.5	1,850	68.0	2013	65.0	2029
Abu Dhabi	61.9	92.2	1,850	66.0	2017	51.0	2026
Venezuela	53.1	77.8	1,713	42.0	1993	41.0	1999
USA	22.0	22.7	5,725	37.0	1973	28.0	1971
China	23.7	18.3	3,415	34.0	2001	30.0	2003
Mexico	17.2	15.7	3,365	27.0	1998	24.0	1999
Libya	30.0	36.0	1,400	25.0	2000	34.0	2011
Nigeria	32.0	25.0	2,120	22.0	1999	28.0	2002
Norway	9.0	10.5	3,035	18.0	1999	16.0	2002
UK	4.5	4.7	2,095	16.0	1997	11.0	1997
Algeria	13.0	11.3	1,050	13.0	1999	15.0	2006
Other Middle East and North Africa Countries (Aphabetical order)							
Bahrain	-	0.1	174	-	-	0.3	1977
Dubai	1.06	4.0	330	-	-	1.1	1991
Egypt	2.4	3.7	750	-	-	4.0	1995
Oman	5.7	5.5	822	-	-	7.0	2003
Neutral Zone	4.7	5.0	600	-	-	7.0	2004
Qatar	15.6	15.2	720	-	-	5.0	1998
Sharjah	-	1.5	45	-	-	0.3	1996
Sudan	0.7	0.6	200	-	-	1.7	2011
Syria	2.28	2.5	528	-	-	3.0	2000
Tunisia	0.5	0.3	66	-	-	1.0	1998
Turkey	0.3	0.3	45	-	-	0.4	1992
Yemen	2.9	4.0	350	-	-	1.80	2003
World Total							
World	1,003	1,263	83,650	1,016	2001	931	2003

Note: *Reproduced from Campbell (2004). Proved reserves for various countries for the end of 2003 are copied from Campbell (2004) and attributed by him to World Oil magazine (WO, 2003) and the Oil & Gas Journal (O&GJ, 2003). Production figures are from Oil & Gas Journal (2003). The columns All Future Reserves (crude oil in billion barrels) represent the sum of Yet-to-Produce and Yet-to-Find according to Campbell (1997) in his 1997 book and his 2004 website report, and his forecasts for the midpoint depletion (approximately the peak year when Hubbert's Curve fits the data).*

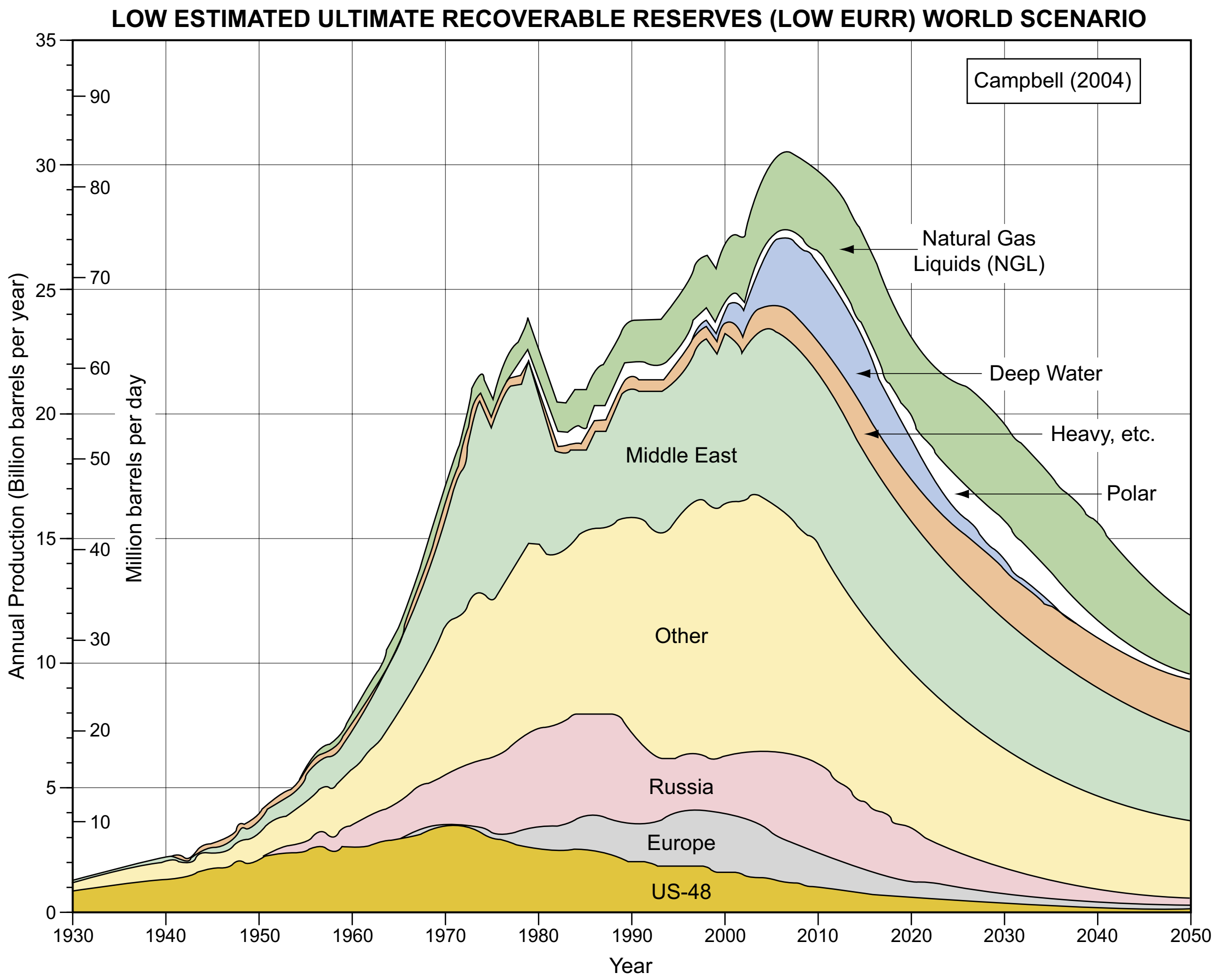

Figure 7: Estimates for the first half of the 21st Century world petroleum energy supplies by Campbell (2004), based on his 2003 data. Campbell, earlier in 1997 (based on 1996 data), predicted the peak of crude oil production would occur in 1998–2001 at a daily rate of about 66 million barrels/day. In this 2004 revision he predicted Hubbert's Peak occurred in 2003 at a rate of 74 million barrels/year.

Campbell, in 1997, forecasted that the world's crude oil production would peak in 1998–2001 at about 67 million barrels of oil per day (his appendix II, p. 195, and appendix IV, p. 201). In his 2004 revision, he predicted the peak year would move to 2003 at 74 million barrels/day (27 billion barrels/year, Figure 7). Campbell's (2004) forecast is similar to the one by Duncan (2000, Figure 1) and other authors who advocate the Low EURR World Scenario (Table 1).

For the world, Deffeyes (2005) calibrated Hubbert's Curve with a straight-line fit between 1983 and 2003. He found A = 0.05 and the EURR = 2,013 billion barrels (Figure 8), and forecasted Hubbert's Peak on November 9, 2005, so as to symbolically coincide with the USA's Thanksgiving Day. Using his formula, the peak production level can be calculated as 0.25 x A x EURR = 25 billion barrels/year or 68.5 million barrels/day.

The Median Estimated Ultimate Recoverable Reserves (Median EURR) World Scenario

In contrast to Campbell (1997), other participants in the mid-1990s debate (Table 1) assumed that much greater quantities of conventional crude oil remained to be discovered, and that the ultimate recoverable reserves from known fields (reserve growth) would eventually be much greater than

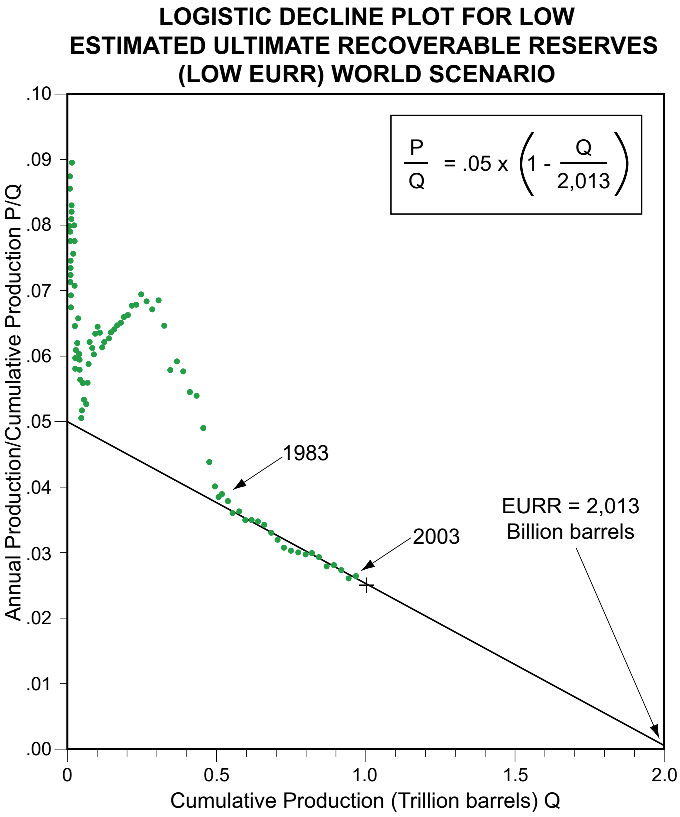

Figure 8: Logistic Decline Plot shows the world's ratio of annual to cumulative crude oil production versus cumulative production. Deffeyes (2005, his figure on page 43) used a straight line to fit the period 1983–2003 crude oil production data. The analysis of Deffeyes (2001, 2005) indicates that the world's EURR is only about 2.0 trillion barrels (where the line intercepts the x-axis). Deffeyes (2005) forecasted Hubbert's Peak to have occurred in late 2005, and symbolically timed it to coincide with the USA's Thanksgiving day on November 24.

previously estimated. These authors argue that new technology and higher oil prices will continue to drive the upstream industry to book greater quantities of conventional oil as proved reserves.

From Table 1, it appears that many authors adopted an EURR of about 3.0 trillion barrels of crude oil, here named the *Median EURR World Scenario*. This estimate is about 1.0 trillion barrels greater than the one used by Campbell (1,800 in 1997 and 1,850 billion barrels in 2004) and other proponents of the Low EURR World Scenario. Edwards (1997), for example, adopted an EURR of 2,836 billion barrels (based on studies by DeGolyer and MacNaughton, 1994; Energy Information Administration, 1994; and Masters et al., 1994) that was partitioned (in 1994) into 720 billion for cumulative production, 1,111 billion for proved reserves, and 1,005 billion for future discoveries and reserve growth in existing fields.

More recently at a National Academy of Science meeting held in Washington D.C. (October 20–21, 2005), ExxonMobil's Manager of Economics & Energy S. Nauman indicated that the world's crude oil EURR is about 3,200 billion barrels and that output will continue to grow to well over 100 million barrels/day at least through 2030. At the same meeting Chevron's Chief Technology Officer, D. Paul also adopted the Median EURR World Scenario and approximately divided it into three equal parts: 1,000 billion consumed, 1,000 billion proven, and 1,000 billion to be found through new field discoveries and reserve growth.

Assuming an EURR of 2,836 billion barrels, Edwards (1997) predicted that world production would peak at about 90 million barrels/day in 2020 (32.85 billion barrels/year, Figure 9). In late 2005, world production was about 85 million/day (31 billion barrels/year), which is nearly 20 million barrels/day above Campbell's peak forecast for 1998–2001 (made in 1997), and 10 million barrels/day above his peak forecast for 2003 (made in 2004). At an annual rate of growth of about 2%, production rates of 90 and 100 million barrels/day may be achieved in 2008 and 2013, respectively. Indeed, according to D. Yergin (August 2005, Los Angeles Times-Washington Post News Service), the world's supply could reach 100 million barrels/day by 2010. The 90 million barrels/day rate corresponds to the

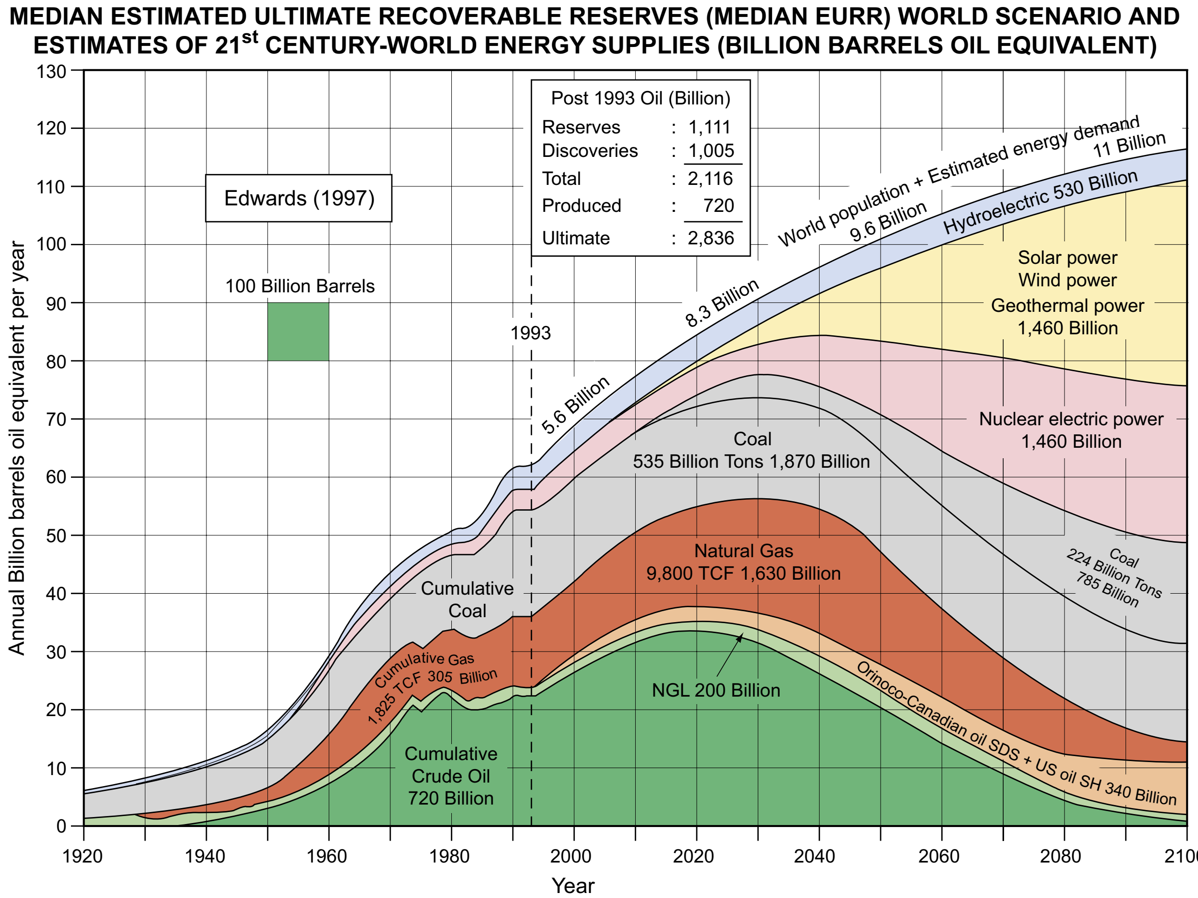

Figure 9: Estimates of 21st Century world energy supplies by Edwards (1997) based on 1994 data and studies by Degolyer and MacNaughton (1994), the Energy Information Administration (1994) and Masters et al. (1994). Note the present production of nearly 85 million barrels of conventional crude oil per day corresponds to 30.7 billion barrels/year and closely matches the prediction by Edwards (1997). The peak production of 90 million/day (32.9 billion/year) was forecast to occur in 2020 but may be achieved before 2010 if supply continues to increase by about 2.0% in the next few years.

forecast by Edwards (1997) for the peak production level in 2020, not 2008 (Figure 6). So, does this mean that a production rate of about 90–100 million barrels/day represents a "production red flag" and the world's production plateau? Not necessarily.

Sensitivity Analysis: EURR, Peak Year and Peak Rate

As we shall see, the relationship between the EURR, peak year, and peak production rate are interrelated in Hubbert's Curve and similar quantitative techniques (Bartlett, 2000; Cavallo, 2002, 2004; Charpentier, 2005). For the world, none of these quantities are sufficiently well known to allow accurate predictions. Estimates of reserves generally increase with time and depend on economic, technological and other factors (Adelman and Lynch, 1997; Ahlbrandt et al., 2005; Charpentier, 2005). So it would seem that until Hubbert's Peak is reached and the ensuing decline is unambiguous – as perhaps flagged by sustained high prices, unmet demand and flat supplies for a decade or more – the Hubbert Curve is essentially unconstrained.

To examine some of these issues, Bartlett (2000) developed an analytical method which does not consider the consequences of the price of oil, nor the law of supply and demand. He explained that economic factors are of significance but only as short-term determinants of the course of oil production in the future. His model, however, allowed him to determine the values of the three parameters that characterize the Hubbert-like graph (Gaussian distribution) that best fits the conventional oil production data, both for the USA and the world. The three parameters are: (1) the estimated ultimate oil recoverable reserves (EURR) as represented by the total area under the Gaussian curve; (2) peak year; and (3) half-width of the Gaussian curve.

To illustrate the importance of accurately determining the three parameters, Bartlett (2000) highlighted that the value of the EURR that best fits the world's oil production curve (as measured by the root mean square deviation) is only 1,128 billion barrels, which he admits is much smaller than the established minimum EURR (cumulative production plus proved reserves) of about 2,000 billion. "This discrepancy", Bartlett emphasized, "points out a limitation of the analysis. In contrast to the case of the USA, the world data do not yet show a long and persistent downturn in production. As a consequence, a wider range of values of the EURR can give plausible fits to the data". For EURRs of 2,000 (Low), 3,000 (Median) and 4,000 (High) billion barrels, his forecasts are summarized in Tables 1 and 3.

Table 3
Sensitivity Analysis (Bartlett, 2000)

World Scenario	EURR (billion barrels)	Peak Year	Peak production (billion barrel/year)	Peak production (million barrel/day)
Low	2,000	2004	29	80
Median	3,000	2019	36	99
High	4,000	2030	43	117

Bartlett (2000) also clarified an important relationship between EURR and peak year in his sensitivity analysis; namely for every new billion barrels of oil added to the world's EURR, the date of the peak is delayed by only 5.5 days! This means that adding 200 billion barrels to the world's EURR only moves the peak by about three years.

In contrast to Bartlett's analysis, Deffeyes (2001, 2005) showed that EURR, peak year and peak production rate can be predicted well before Hubbert's Peak occurs. As we saw earlier this simply involves fitting a straight line (Logistic Decline Plot) to the ratio of annual to cumulative production (P/Q) versus Q after the decline rate has stabilized (Figure 2 for the USA, and Figure 8 for the world). This is an important conclusion because the decline rate stabilizes some 10–15 years before Hubbert's Peak occurs.

World Reserve-to-Production Ratio and EURR

The widely quoted *reserves-to-production ratio* (R/P) is the number of years the current reserves would last if the current annual production continued unchanged. Bartlett (2000) cautioned that the R/P ratio incorrectly suggests to some that the world production might remain constant for a fixed period of years and then abruptly drop to zero. He tentatively presented a more meaningful interpretation for the R/P ratio by calculating it for world oil production scenarios that correspond to three EURRs (2,000, 3,000 and 4,000 billion barrels).

For an EURR of 3,000 billion (Median EURR World Scenario), Bartlett (2000) estimated that the world R/P ratio in the year 2000 should be about 74 years. For an EURR of 2,000 billion barrels, the R/P ratio is about 42 years. At the end of 2004 the world's R/P ratio was 40.5 years (BP, 2005). So does this mean that the world's EURR is about 2,000 billion barrels (Low EURR World Scenario)? Not according to the USGS (2000) and US Energy Information Administration (2005) who believe that the EURR may be as great as 4.0 trillion barrels, the *High EURR World Scenario*.

The US Geological Survey (USGS) High EURR Assessment and the US Energy Information Administration (EIA) Scenarios

In June 2000, the USGS released a report on the assessment of the world's crude oil, natural gas and natural gas liquids (NGL) resources based on a 5-year study by 40 geoscientists. The report was summarized by Ahlbrandt (2002) and in AAPG Memoir 86 (Ahlbrandt et al., 2005). The USGS' mean estimate for the world's recoverable oil reserves (resources) for the period 1996-2025 is 3,021 billion barrels (Table 4) with a highside potential (5% probablity) of 3,896 billion barrels (Ahlbrandt et al., 2005). Since the release of the USGS report in 2000, several papers by USGS authors have provided detailed comparisons of the techniques used in the USGS (2000) assessment and alternative statistical and deterministic approaches (Ahlbrandt and Klett, 2005; Charpentier, 2005).

Table 4
Mean Estimates of Conventional Oil Resources in 1996-2025
(USGS, 2000 and EIA, 2005) (Billion barrels)

Category	USGS (2000) billion barrels		EIA (2005) billion barrels	
Undiscovered resources	732.0	24.2%	938.9	25.7%
Reserve growth	688.0	22.8%	730.2	20.0%
Remaining reserves	891.0	29.5%	1,277.7	34.9%
Cumulative production	710.0	23.5%	710.0	19.4%
Total	3,021.0	100.0%	3,656.8	100.0%

Table 5
Estimated World Oil Proved Reserves; Reserve Growth and Undiscovered Resources (1996-2025)
(Billion barrels) (EIA, 2005, their table 4, p. 30)

Region	Proved Reserves at end-2004 (BP, 2005)	Proved Reserves at end-2004 (O&GJ, 2004)	Reserve Growth (EIA)	Undiscovered Reserves (EIA)
Africa	112.2	100.8	73.5	124.7
Australia	4.0	1.5	2.7	5.9
Canada	16.8	178.8	12.5	32.6
China	17.1	18.3	19.6	14.6
East Europe	-	1.5	1.5	1.4
F.S.U.	120.8	77.8	137.7	170.8
India	5.6	5.4	3.8	6.8
Japan	-	0.1	0.1	0.3
Latin America	101.2	100.6	90.8	125.3
Mexico	14.8	14.6	25.6	45.8
Middle East	733.9	729.6	252.5	269.2
United States	29.4	21.9	76.0	83.0
West Europe	18.7	15.8	19.3	34.6
Other Asia	-	11.0	14.6	23.9
World Total	**1,188.6**	**1,277.7**	**730.2**	**938.9**
OPEC	890.3	885.2	395.6	400.5
Non-OPEC	177.4	392.5	334.6	538.4

Note: *Canadian reserves include all tar sands in Oil & Gas Journal (O&GJ, 2004), but only those "under active development"in the BP Statistical Review (2005).*

In 2001, based on the assessment of the USGS (2000), the US Energy Information Administration (EIA, 2001) modeled long-term world oil supply (Figure 10 and Table 6, see also Williams, 2003; Wood et al., 2004) for four scenarios for the world's annual demand growth (0%, 1%, 2% and 3%). They adopted the three fractal EURRs of the USGS (2000):

- a low EURR of 2,248 billion barrels corresponding to 95% probability (about 250 billion barrels greater than the Low EURR World Scenario of this article);

Table 6
USGS (2000) Estimates of Ultimate Recoverable Resources and EIA (2001) World Scenarios

Estimated EURR (Probability)	EURR billion barrel	Annual Demand Growth	Peak Year	Peak Rate billion barrel per year	Peak rate million barrels per day
Low Scenario (95%)	2,248	0.0%	2045	24.55	67
		1.0%	2033	34.82	95
		2.0%	2026	42.79	117
		3.0%	2021	48.51	133
Mean (expected value)	3,003	0.0%	2075	24.58	67
		1.0%	2050	41.24	113
		2.0%	2037	53.21	146
		3.0%	2030	63.3	173
High Scenario (5%)	3,896	0.0%	2112	24.58	67
		1.0%	2067	48.84	134
		2.0%	2047	64.86	178
		3.0%	2037	77.95	213

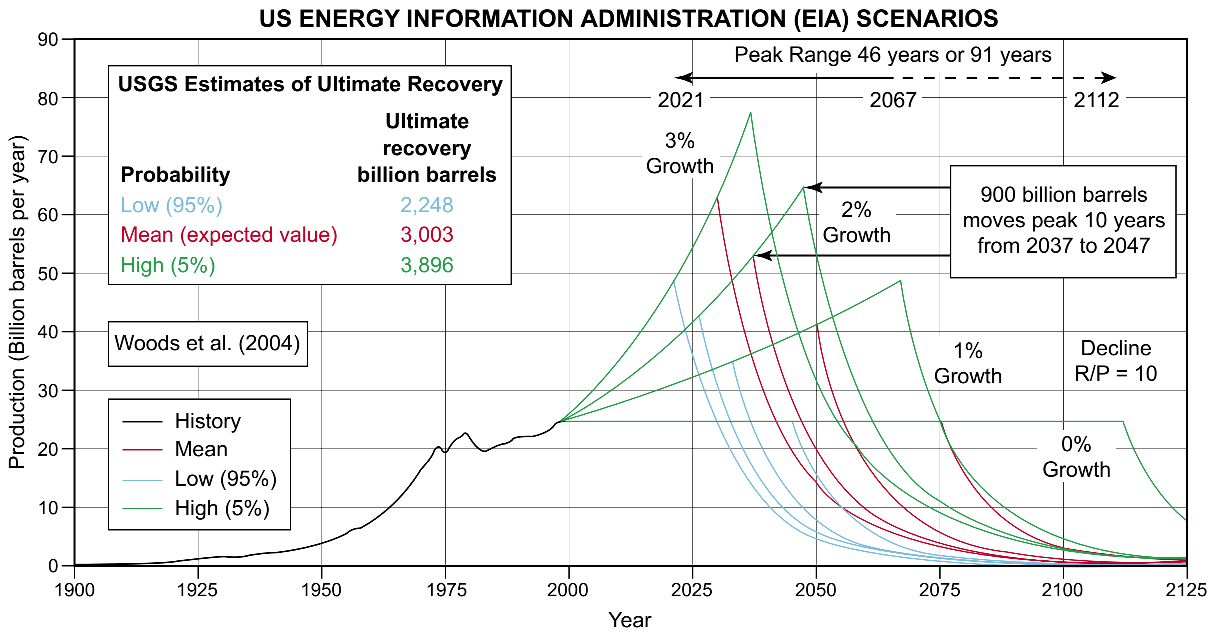

Figure 10: The 12 EIA Scenarios (EIA, 2001; Wood et al., 2004) are based on three USGS (2000, Ahlbrandt et al., 2005) fractile estimates of the EURR: 2,248 (95% certainty), 3,027 (mean or most likely) and 3,896 (5% certainty) billion barrels. The production curve 1900–2000 is historical; in 2004 world production crossed the 30 billion barrels/year (82 million barrels/day) and was tracking the annual demand growth curve of about 2.0%. The post-peak decline is fixed at a reserves-to-production ratio R/P=10 years as in the USA today, compared to about 40 years for the world. Assuming the mean EURR (red curves) and a demand growth of 2.0%, implies the peak production year in 2037 at a rate of 53 billion barrels/year (146 million barrels/day). In this scenario, the production level would drop to 55 million barrels/day (20 billion barrels/year), or 40% of peak production by 2050, just 13 years later. A demand growth of 1.0% would defer the peak year to 2050 when production would reach 113 million barrels/day (41 billion barrels/year); this scenario predicts a drop to 55 million barrels/day (20 billion barrels/year), or 50% by about 2060, just a decade later. A zero-growth in annual demand could produce a production plateau that could last until after 2100. If this had started in 2000 then the production level would be 67 million barrels/day (25 billion barrels/year). By adding 900 billion barrels to the mean USGS (2000) resource estimate in the 2% growth case, delays the estimated production peak by 10 years from 2037 to 2047. Similarly, subtraction of 850 billion barrels in the same scenario accelerates the estimated production peak by 11 years (2037 to 2026). A 1.0% decrease in the pre-peak growth rate has roughly the same effect that adding 900 billion barrels to the estimated resource base does.

- mean EURR of 3,021 billion corresponding to a 50% probability of being correct (nearly identical to the Median EURR World Scenario of this article);
- high EURR of 3,896 billion corresponding to a 5% probability (about 100 billion barrels less than the High EURR World Scenario of this article).

EIA authors Wood et al. (2004) emphasized that the EIA (2001) Scenarios quantitatively deal with both demand and supply, whereas others' scenarios incorporate demand only implicitly. They also indicated that the EIA Scenarios do not assume that the declining production trend after the peak will be a mirror image of the incline prior to the peak. They argued that there is no physical or economic rationale that supports a symmetrical world production outcome. Instead, the EIA Scenarios combine two functional forms (Figure 7): (1) the first extends production from the past along a constant percentage growth path until the production peak is reached; and (2) the second reduces post-peak production at a constant reserves to production (R/P) ratio (not to be mistaken for a constant decline rate). The EIA selected an R/P ratio of 10 years as being representative based on the USA's post-peak production experience.

The EIA's (2001) mean EURR scenario (about 3,000 billion barrels) for all four demand growth rates forecasts the peak crude oil production year after 2030 (Table 6). At a 2.0% growth in supply and demand, the mean EURR scenario predicts that production will rise by 70% from today's 85 million barrels/day to a spike at 146 million barrels/day in 2037, and then drop by 64% to 55 million barrels/day by 2050 (Figure 7).

In 2005, the EIA (in their table 4, p. 30) revised the USGS (2000; Ahlbrandt et al., 2005) mean EURR upwards from 3,021 to 3,656.8 billion barrels (Tables 4 and 5). Wood et al. (2004) wrote that the USGS' (2000) estimates for EURR are "conservative for a variety of reasons, chief among which are that the USGS' assessment did not encompass all geologically conceivable small sources of conventionally reservoired crude oil, and was limited to the assessment of reserves that would be added within a 30 year time frame" (1996-2025).

Forecasts Based on the Price of a Barrel of Oil

In the EIA's 2005 report, the role of the price of oil is considered for three price scenarios (in 2003 dollars). The report considers a reference production scenario of 119 million barrels/day in 2020 assuming a price of $35/barrel. The high-side production level of 127.6 million barrels/day in 2020 corresponds to a price of $20/barrel, and the low-side in 2020 to 113 million barrels/day at $50/barrel.

In the models that are reviewed here, upstream supply is forecast without taking into consideration storage, transportation and downstream capacities; these midstream and downstream components impose their own constraints to the total flow of the world's supply. Moreover, the various forecasts do not account for the long time lags of typically 5–10 years or more, that occur between growth in demand and the industry's response with new supplies. For example, the world in 2005 appeared to be tracking an annual demand growth curve that is nearly 2.0% but with prices that are 2–3 times higher than predicted for 2020 by the EIA ($60–70 in 2005 versus $20-35 in 2020). Such a high price could dampen or even reverse demand growth before new supplies are available. These types of price-related production valleys occurred shortly after 1973 and 1979, and are unrelated to Hubbert's Peak (Figure 1).

DISCUSSION

Economic factors aside, Hubbert's Curve and similar techniques do provide useful insights and ranges of possible world crude oil production outcomes that clarify some aspects of the peak oil debate. Firstly, these quantitative models require the geoscientists, engineers and economists to provide estimates for the ultimate recoverable reserves (EURR). For example, using the compilation of Edwards (1997, Table 1), Bartlett (2000) calculated the average EURR and peak year from 19 pre-1995 forecasts (Table 1) to be 2,400 ± 400 billion barrels and 2010 ± 11 years. This EURR range falls between the Low and Median EURR World Scenarios (2.0–3.0 trillion barrels) of this article. The USGS (2000) assessment (Ahlbrandt, 2002; Ahlbrandt et al., 2005), using geological and statistical analysis, calculated the mean EURR as 3,021 billion barrels by 2025, of which 1,420 billion barrels would be added between 1996-2025. The Median EURR of about 3.0 trillion barrels is identical to the estimate by Chevron and close to that of ExxonMobil (3,200 billion barrel). So is 3.0 trillion barrels the most likely estimate of the EURR? To answer this question, consider the world's progress in adding reserves since 1996, the starting year for the USGS (2000) assessment.

From an exploration side, the USGS (2000) undiscovered conventional world oil reserves (resources) for the period 1996–2025 (Table 4) are estimated as 732 billion barrels. These predicted exploration reserves represent about 25% of their EURR by 2025, and if correctly assessed then they would need to be discovered (since end-1995) at a rate of about 25 billion barrels/year. Since the 1960s, however, the world's rate of exploration reserves has been systematically declining; it appears to have averaged about 10 billion barrels/year in the 1990s (Figure 4). According to Heinberg (2003), new reserves in the 1990s decade have averaged 9 billion barrels per year, but for *both* exploration and reserve growth. The lowest estimate for exploration reserves was given by Zagar and Campbell (2005) who attribute only about 6 billion barrels/year in new-field discoveries in recent years.

In support of the USGS assessment (2000, Ahlbrandt et al., 2005), Klett et al. (2005) provided a quantitative evaluation by reviewing the exploration data for the 8-year period 1996–2003 (i.e 27% of the study period 1996-2025). Their evaluation excluded the USA (with 83 billion barrels attributed to undiscovered resources), and is valid for only 128 provinces of the 309 world provinces where oil exists. Klett et al. (2005) reported, based on proprietary IHS data bases, that between 1996 and 2003, 2,142 new oil and gas fields were discovered containing recoverable crude oil reserves of 69 billion barrels. This amounts to 11% of the assessed 649 billion barrels and averages about 8.6 billion barrels/year. The greatest contribution to field discoveries occurred in sub-Saharan Africa. Klett et al. (2005) note that one reason for this shortfall is that important prospective areas in the Middle East, North Africa and the former Soviet Union were not sufficiently explored during the 1996–2003 period due to economic and political factors.

According to T. Ahlbrandt (written communication, 2005), another reason for the shortfall is that most companies have apparently chosen to add reserves by developing discovered fields (i.e. reserve growth) or acquiring other companies, rather than through exploration activities. He noted that exploration wildcats have declined by nearly an order of magnitude in the last decade from over 12,000 wells/year to less than 2,000 wells/year; in 2004 alone, exploration drilling worldwide decreased by 7%.

A third reason for the exploration shortfall is that some remote areas were not explored in the 1996-2003 period. For example, T. Ahlbrandt (2005, written communication) pointed out that the northeast coast of Greenland has four giant oil fields that have been exhumed, and it forms part of the largest oil and gas province in the world (includes the North Sea and West Siberia). He added that the available seismic and geochemical data indicate that this area may be highly prospective, but the technological risks are great. This is because pipelines cannot be buried deep enough below the shifting massive icebergs and sea ice. Accordingly, for northeast Greenland, the USGS attributed a 95% chance that no resources would be added by 2025, and a 50% chance that 47 billion barrels would be discovered by 2025.

From the production side, reserve growth of crude oil in developed fields (outside the USA) was estimated at about 612 billion barrels (USGS, 2000; Ahlbrandt et al., 2005), and it accounts for nearly 20% of their EURR for 1996–2025. Klett et al. (2005) reported that between 1996 and 2003, reserve growth (for fields that could be traced in the proprietary IHS data bases from 1996 to 2003) amounted to 171 billion barrels, or about 28% of the assessed 612 billion barrels. Most of the reserve growth was booked in the Middle East and North Africa where reserves data are not generally reported in a consistent and detailed manner.

Aside from uncertainty in the world's EURR, another important aspect of the peak oil debate is forecasting Hubbert's Peak year and the accompanying peak production rate. To illustrate this aspect, let's assume that the world's EURR is 3.0 trillion barrels and that Hubbert's Curve (and similarly shaped graphs) can be used to forecast the world's production. For this EURR, a peak production level of between 90 and 100 million barrels/day would occur in 2020 or so (e.g. Figure 6, Edwards, 1997; Table 3, Bartlett, 2000). In contrast to Hubbert's Curve, the EIA's production graphs are not bell-shaped; instead they are characterized by a production spike (Figure 7). For an EURR of 3.0 trillion barrels and an annual growth in demand (and supply) of 2.0%, the EIA forecasts the peak year in 2037 at a production rate of 146 million barrels/day. Relative to Hubbert's Curve, this EIA forecast achieves a production rate that is 50% greater and defers it by 17 years by 'borrowing' reserves from after 2037.

CONCLUSIONS

The reliability of the long-term forecast of the world's crude oil production depends on an accurate estimate of the world's ultimate recoverable reserves (EURR). Estimates by various authors (Table 1) suggest a three-sided debate with positions falling into either a Low (2.0 trillion barrels), Median (3.0 trillion barrels) or High EURR (4.0 trillion barrels) World Scenario. The three scenarios approximately correspond to the geological-statistical assessment of the US Geological Survey (2000): at 95% confidence the low EURR is 2,250 billion barrels, the mean EURR is 3,021 billion barrels, and at 5% confidence the high EURR is 3,900 billion barrels. The Median EURR World Scenario (3.0 trillion barrels) is similar to the recent estimate of Chevron, and 200 billion less than the one by ExxonMobil.

As of late 2005, the world has consumed about one trillion barrels, and proved reserves are reported to be about 1.2 trillion barrels. The Median EURR World Scenario implies that approximately another 800 billion barrels remain to be discovered in new fields and added as reserve growth in existing fields. If the Median EURR World Scenario (3.0 trillion barrels) is assumed to be approximately correct and if Hubbert's Curve (and similar techniques) is adopted, then the peak year would occur in 2020, or so, at a production level of between 90–100 million barrels/day (versus 85 million barrels/day in late 2005). Sensitivity analysis suggest that the peak year will move by three years for an error of 200 billion barrels in the EURR. For EURRs of 2.0 and 4.0 trillion barrels, Hubbert's Peak would fall in 2004 and 2030 at production levels of about 80 and 120 million barrels/day, respectively.

Hubbert's Curve (and similar techniques) does not explicitly consider the price of oil and the law of supply and demand in forecasting the outcome of world crude oil production. In the past (e.g. 1973 and 1979), imbalances between supply and demand caused variations in the price of oil and temporary short-lived peaks that were not related to Hubbert's Peak. So does the recent high price of oil represent a temporary supply-demand imbalance that will pass if and when supply rises to 90-100 million barrels/day? Or is the record price a signpost for the world's Hubbert's Peak? In the absence of an accurate EURR it would seem that only time can provide the answer.

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