An Armchair Audit of World Oil Reserves

It is well known that the lack of international standards on reserves estimation methodologies has led to disparities in the oil reserves reported by the more than 90 oil producing countries. For instance, most of the countries with large oil reserves, notably, Iran, Iraq, Kuwait, Saudi Arabia and Venezuela are known to report up to five times more reserves[1] to sustain a similar level of production capacity when compared with other major oil producing countries such as Mexico, Norway, Russia, UK and the USA. In the case of the North Sea, Norway reports twice as many proven reserves as the UK although the petroleum geology of the basins is common in size, and the number of fields to both countries. Additionally, because of the importance of oil in their balance of payments and in the economy, many oil-producing developing countries outside OPEC have developed a policy of withholding technical information on reserves and production[2]. Although production statistics are temporarily held confidential by some countries, it is generally felt that because oil is such an important commodity in world trade, surveyed production data by reputable international firms is fairly reliable. Usually when the production data is released it compares satisfactorily with the surveyed data. In the case of reserves, however, there is no source for comparison.

The objective of this study is to use decline curve analysis of production data to independently corroborate the crude oil reserves of ten important oil producing countries over a period of twenty years, from 1980 to 2000. Five are members of OPEC - Saudi Arabia, Kuwait, Iran, Venezuela and Nigeria; the others are the USA, Russia, Mexico, Norway and the UK. Together these ten countries account for almost two-thirds of the reported world's crude oil reserves and all are net exporters of oil with the exception of the USA.

The Reserves Estimation Issue

The determination of proven, probable, and possible reserves in an oilfield is a difficult task primarily because reserves cannot be measured directly. Oil reservoirs may be buried several miles below the surface or located underneath tough environments such as deep water. Additionally the oilfield may consist of a few massive (thousands of feet in thickness) reservoir sands, typical of the geology in the Persian Gulf, or multiple stacked thin sands (~25 feet or more) as in Venezuela. In any case, the only source of direct measurements of rock and fluid properties are the wells drilled, but these can be sparsely located - as few as one for every 25 square miles - in an oilfield which can be as extensive as 2,800 square miles (178 mi. x 16 mi.) like the famous super giant Ghawar field in Saudi Arabia.

[1] OPEC's Challenge: Rethinking its Quota System, Sandrea, R., O&GJ, July 28, 2003
[2] The Association for the Study of Peak Oil and Gas (ASPO), Newsletter No. 46, Oct. 2004

The combination of sparce areal coverage and the thickness distribution of the oil column, among others, limits the number of samples of reservoir data that can be economically retrieved from an oilfield. The bottom line is that reservoir data is often insufficient and therefore the determination of reserves is subject to judgmental factors. To stay within a 5 percent range of error which is reasonable, the key is consistency in the reserves estimates using different tools over the life of the field.

Prior to start-up of production, volumetric estimates of reserves, either deterministic or stochastic methods, are the only option. As production data become available several methods based on reservoir performance, such as production decline analysis and reservoir simulation, provide more accuracy in the reserves estimates. The decline curve[3] [4] approach is generally regarded as one of the primary tools for reserves calculations, both for its simplicity and minimizing of arbitrary assumptions on geologic and raw engineering data that go into the volumetric formula. Decline analysis is based entirely on measured production data and the logistic equation (Appendix) has proven[5] [6] to be a powerful and versatile decline tool. It is applicable not only to individual oilfields but also to conglomerates of oilfields, typical of oil producing countries.

Methodology

The logistic decline method was applied to the production data of the ten sample countries mentioned previously. Three periods were chosen to evaluate the reserves: 1980, 1990 and 2000. These years represent milestones in recent world oil production history which must be factored into the decline analysis.

The OPEC countries experienced a robust production growth through 1980. Thereafter, production rates were severely curtailed, picking up again at the end of the decade and continuing through 2000. Saudi Arabia's production history is a typical example. Its production grew continuously from 1.3 million barrels per day (b/d) at the start of the 1960s to an all time high of 10 million b/d in 1980. Production subsequently dropped to a low of 3.2 million b/d in 1985, rebounding to 8 million b/d in 1991 and essentially staying around this level through 2003. In contrast, none of the five non-OPEC countries in this study has experienced any major oil production fluctuations over the same time period.

Straight line portions of the decline plot were constructed using as the end point the cumulative production data through each of the three years, 1980, 1990 and 2000. This theoretically could generate three different best fitting straight lines, each with a

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[3] Arps, J.J., AIME Trans., 160 (1945), p. 228

[4] Estimation of Reserves and Resources, EIA-U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves 2002 Annual Report

[5] Early Estimation of the Onset of an Oil Field's Peak Production, Sandrea, R., August 17, 2004. Available at http://www.its.com.ve/publications.htm

[6] Hubbert's Peak – the Impending World Oil Shortage, Deffeyes, K.S., Princeton University Press, 2001.

different ultimate recovery value in time as more data became available. In order to minimize data fluctuations caused by short-term events, the production rate values were smoothed over 5-year intervals. This did not mask, however, any major production changes due to long-term market variations as occurred during the 1980s, new IOR programs and any significant new discoveries made during the course of the country's production history.

Figs. 1, 2 and 3 illustrate the graphical techniques used to establish the ultimate recovery values for the USA, Russia and Saudi Arabia, respectively, over the 20 year evaluation period. In the case of the USA and Russia, a single straight line was valid for the three periods, 1980, 1990 and 2000. This implies that their ultimate recovery values were stable - no major changes due to market events, new discoveries or IOR programs - over the entire 20 year interval. For Saudi Arabia, however, the decline history through 1980 is not useful for extrapolation because steady state conditions did not prevail at the time. Steady state conditions generally set in after more that 20 percent of the initial reserves have been produced[7]. Likewise, the production data during the 1980s also has to be filtered because of severe market events. The valid straight line portion of the decline curve, after 1990, indicates an ultimate recovery of 160 Gb. Similar detailed analyses were made for each of the countries in this study.

It should be emphasized that with the explicit exclusion of the unsteady state and the non-production mechanically related data values such as those pertaining to extreme market events, the decline lines generated in this study are all data-driven.

In the event that the decline plot had not stabilized by a specific year for example 1980, the ultimate recovery of the following period (1990) was assumed applicable to the previous period. These back extrapolated values are marked with an asterisk. This situation affected six countries. Norway and the UK only began producing in the mid 1970s, not long enough a period to establish steady state by 1980. Others like Iran that began production around 1915, Mexico (1900s), Saudi Arabia (1940s) and Nigeria (1960s) still had not reached their steady state production threshold by 1980. Fig. 4 illustrates the case of Mexico.

Remaining reserves are equal to the ultimate recoverable reserves minus the cumulative production. This relationship is used to calculate the 'decline' remaining reserves value once the ultimate recovery is established. They were then compared with the remaining reserves reported[8] [9] for the different countries at the end of each of the three years (1980, 1990, and 2000) evaluated.

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[7] Early Estimation of the Onset of an Oil Field's Peak Production, Sandrea, R., August 17, 2004. Available at http://www.its.com.ve/publications.htm

[8] Oil and Gas Journal, Dec. 1980, 1990, 2000

[9] OPEC Annual Statistical Bulletin, 2003.

Highlights of the Audit

The results of this study, shown in Table 1, can be summarized as follows:

- **At the end of 2000, the five OPEC countries in this study together 'reported' 523 Gb of remaining crude oil reserves, almost *four* times the volume estimated by the 'decline' method of 140 Gb.**

- **On the other hand, the 115 Gb of reserves 'reported' by the five non-OPEC countries at the end of 2000 were roughly *one-third less* than the corresponding 'decline' value of 177 Gb.**

- **Overall, the total remaining reserves 'reported' by the ten countries at the end of 2000 is *twice* the volume determined by the 'decline' method - 638 Gb versus 317 Gb.**

- **Russia and Nigeria each 'reported' reserves within 6 percent of the corresponding 'decline' values for 2000. The next closest approximations to the 'decline' values were Mexico with a 33 percent difference and the USA with 46 percent. Norway and the UK 'reported' differences of 58 percent and 69 percent, respectively. In the group of OPEC countries, Venezuela 'reported' reserves roughly three times greater than its 'decline' value. Saudi Arabia and Iran 'reported' approximately four times their respective 'decline' reserves values, and Kuwait an extraodinary twelve times!**

- **All of the countries in this study with the exception of Mexico, Norway and Nigeria had produced more than half of their ultimate recoveries by the end of 2000. The half life of the ultimate recovery corresponds with the peak potential.**

- **The annual production decline rates in 2000 for the different countries in this study ranged from 1.3 percent for the USA to 8.2 percent for Norway.**

- **To further corroborate the consistency of the 'decline' reserves determined in this study, the reserves/production (R/P) ratio for each country was calculated for both the 'reported' and the 'decline' reserves at the end of 2000 (see Table 2). The constancy of the ratios using 'decline' values of the reserves contrasts notably with the wide variations of the values obtained using 'reported' reserves. The R/P ratios for the 'decline' reserves vary from 12 for Kuwait to 38 for Mexico while those based on 'reported' reserves show a broad spread, from 6 for the UK to 146 for Kuwait. R/P ratios should normally remain within a narrow range of values with variations depending mostly on reservoir dynamics and the mix of oils produced.**

Final Remarks

- **Extrapolating the 'decline' results of the ten countries in this study shows that the world crude oil remaining reserves at the end of 2000 were 540 Gb, almost half as much as the 991 Gb 'reported'.**

- **While the 'reported' world crude oil reserves show an *increasing* trend from 650 Gb in 1980 to 991 Gb at the end of 2000, the extrapolated 'decline' reserves values indicate a *decreasing* tendency, from 800 Gb to 540 Gb over the same period.**

- **At the end of 2000, world oil reserves were declining at an annual rate of 2.3 percent. The decline rates for the oil reserves of the the Big Three – the USA, Russia and Saudi Arabia – were 3.7 percent, 3.5 percent, and 2.5 percent, respectively.**

- **The extrapolated 'decline' value of the world's ultimate recoverable crude oil reserves at the end of 2000 is 1400 Gb which is substantially less than the 2000 Gb value generally accepted[10]. As far back as 1997, Campbell had suggested[11] what he called an 'adjusted' figure of 1420 Gb.**

- **In order to independently clarify this gap, a decline curve analysis was made of the world production data. As shown in Fig. 5, the results substantiate the 1400 Gb value and also establish that the half life of the world's ultimate recoverable reserves of crude oil ocurred about 1995! Fig. 6 depicts the world production rate history from 1905 through its current peaking period. Fig. 7 shows the global distribution of crude oil reserves discovered (~1400 Gb) since the birth of the oil industry, circa 1850s The data is from this study and others[12].**

- **Why would the USA, the UK, and Norway constantly understate their oil reserves by more than 35 percent? There are many business-driven considerations that work their way into the reserves figures. It is common industry practice to restate oil and gas reserves as a result of commodity prices and other industry-wide factors. Furthermore tail-end production is costly and the companies might justify not claiming the corresponding reserves until they actually commit to produce them. Nonetheless, 35 percent plus is a huge adjustment.**

[10] Hubbert's Peak – the Impending World Oil Shortage, Deffeyes, K.S., Princeton University Press, 2001.
[11] Better Understanding Urged for Rapidly Depleting Reserves, Campbell, C.J., O&GJ, April 7, 1997.
[12] Encircling the Peak of World Oil Production, Duncan, R.C.and Youngquist, W., presented at Minnesotans for Sustainability Society, June 1999.

- **The Sarbanes-Oxley Act passed by the US Congress in 2002, will most likely impact the reporting of oil and gas reserves worldwide. The legislation requires certificaction of financial reports not only of US companies but also of foreign-based companies that obtain financing through US capital markets.**

- **Why would the group of OPEC countries increasingly overstate their reserves starting at 41 percent in 1980, growing to 256 percent in 1990, and to almost 400 percent at the end of 2000? Perhaps the importance of oil in their economy – approximately 40 percent of their GDP – is the primary reason. Reserves essentially determine the country's worth. Maybe they are stretching their proven reserves by including some probable and even possible reserves.**

- **The logistic decline method is an effective, independent and non-invasive statistical tool for corroborating country oil reserves. It measures reserves from past and present producing oil fields but does not take into account yet-to-find reserves.**

Finally, David O'Reilly, CEO of ChevronTexaco, recently summed up succintly the *why* of the current record energy prices, "the world oil market is quite tight due to the narrow gap between production capacity and demand". Evidently, the oil bubble is popping. Rising oil prices will serve to contain the current unabated pace of demand, a sizzling 8 percent, and encourage the enormous investments required to discover new oil now that the world is past its peak production potential.

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Rafael Sandrea, PhD
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Table 1. Comparative Estimates of Crude Oil Reserves for Ten Major Oil Producing Countries

Country	Reserves, Gb									Cumulative Production	Decline Rate
	1980			*1990*			*2000*			*2000*	*2000*
	Ultimate Recovery	'Reported' Remaining Reserves	'Decline' Estimate of Remaining Reserves	Ultimate Recovery	'Reported' ***Remaining Reserves***	'Decline' Estimate of Remaining Reserves	Ultimate Recovery	'Reported' Remaining Reserves	'Decline' Estimate of Remaining Reserves	Gb	% / year
Saudi Arabia	160*	166	120	160*	260	100	160	263	71	89	3.2
Iran	75*	58	45	75*	93	36	75	100	23	52	2.5
Venezuela	54	20	18	60	25	16	68	40	15	53	2.0
Kuwait	35	70	15	35	96	11	38	96	8	30	2.6
Nigeria	44*	17	36	44*	21	30	44	24	23	21	3.4
Sub-total	*368*	*331*	*234*	*374*	*495*	*193*	*385*	*523*	*140*	*245*	
USA	220	26	93	220	25	65	220	22	41	179	1.3
Russia	190	63	125	190	57	80	190	49	52	138	2.5
Mexico	70*	44	62	70*	51	53	70	28	42	28	3.9
Norway	40*	6	39	40	10	36	40	11	26	14	8.2
UK	35*	15	33	35*	4	25	35	5	16	19	4.9
Sub-total	*555*	*154*	*352*	*555*	*147*	*259*	*555*	*115*	*177*	*378*	
Total	**923**	**485**	**586**	**929**	**642**	**452**	**940**	**638**	**317**	**623**	
World	**1250e**	**650**	**800e**	**1330e**	**968**	**700e**	**1400e**	**991**	**540e**	**860**	**2.6**

Notes: *Ultimate recovery* is the extrapolated value of the straight line portion of the decline plot. *Reported remaining reserves and Production* figures were taken from the following sources: O&GJ, OPEC Annual Statistical Bulletin, Merrill Lynch. Reserves and production are for crude oil; the non-conventional component was deducted from the reserves data for Venezuela and from the corresponding World figures. *'Decline' estimate* of remaining reserves equals the ultimate recovery minus cumulative production for the year end in question. The production *decline rate* is obtained from the decline plot; it can also be estimated using Equation 1 in the Appendix. Gb is billion barrels. 'e' indicates the value was extrapolated from the 'decline' reserves calculated for the ten countries in this study. Asterisk indicates that the values were taken from the following period because the decline plot had not reached steady state. For example, the ultimate recovery value for Norway in 1980 could not be established from the decline plot because of lack of steady state conditions - the country started production only in the late 1970s; it was therefore assumed equal to the 1990 value of 40 Gb.

Table 2. Comparative Reserves/Production (R/P) Ratios – 2000

Country	'Reported' Reserves(R_1) Gb	'Decline' Reserves(R_2) Gb	Production (P) million b/d	'Reported' R_1/P years	'Decline' R_2/P years
Saudi Arabia	263	71	8.1	88	24
Iran	100	23	3.7	74	17
Venezuela	40	15	2.9	38	14
Kuwait	96	8	1.8	146	12
Nigeria	24	23	2.0	33	32
Sub-total	*523*	*140*	*18.5*	*77*	*21*
USA	22	41	5.8	10	19
Russia	49	52	7.6	18	19
Mexico	28	42	3.0	25	38
Norway	11	26	3.2	9	22
UK	5	16	2.4	6	18
Sub-total	*115*	*177*	*22.0*	*14*	*22*
Total	**638**	**317**	**40.5**	**43**	**21**

Appendix

The logistic decline model is[13]:

$$(dQ/dt)/Q = r_o(1 - Q/K) \qquad (1)$$

where Q is the cumulative oil production, (dQ/dt)/Q is the annual percentage production decline rate, r_o is the initial production decline rate, and K a capacity constant. The Q/K term represents a physical constraint, namely, that the final production of the field is limited to the capacity or amount of recoverable oil. K is therefore the ultimate recovery Ru, (Ru = STOIIP*recovery factor) of the field, and (K – Q) the remaining reserves at time t. Equation (1) reverts to the exponential decline model for Q/K « 1.

[13] Early Estimation of the Onset of an Oil Field's Peak Production, Sandrea, R., August 17, 2004. Available at http://www.its.com.ve/publications.htm

Fig. 1 Production Decline Plot - USA

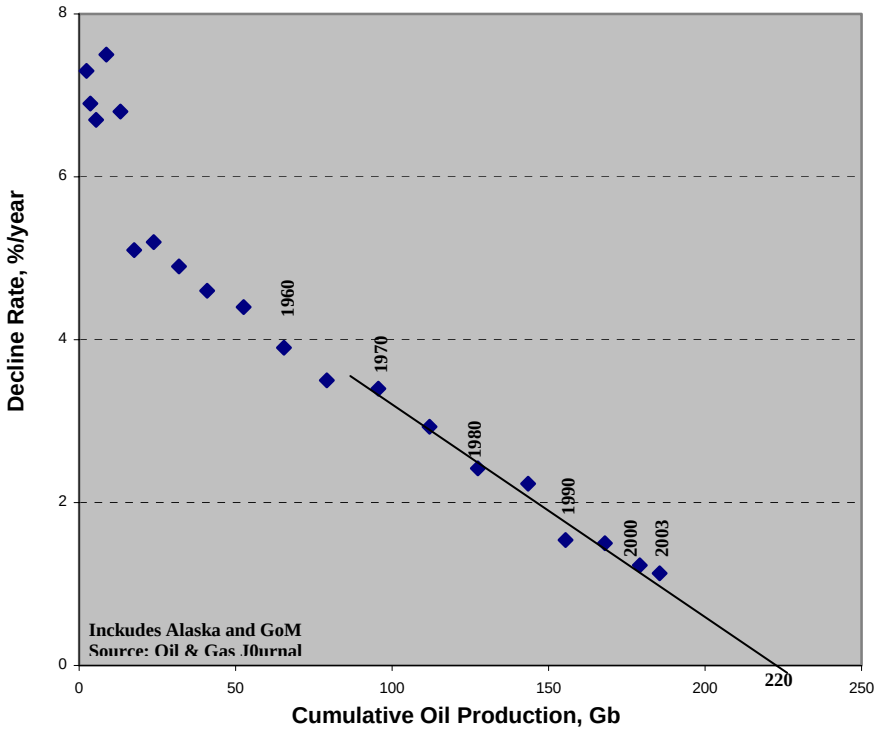


Fig. 2 Production Decline Plot - Russia

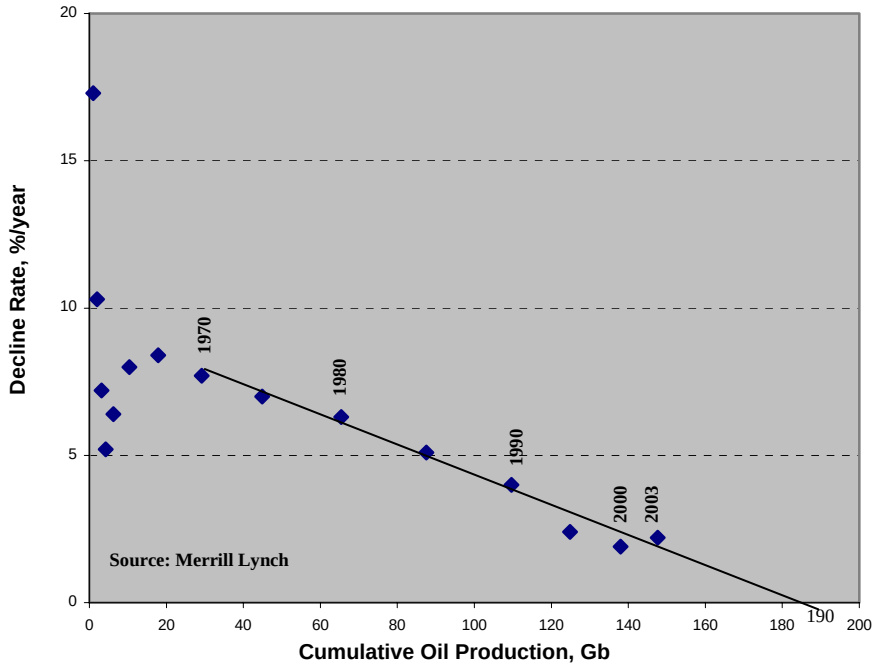


Fig. 3 Production Decline Plot - Saudi Arabia

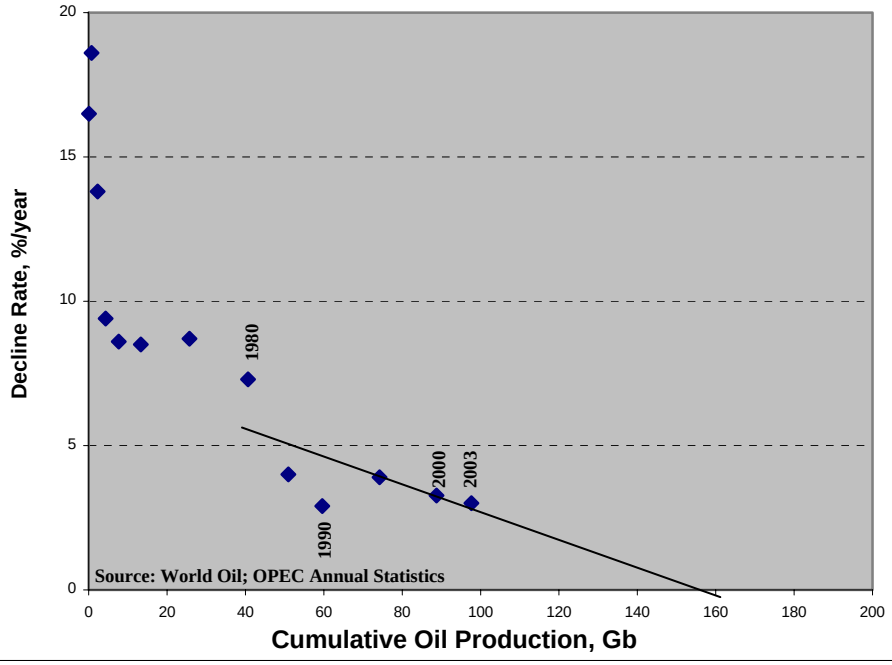


Fig. 4 Production Decline Plot - Mexico

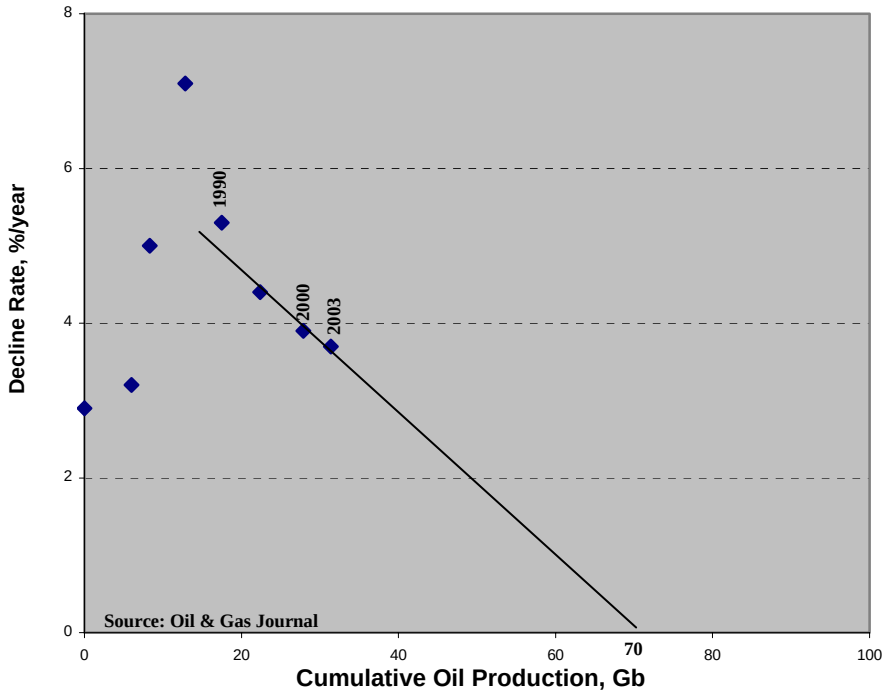


Fig. 5 Production Decline Plot - World

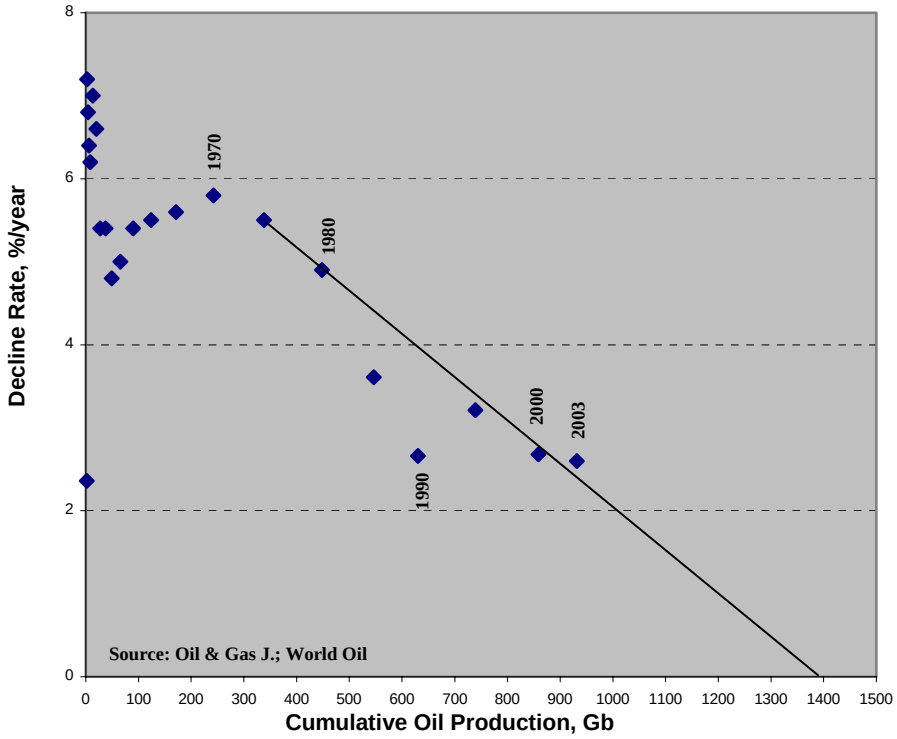


Fig. 6 Oil Production Rate - World

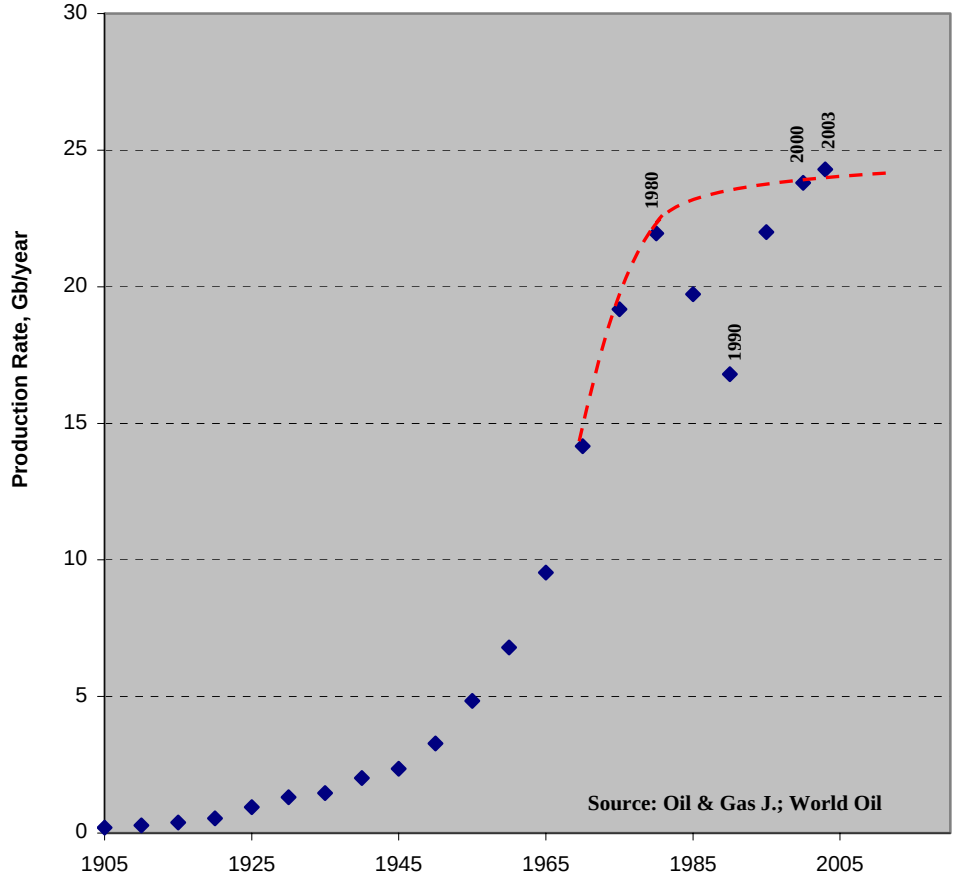
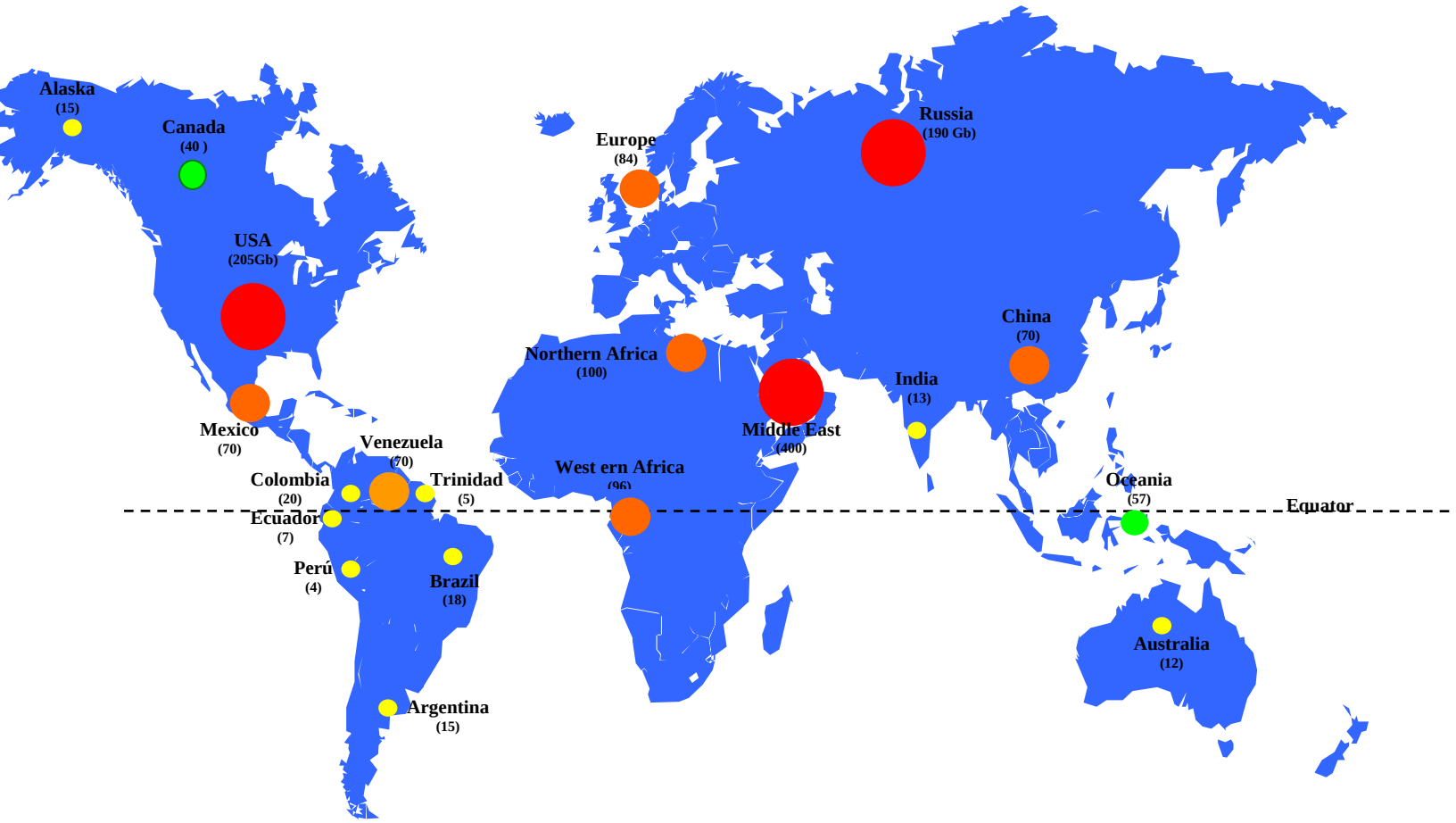


Fig. 7 - Crude Oil Reserves Discovered since 1850s



> 100 Gb 100 – 61 Gb 60 – 21 Gb 20 – 1 Gb