Global Natural Gas Reserves – A Heuristic Viewpoint

Supply and demand of natural gas, the world's fastest growing energy source, has increased by 15% over the last five years, from just over 260 billion cubic feet per day (Bcfd) to 300 Bcfd. The impressive world energy demand escalation that pushed crude oil prices to more than $55 per barrel in 2004 and to a record high of $70 in 2005 has made apparent a potential oil supply gap due to imbalances in supply and demand. Natural gas is expected to fill this void.

According to the BP Statistical Review, worldwide remaining proved reserves of natural gas stood at 6,150 trillion cubic feet (Tcf) as of January 1, 2004 and have more than doubled since 1980. In terms of liquid volumes, remaining reserves of natural gas are equivalent to roughly 1,025 billion barrels (Gboe) of oil, a level similar to that of crude oil reserves. World natural gas production of 300 Bcfd is equivalent to about 50 million barrels of oil per day while world crude oil production stands at approximately 71 million barrels per day. International gas trade is currently 24% of world production and inter-regional gas trade is already 8%. The latter is expected to grow significantly as liquefied natural gas (LNG) projects in Asia, Middle East and North and West Africa come on stream in response to higher demand in North America, Western Europe and Asia.

Prior to the severe damage caused by Hurricanes Katrina and Rita to the U.S. Gulf of Mexico natural gas infrastructure, the trend in natural gas prices was also upbeat. The average U.S. wellhead price[1] of gas in 2004 was $5.40/Mcf or roughly $32 per barrel of equivalent crude oil, compared to $37.30 for the wellhead price of crude oil. In 2005, prices appear to have settled above $10/Mcf, a five-fold increase from the average of the 1990s.

For years natural gas has been a resource looking for a market and therefore there was little economic incentive to evaluate in detail gas discoveries. Many discoveries were even considered unwanted because of a lack of market, particularly in the non-industrialized producing countries. The evaluation of unconventional gas such as coalbed methane (CBM), shale gas and methane hydrates is still in its infancy. On the production side, the U.S. Energy Information Administration (EIA) estimates that in 1976 more than three-quarters of gas produced in the Middle East was flared; worldwide, 12.2% was flared, a whopping 20 Bcfd. By 2002 the amount of gas flared worldwide had been reduced to 2.3% but still stood at 7 Bcfd with an energy equivalence of 1.2 million b/d of oil! This gas is often referred to as stranded gas. Reported values of global ultimate recoverable reserves vary widely from 8,500[2] to 11,800[3] Tcf. All things considered it would be prudent to assess the proven reserves of conventional natural gas available for the task ahead of filling a big share of the global energy market growth.

The objective of this article is to demonstrate the applicability of the logistic decline model to appraise proven conventional natural gas reserves in several of the world's largest producing gas fields. The analysis is then extended to important gas producing countries and finally to an estimation of proven conventional worldwide gas reserves. Others[4] [5] have used a modified form of the logistic model to predict ultimate gas reserves. The contention is that the standard logistic decline model is not applicable to natural gas. The so-called Multicyclic Hubbert Model essentially matches early historical production data for each country and then forecasts future production trends. This approach has not been shown to provide reliable estimates even in the case of a simple, closed system such as an oil field or gas field where the ultimate recoverable reserves are known.

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[1] "Oil to lead US Energy demand growth in 2005", Marilyn Radler, Oil and Gas Journal, Jan. 17, 2005
[2] "Natural Gas Future Supply", Jean Laherrere, IIASA-IEW, June 22-24, 2004
[3] " Where America's Energy Comes From", Pete Stark and Kenneth Chew, IHS Energy, March 2005
[4] "Multi-Hubbert Modeling", Laherrere, J.H., www.hubbertpeak.com/Laherrere/multihub.htm, 1997.
[5] "Multicyclic Hubbert Model shows global conventional gas output peaking in 2019", Asher Imam, Richard A.Startzman and Maria A. Barrufet, Oil and Gas Journal, Aug. 16, 2004.

Reserves Evaluation Basics

Prior to start-up of production, volumetric evaluation of reserves based on geologic and raw engineering data – porosity, saturation, areal coverage and formation thickness – is the only option. As production data becomes available several methods based on reservoir performance, such as production decline analysis and reservoir simulation, provide more accuracy in the reserves estimate. Decline curve analysis is generally regarded as one of the primary tools for reserves evaluation largely because of its simplicity and reliability. Since it is based entirely on measured production data, decline curve analysis distinctively provides an estimate of proven reserves.

The logistic model is defined as[6]:

$(dQ/dt)/Q = ro\,(1 - Q/K)$ (1)

where Q is the cumulative gas production, (dQ/dt)/Q is the annual percentage production decline rate, ro 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 gas. K is, therefore, the ultimate recovery (URR) of the field and (K – Q) the remaining reserves at any time t. A plot of the annual percentage decline rate versus cumulative production is a straight line which can simply be extrapolated to Q = K, the URR value.

However, prior to determining the beginning of the straight-line portion of the logistic model to be extrapolated, several conditions must be met – the most important is that production decline be in a stabilized mode. This occurs after the end of the early production period. During this early period, Q/K << 1 and Equation (1) reverts to:

$dQ/dt = ro\,Q$ (2)

which is the familiar exponential model used widely in well and reservoir analysis. Production rate (dQ/dt) versus cumulative production (Q) plots as a straight-line through the origin Q = 0. When this trend breaks down, it is indicative that production is entering the decline phase. As a rule of thumb the decline curve for gas fields stabilizes after approximately 20-25% of the original reserves have been produced. The response varies with the size of the reserves.

Reserves Estimates for Six Giant Gas Fields

The logistic decline method was applied to the production data of six of the top giant gas fields in the world: Urengoy (Russia), Yamburg (Russia), Orenburg (Russia), Medvezhye (Russia), Groningen (Netherlands) and Hugoton (USA). They were selected because they are mature fields with known ultimate recoverable reserves substantiated by other reservoir models. Figs. 1-3 illustrate the trend lines of the stabilized decline curves for three of the fields: Urengoy, Groningen and Hugoton. Also shown on the graphs are the dispersed data points prior to stabilization and the extrapolated values of ultimate recoverable reserves (URR) calculated from a least squares fit of the trend lines.

Table 1 summarizes the URR values obtained by decline curve analysis for the six sample fields and their original volumetric reserves estimates. The volumetric estimate may be high or low, relative to the decline value, but it gives an insight into the perceived extent of the field early in its development. With a couple of exceptions, the original volumetric estimates were on the average one-third higher than the final URR values for the fields. These examples demonstrate that the standard logistic model successfully replicates the decline behavior of non associated gas fields.

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[6] "What About Deffeyes' Prediction That Oil Will Peak in 2005?", Rafael Sandrea, MEES, Sept. 12, 2005.

Reserves Estimates for Six Major Gas Producing Countries

The decline behavior of six of the top ten gas producing countries: Russia, USA, Canada, Netherlands, Algeria and Indonesia were analyzed. Together they account for 60% of the world's production of natural gas (see Table 2). As a general observation, the decline curves for most major gas producing countries, including the U.S., Russia and Canada, only recently began to stabilize in the late 1990s. The major gas reserves of the Middle East are still in the developmental stage and therefore not susceptible to decline curve analysis.

Table 3 summarizes the results of the ultimate recovery reserves determined by decline curve analysis for the six countries and compares them with recently published values, product of other predictive techniques[7]. Figs. 4-6 illustrate the decline plots and trend lines for the Big Three: Russia, USA and Canada that account for half of the world's production. These three cases are discussed in more detail since their calculated URR values differ substantially from recently reported values.

In the case of Russia, its calculated ultimate reserves are 1,147 Tcf (see Fig. 4) versus 2,925 Tcf recently reported. Sixty-two percent or 710 Tcf had been produced through 2003. Russia presents an unusual situation. It has several giant gas fields with reserves estimated between 260[8] and 350 Tcf that are undeveloped and/or awaiting production and transport infrastructure to go on stream – also referred to as stranded gas. It is important to emphasize that the decline curve technique only reflects proven reserves being produced. It cannot reflect yet-to-find reserves or production on hold for lack of facilities. These substantial reserves on hold in the Russian situation may change the slope of the current decline trend line whenever production goes on stream. Considering the calculated ultimate reserves and the high end of the undeveloped reserves, Russia's final URR may be around 1,500 Tcf. However, this probable value would still be approximately half the size of recently published values.

The U.S. situation is unique in that its gas output comes from several distinct sources. Gas production from traditional oil and gas fields maxed at 22 Tcfy in 1973, subsequently declining to a low of 16 Tcfy in 1986. This fall-off triggered major technological efforts to develop gas production from other sources, specifically tight-gas sands, CBM and shale gas. Modest production from these three sources began in the 1980s and has grown to a significant 35% of the present U.S. total dry gas output. Tight gas is by far the dominant contributor with 24%, followed by CBM with 9%, and shale gas with 2%. Originally all three sources were classified as unconventional but recent work[9] suggests that tight-gas reservoirs behave more like conventional low permeability sandstones. This is the position taken in this study. Production data from CBM and shale gas were therefore not included in this decline analysis.

Fig. 5 illustrates two distinctive stabilized decline trends, one for the production from the traditional oil and gas fields, which begins in the 1970s and extrapolates to an URR value of 933 Tcf. The other trend line reflects the impact of tight-gas reserves beginning in the 1990s and extrapolates to an URR value of 1820 Tcf. This would imply an URR value of 887 Tcf for tight-gas, more than three times the EIA's[10] recently published value of 254 Tcf. Additionally, it should be pointed out that the decline URR value of 1820 Tcf does not include reserves on hold in North Slope Alaska, estimated in 35 Tcf. Cumulative production of conventional natural gas for the U.S. as of January 1, 2005 is 1007 Tcf or 54% of its ultimate recoverable reserves. The remaining conventional reserves of 848 Tcf are good for 56 years at current production rates. For the sake of comparison, the recoverable reserves of conventional natural gas of the U.S., in terms of liquid volumes, are 37% higher than those of crude oil, 309 Gboe versus 225 Gb[11].

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[7] "Multicyclic Hubbert Model shows global conventional gas output peaking in 2019", Asher Imam, Richard A.Startzman and Maria A. Barrufet, Oil and Gas Journal, Aug. 16, 2004.
[8] "Natural Gas Future Supply", Jean Laherrere, IIASA-IEW, June 22-24, 2004
[9] "Tight-gas myths, realities have strong implications for resource estimation, policymaking, operating strategies", Keith W. Stanley, John Robinson and Robert M. Cluff, Oil and Gas Journal, August 2, 2004.
[10] Energy Information Administration, Annual Energy Outlook 2004 with Projections to 2025 (www.eia.doe.gov/oiaf/aeo).
[11] "What About Deffeyes' Prediction That Oil Will Peak in 2005?", Rafael Sandrea, MEES, Sept. 12, 2005

The decline curve estimation of ultimate reserves for Canada is 720 Tcf (see Fig. 6) versus 409 Tcf recently reported. A little over 20% had been produced through 2004. Overall, ultimate recoverable conventional natural gas reserves for North America (U.S. and Canada) show a strong figure of 2,575 Tcf, 38% higher than current estimates of the United States Geological Survey (USGS)[12] and IHS Energy[13]. At current production rates of conventional gas - roughly 23 Tcfy - the half-life for these reserves is 5 years away. ***(The half-life of reserves is analogous with peak production. However, the author prefers the use of half-life since field production normally is maintained at a plateau over a long period so as to optimize the capacity of installed facilities.)***

Finally, decline curve analysis was applied to the production data for the world as a whole. The logistic plot for the period after the decline had stabilized is shown in Fig. 7. The trend line extrapolates to a value of 7,200 Tcf for the ultimate recoverable reserves. Akin to the case of Russia, some 1,680 Tcf of discovered gas resource worldwide[14] has not yet been brought on stream and are therefore not reflected in the nepionic stabilized decline curve. This prompted using a heuristic approach, based on an assumed analogy between giant oil and gas fields, to obtain a second approximation for global ultimate recoverable gas reserves. The basis of the analogy stems from the premise that oil and conventional natural gas are produced by the same geologic process and are often found together in the most important hydrocarbon rich provinces.

A Heuristic Approach

Many of the largest gas fields in the world have not yet been brought on stream or are in the start-up mode. For example, the world's largest gas field, North Dome (North Field - South Pars), is only producing 10% of its planned full-scale production of 45 Bcfd. Production from other giant fields like Prudhoe Bay and several Russian and Middle Eastern fields is on hold pending the construction of pipeline systems and customers.

Giant oil fields are the core of the oil industry because they provide a significant share of the world's supply. The world's 120 largest oil fields - 3% of the 4,000 total active oil fields - produce almost half of the world's production[15]. For this comparative analysis, the world's fifteen top oil and fifteen top non associated gas fields were selected. Table 4 lists these thirty special giant fields specifying their size and year of discovery. The size of the gas fields is also expressed in volumes of equivalent oil so as to make easy their comparison with the oil counterparts. Eight of the fifteen giant gas fields are located in Russia and contain 30 % of the total reserves of the group. Two fields in the Middle East together account for 55% of the group's reserves. Fig. 8 illustrates graphically the size distribution of each set of oil and gas fields.

Before analyzing the size distributions, it should be pointed out that in contrast to the giant oil fields for which estimates of their recoverable reserves are well established, this is not the case with the gas giants. Eight (identified with an asterisk in Table 4) of the 15 top gas fields have only volumetric estimates of their reserves either because they have yet to go on production or have very little production history as is the case of the North Dome and Zapolyarnoye fields. Both circumstances preclude the options of decline curve analysis or of any dynamic reservoir modeling technique to determine reserves. The eight gas fields with volumetric estimates have all been properly audited and committed to large scale developmental investments, indicative of a high level of confidence in the estimate of their reserves. Nonetheless, volumetric estimates generally have a tendency to be on

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[12] "An evaluation of the U.S. Geological Survey World Petroleum Assessment 2000", Klett, T.R., Gautier, D. L.,and T. S. Ahlbrandt, AAPG Bulletin, V. 89, No. 8 (August 2005), pp. 1033-1042..
[13] "Where America's Energy Comes From", Pete Stark and Kenneth Chew, IHS Energy, March 2005
[14] The American Association of Petroleum Geologists, Memoir 2005.
[15] " The World's Giant Oil Fields", Matthew R. Simmons, Hubbert Center Newsletter # 2002/1, Jan. 2002.

the high side. This departure in the discussion was considered essential since the eight fields in question represent 70% of the reserves of the entire group of fifteen.

Two observations are pertinent about the size distributions. The biggest gas field, North Dome, is almost three times the size of Ghawar, the world's largest oil field. In contrast, the remaining 14 gas fields tend to be significantly smaller - roughly one-third less in size - than their 14 oil counterparts. Taken all together, both groups of fifteen fields contain similar volumes of reserves: 369 Gb for the oil fields and 433 Gboe for the gas fields. This difference of roughly 15% is not considered significant in view of the fact that the majority of the gas fields have only volumetric estimates of their reserves versus more reliable estimates for the oil fields. Additionally, the volumetric gas reserves values are further converted to their thermal equivalence of oil.

The general conclusion would be that, in the best-case scenario, there appears to be as much ultimate recoverable reserves of non associated gas as there are of crude oil. Based on a median value of 2,000 Gb from published[16] estimates of the ultimate reserves of oil, the corresponding value for non associated gas would be roughly 12,000 Tcf. To this value, estimates of associated natural gas reserves would have to be added. These are approximately 1,500 Tcf based on an average solution gas-oil ratio of 750 cubic feet per barrel for the 2,000 Gb reserves of crude. The total best-case estimate of global ultimate recoverable gas reserves would then be 13,500 Tcf.

Conversely, if the outsize North Dome field is considered an anomaly and the comparison is made of the size distributions of the remaining 14 fields in each group, the estimate of non associated gas reserves would be one-third less than the previous case, or 8,000 Tcf. After adding the associated gas reserves of 1,500 Tcf, total reserves of associated and non associated gas in this alternate scenario would stand at 9,500 Tcf. Finally, global ultimate recoverable gas reserves should then fall in a range between 9,500 and 13,500 Tcf.

The USGS recently published[17] their assessment of world resources of conventional natural gas. Using geoscientific analyses they established values in a range from 10,200 to 15,400 Tcf. The higher limit includes estimates (5,200 Tcf) of yet-to-find reserves. The propinquity of the results from two radically different heuristic approaches is reassuring.

The Impact of LNG and GTL Technologies on Reserves

Undoubtedly LNG facilities are vital to the worldwide monetization of natural gas. A typical one Bcfd project requires a massive 15 Tcf of proven reserves over 30 years[18]. A huge 35% of the wellhead gas is lost creating, transporting and regasifying the LNG. Likewise, emerging gas-to-liquids (GTL) plants to produce synthetic fuel products, mostly diesel and naphtha, also require major reserves[19]. The thermal efficiency of current GTL processes is about 60% implying a requirement of 10 MMcf of dry gas for each barrel of diesel produced. A 50,000 b/d plant would therefore require 5 Tcf of reserves over 20 years, approximately the time needed to amortize the large investments. The relatively low efficiencies of these processes will evidently have to be factored into the ultimate recoverable gas reserves, at both the field and country levels. This is perhaps one of the reasons why Qatar has slowed or delayed some of the GTL projects into the next decade.

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16 "Oil Prophets: Looking at World Oil Studies Over Time", Steve Andrews and Randy Udall, ASPO Conference, May 26-27, 2003, Paris.

17 "Global Perspectives on Petroleum Resources", Thomas Ahlbrandt, USGS World Energy Project Chief, 3rd Joint OPEC/IEA Workshop, May 15, 2005.

18 Matthew Simmons in interview fo r glogalpublicmedia.com, May 19, 2004.

19 "Stranded Gas, Diesel Needs Push GTL Work", I. I. Rahmim, Oil and Gas Journal, March 14, 2005.

Highlights

- **The standard logistic decline model has proved to be a simple and reliable tool to validate the reserves of non associated gas fields. It was used to evaluate the reserves of six of the largest mature gas fields in the world, where production has stabilized.**

- **The model was subsequently used to validate the reserves of six of the top gas producing countries: Russia, USA, Canada, Netherlands, Algeria and Indonesia. The Big Three: Russia, USA and Canada account for half of the world's production and roughly half of its ultimate recoverable reserves.**

- **The ultimate recoverable conventional gas reserves for the U.S. are determined to be 1855 Tcf, 55% higher than EIA's values for technically recoverable conventional and unconventional recoverable resources combined. The calculated URR value for Canada (720 Tcf) is 76% higher than previous reported values. By contrast, the ultimate reserves estimated for Russia (1,500 Tcf) amount to *half* of recently published values. The 1,500 Tcf value is a stretch of the calculated value by decline analysis (1,147 Tcf) when combined with additional proven reserves (350 Tcf) not yet on stream.**

- **The U.S. has remaining conventional gas reserves (848 Tcf), with duration of 56 years at current production rates of 15 Tcf per year. Production has just passed the half-life mark of its ultimate conventional recoverable reserves. Canada has produced a little over one-fifth of its ultimate reserves. Russia would be close to its half-life, having produced 47% of its probable ultimate reserves of 1,500 Tcf. The ultimate conventional reserves of North America have been estimated to be a robust 2,575 Tcf. The half-life is 5 years away at current production rates.**

- **When the logistic model was applied to worldwide conventional gas production data, the extrapolated ultimate recovery value obtained was 7,200 Tcf. Akin to the Russian situation, more than 1,680 Tcf of discovered gas resource worldwide has not yet been brought on stream and are therefore not reflected in the actual decline trend line. A similar condition arises for the potential reserves of the Middle East and Africa.**

- **A heuristic approach was taken to obtain a second approximation of worldwide gas reserves based on a comparative analogy of the size distributions of giant oil and giant non associated gas fields. The results indicate that in a best-case scenario the ultimate recoverable reserves of conventional natural gas may be similar to those of crude oil. Global reserves were estimated to range between 9,500 and 13,500 Tcf. The comparable range of values assessed by the USGS varies from 10,200 to 15,400 Tcf.**

- **Gas exporting countries are in a headlong rush to install LNG facilities and, to a lesser extent, build emerging GTL plants to produce synthetic fuel products. These projects require major capital investments and enormous reserves. The efficiencies of these technologies range about 60-65%, which implies that losses of wellhead gas and hence reserves are high, roughly one-third.**

The world is also known to have substantial unconventional natural gas resources[20] that have received very little attention. After U.S. gas production from traditional oil and gas fields maxed at 22 Tcfy in 1973, output from unconventional sources - CBM and shale gas - has grown significantly over the last 20 years. Together they now account for 11% of U.S. dry gas production. Present estimates of likely recoverable reserves of U.S. CBM and shale gas resources are 60 Tcf and 55 Tcf, respectively. Boosting these reserves is the next challenge.

CBM development is now widespread around the globe but shale gas activity is very low. Worldwide, likely recoverable resources of CBM are estimated to be 550 Tcf, and of shale gas it is roughly 250 Tcf. At the more speculative end are methane hydrates with worldwide estimates of 3,000 Tcf of in-place resource apt to be developed in the near term.

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Dec. 16, 2005

[20] "Unconventional gas resources fill the gap in future supplies", Perry A. Fischer, Editor, World Oil, August, 2004

Table 1. Comparative Reserves Estimates - Decline Curve vs. Volumetric - for Six Giant Gas Fields

Field	Discovery/Production Year	Cumulative Production, Tcf (2003)	Ultimate Reserves, Tcf		% Volumetric Difference
			Volumetric	Decline	
Urengoy	1966/1978	176.7	176	222	– 21
Yamburg	1969/1985	93.2	155	138	+ 12
Orenburg	1966/1971	35.8	74	45	+ 64
Medvezhye	1967/1972	59.5	55	68	– 24
Groningen	1959/1963	60.8	104	73	+ 42
Hugoton	1926/1928	74.3	117	81	+ 46

Notes: Volumetric reserves refer to the original geologic estimate of the newly discovered field. The decline values were calculated in this study.
Source for the original volumetric estimates: "Natural Gas", E.N. Tiratsoo, Gulf Publishing Co., 1979

Table 2. World's Top Ten Gas Producing Countries
Jan./Feb. 2005, Bcfd

Country	Production	Country	Production
Russia	66.1	Norway	8.8
USA	54.1	Algeria	8.6
Canada	20.5	Iran	7.2
Netherlands	12.9	Indonesia	6.1
UK	10.6	Saudi Arabia	5.3
Top Ten	**200.2**		
World	**282.9**		

Notes: Production is the daily average for the first two months of 2005; includes both associated and non associated gas, and gas from unconventional sources; excludes gas flared, recycled or re-injected**.**
Source: Oil and Gas Journal-Industry Statistics.

Table 3. Comparative Conventional Reserves for Six Top Gas Producing Countries
(Tcf)

Country	Cumulative Production (2003)	Ultimate Reserves (URR)		% Diff.
		This Study	Others	
Russia	710	1147	2925*	+ 155
USA	992***	1855	1075**	– 42
Canada	156	720	409*	– 43
Netherlands	94	138	111*	– 20
Algeria	46	125	201*	+ 61
Indonesia	45	87	67*	+ 24
Top Six	2043	4072	4788	
World	2603	9,500-13,500	9,215*	

*****"Multicyclic Hubbert Model shows global conventional gas output peaking in 2019", Asher Imam, Richard A.Startzman and Maria A. Barrufet, Oil and Gas Journal, Aug. 16, 2004
******www.naturalgas.org/overview/resources.asp; includes tight gas reserves.
******* Includes tight gas production; excludes production of CBM and shale gas.

Table 4. World's Fifteen Largest Oil and Gas Fields

Oil Fields			Gas Fields			
Field, ***Country***	**Discovery year**	**Size Gb**	**Field, Country**	**Discovery year**	**Size Tcf →**	**Gboe**
Ghawar	**1948**	**80**	**North Field-South Pars**	**1976**	**1400***	**233**
Saudi Arabia			***Qatar-Iran***			
Burgan	**1938**	**60**	**Urengoy**	**1966**	**222**	**37**
Kuwait			***Russia***			
Bolívar Coastal	**1917**	**32**	**Yamburg**	**1969**	**138**	**23**
Venezuela			***Russia***			
Sufaniya	**1951**	**30**	**Hassi R'Mel**	**1956**	**123**	**20**
Saudi Arabia			***Algeria***			
Rúmiala	**1953**	**20**	**Shtokman**	**1989**	**110***	**18**
Iraq			***Russia***			
Ahwaz	**1958**	**17**	**Zapolyarnoye**	**1965**	**95***	**16**
Iran			***Russia***			
Marun	**1964**	**16**	**Hugoton**	**1926**	**81**	**13**
Iran			***USA***			
Kirkuk	**1927**	**16**	**Groningen**	**1959**	**73**	**12**
Iraq			***Netherlands***			
Romashkino	**1948**	**16**	**Bonavenko**	**1971**	**70***	**12**
Russia			***Russia***			
Tengiz	**1979**	**15**	**Medvezhye**	**1967**	**68**	**11**
Kazakhstan			***Russia***			
Gachsaran	**1928**	**15**	**North Pars**	**1973**	**48***	**8**
Iraq			***Iran***			
Aghajari	**1938**	**14**	**Dauletabad-Donmez**	**1974**	**47***	**8**
Russia			***Turkmenistan***			
Samotlor	**1966**	**14**	**Karachaganak**	**1979**	**46***	**8**
Russia			***Kazakhstan***			
Zakum	**1964**	**12**	**Orenburg**	**1966**	**45**	**7**
Abu Dhabi			***Russia***			
Abqaiq	**1964**	**12**	**Kharsavey**	**1974**	**42***	**7**
Saudi Arabia			***Russia***			
	Top 15	**369**		***Top 15***	**2608**	**433**
	World	**2000**		***World***	**9500 - 13500**	

Notes: Gas fields are non associated gas and gas condensate. Size refers to ultimate recoverable reserves expressed in Tcf and Gboe. Asterisk (*) indicates the reserves estimate is volumetric.
Sources: "Natural Gas", E.N. Tiratsoo, Gulf Publishing Co., 1979; Gibson Consulting Oil Statistics; EIA Reports; IIASA 2004; Author's decline estimates.

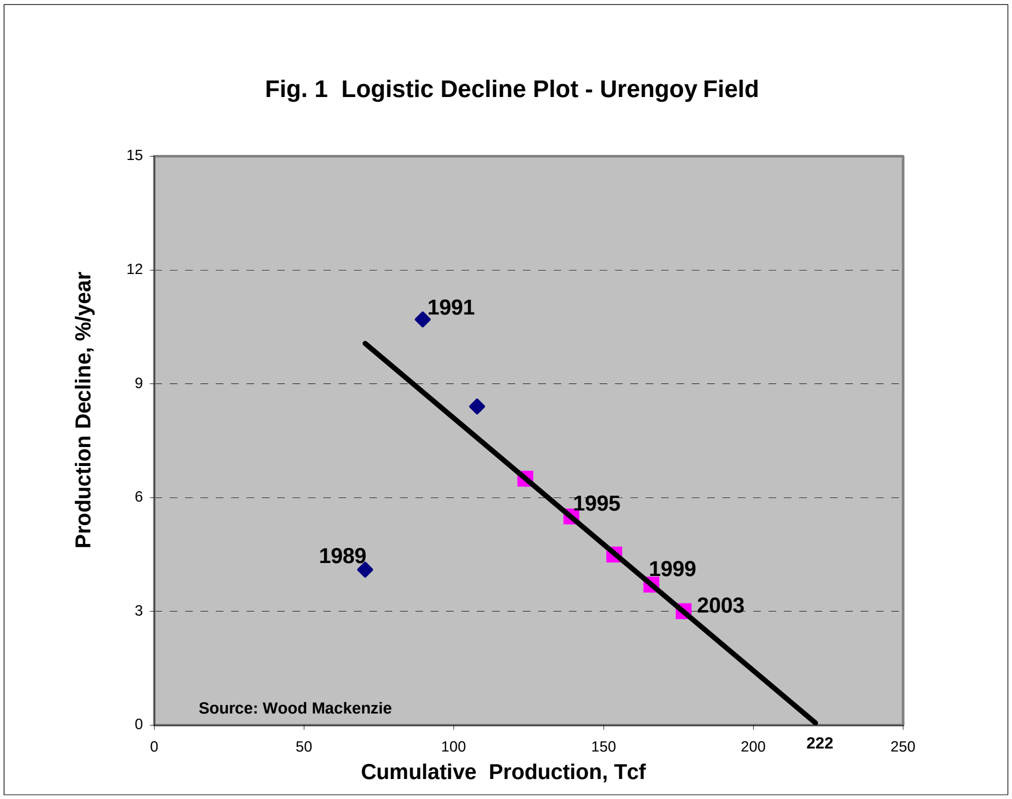


Fig. 1 Logistic Decline Plot - Urengoy Field
Production Decline, %/year
15
12
9
6
3
0
1991
1995
1989
1999
2003
Source: Wood Mackenzie
0
50
100
150
200
222
250
Cumulative Production, Tcf

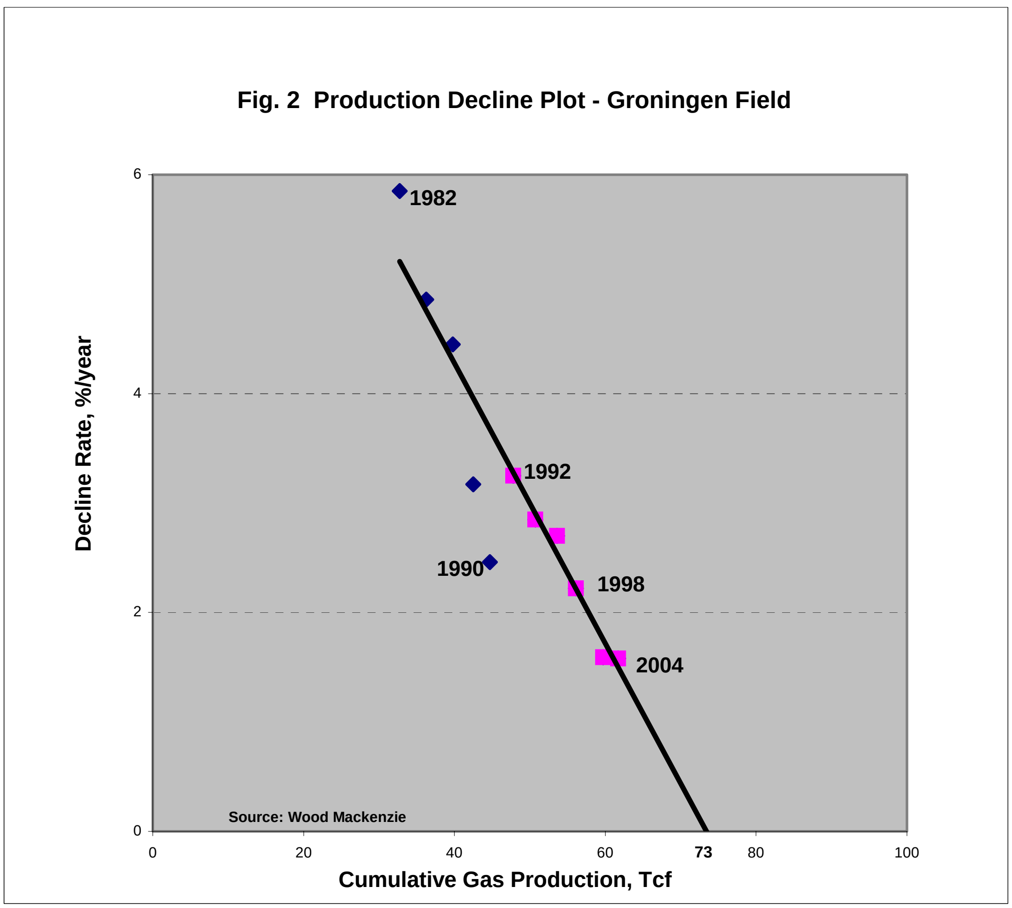


Fig. 2 Production Decline Plot - Groningen Field
Decline Rate, %/year
6
4
2
0
1982
1992
1990
1998
2004
Source: Wood Mackenzie
0
20
40
60
73
80
100
Cumulative Gas Production, Tcf

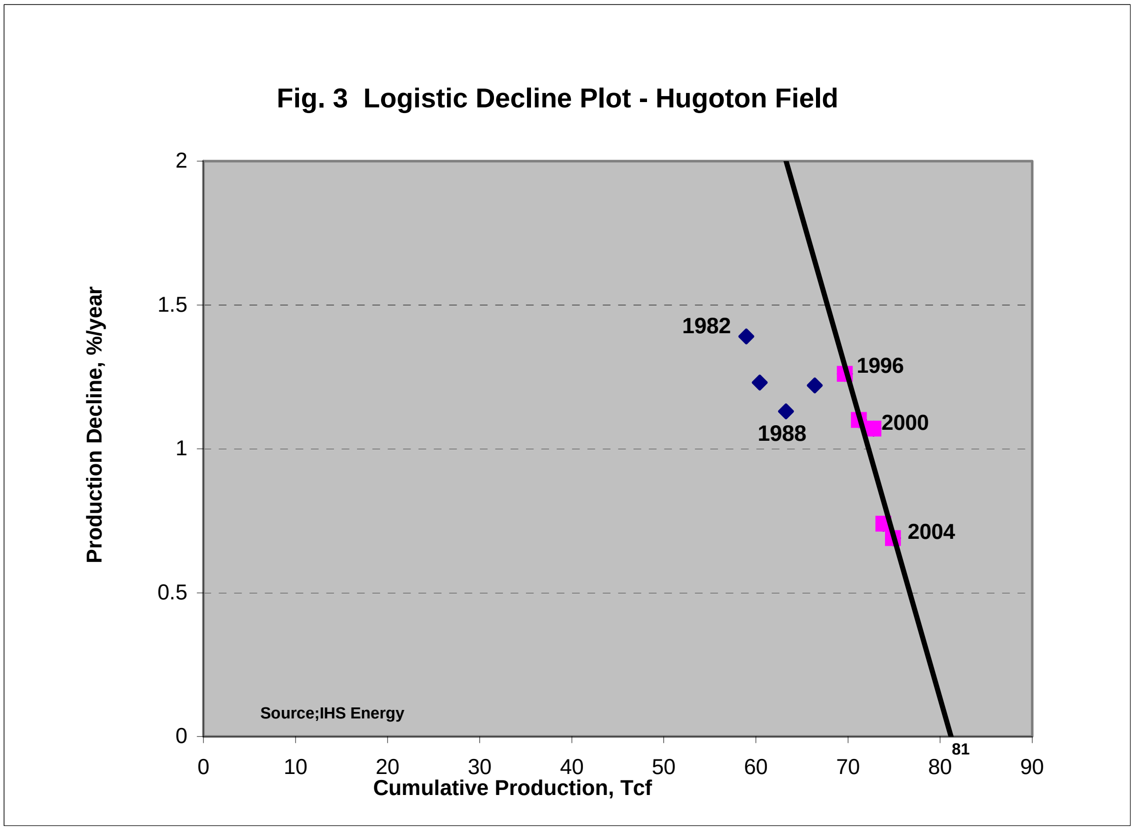


Fig. 3 Logistic Decline Plot - Hugoton Field
Production Decline, %/year
Cumulative Production, Tcf
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
80
90
81
1982
1988
1996
2000
2004
Source;IHS Energy

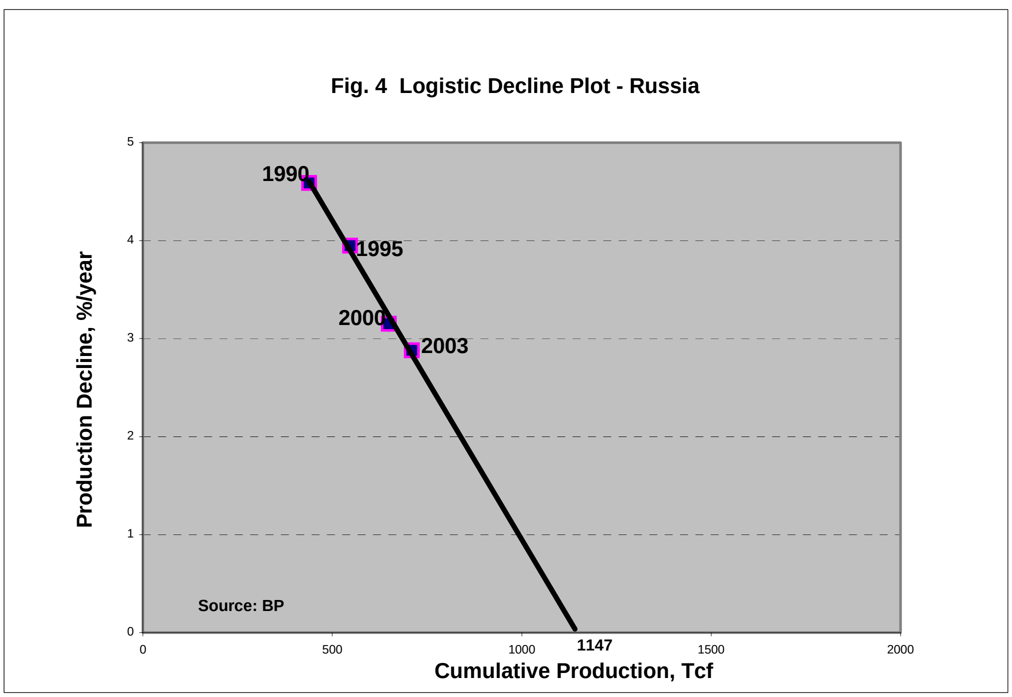


Fig. 4 Logistic Decline Plot - Russia
Production Decline, %/year
Cumulative Production, Tcf
5
4
3
2
1
0
0
500
1000
1147
1500
2000
1990
1995
2000
2003
Source: BP

Fig. 5 Logistic Decline Plot - USA

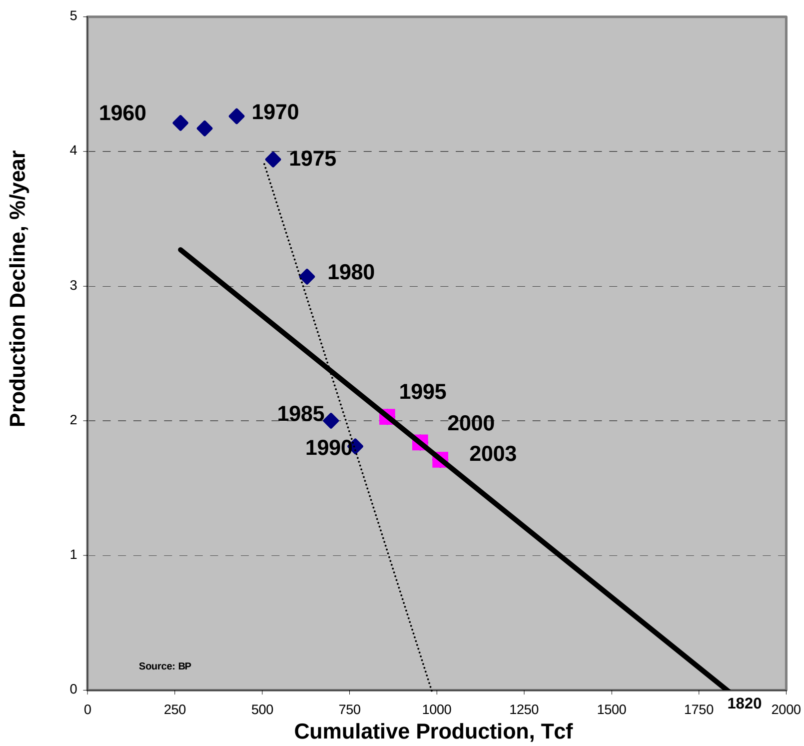
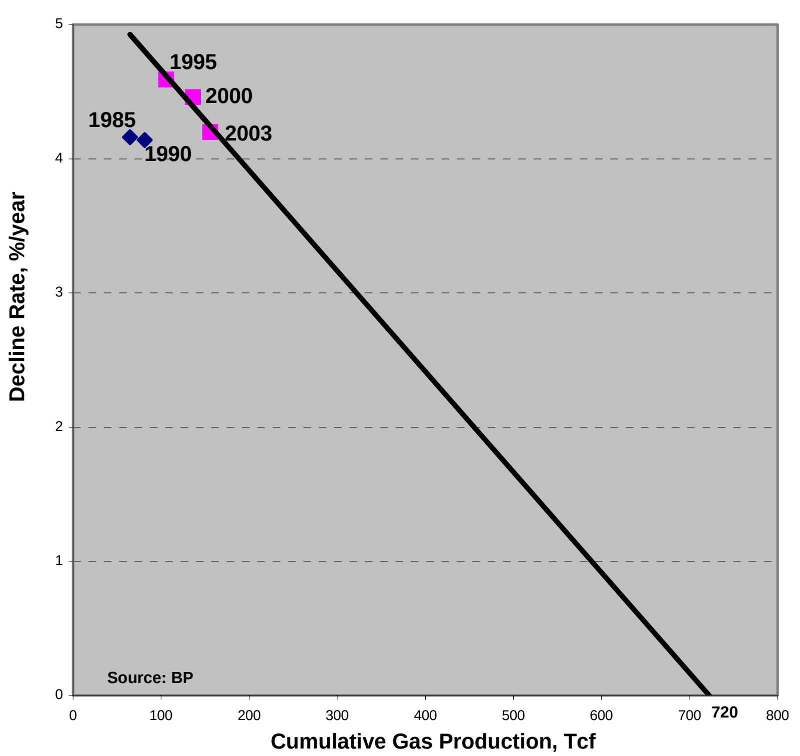


Fig. 6 Production Decline Plot - Canada



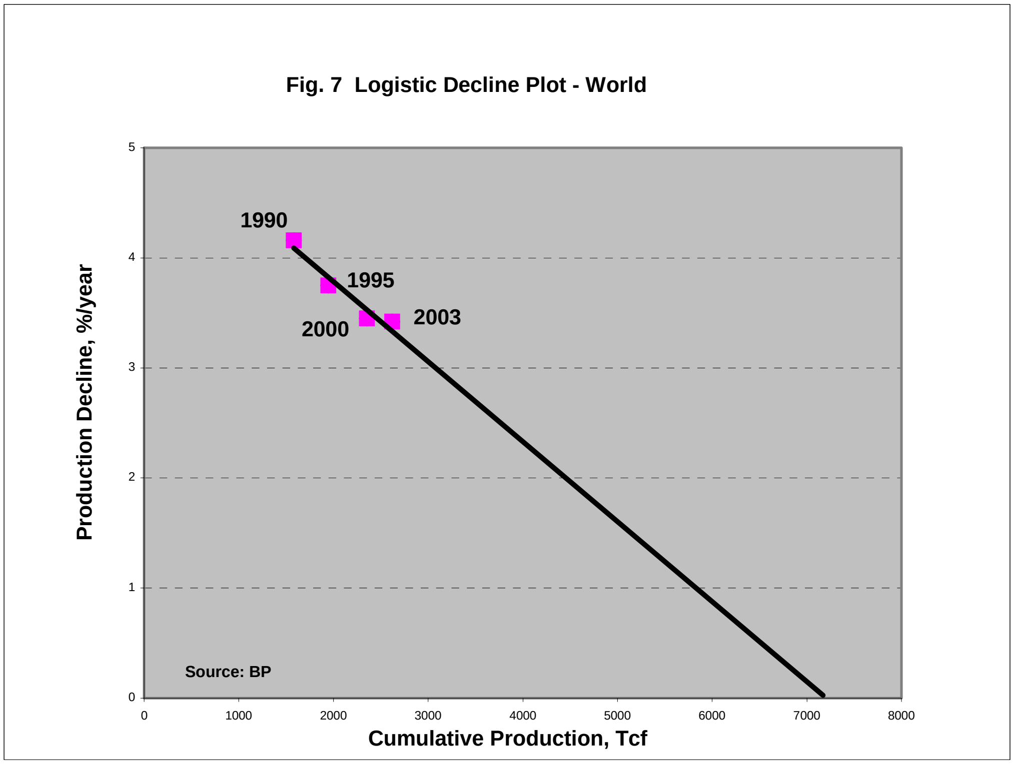


Fig. 7 Logistic Decline Plot - World
Production Decline, %/year
Cumulative Production, Tcf
1990
1995
2000
2003
Source: BP
0
1
2
3
4
5
0
1000
2000
3000
4000
5000
6000
7000
8000

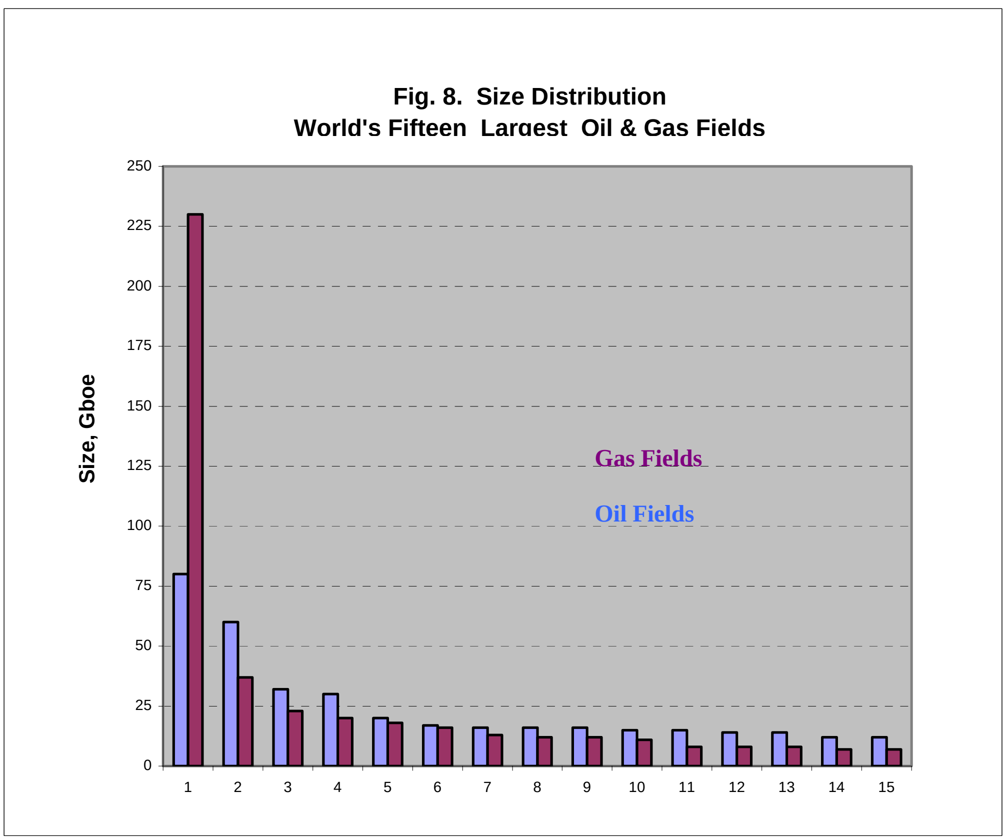


Fig. 8. Size Distribution
World's Fifteen Largest Oil & Gas Fields
Size, Gboe
Gas Fields
Oil Fields
0
25
50
75
100
125
150
175
200
225
250
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15