# Global offshore oil: geological setting of producing provinces, E&P trends, URR, and medium term supply outlook

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# Executive Summary

Offshore oil production has been expanding since first oil was produced in 1940s and it reached 25 mb/d in 2005, whilst technological developments have permitted the industry to explore to water depths of more than 2000 meters. In 2005 the Persian Gulf/Middle East topped the list of offshore producers, followed by the North Sea, West Africa, the Gulf of Mexico (US and Mexico), Asia/Australasia, Brazil, China, Caspian and Russia/Artic. The world largest offshore oil producing regions have a long history of exploration both onshore and offshore and significant discovered resources. In all regions offshore production has been rising steadily, some of the smallest producing regions are just beginning to develop their vast resources, whilst others with known reserves and large potential have not produced oil yet. The only region that has been on permanent decline is the North Sea (since 2000).

Globally, a total of 500 Bb of oil have been discovered in the offshore, of which 200 Bb have been produced. Sixty seven giant offshore fields represent 41% of the total oil discovered and these are located in several regions in few geological settings. Over the decades, E&P trends have remained highly encouraging, particularly the fact that yearly discoveries (~8 Bb per year) have remained the same for four decades, whilst average field sizes have remained the same for three decades. Estimates for global offshore oil reserves are only available from IHS Energy, but an alternative approach developed in this report based on exploration by analogy suggests that there could easily be 30% more oil than what is currently estimated. In addition to this, the USGS has identified a large undiscovered oil potential of 300 Bb (47% of world total). Several offshore provinces remain under explored, whilst other have not been explored at all. Some of these are in China, Brazil, deep Mexico, Russia/Artic, Red Sea, North Atlantic, Pacific and North Africa. Ultimate recoverable reserves (URR) are estimated to be least 1000 Bb.

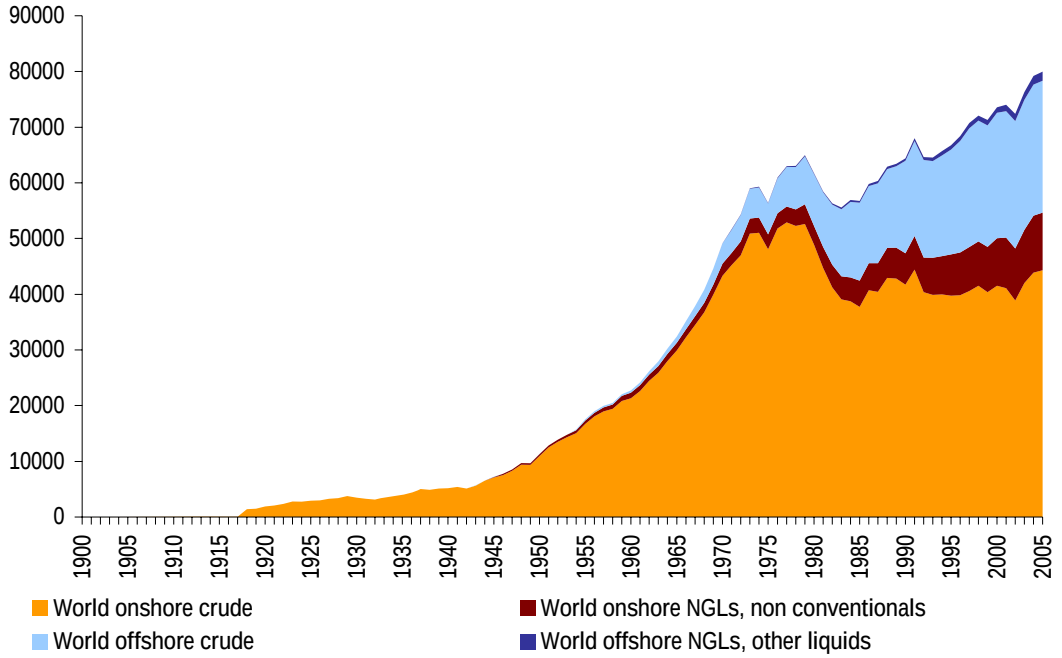
In terms of future production, giant fields played a role in the past, but many have not even been developed yet whilst some are undergoing redevelopment now. In the shallow offshore, nearly 200 are being developed and 1000 fields are in production. New discoveries in deepwater have made a significant contribution since the 1980's, but their production impact is expected to be strongest in the next few years as over 60 projects come on-stream, whilst new fields in the Russia/Caspian/Artic are just ramping up. Looking ahead, there is no doubt that global offshore oil production will grow in the medium term and beyond. Another 7 mb/d could be added in the next 6 years and 10 mb/d in the next 15 years. The global offshore represents the best prospect for the industry.

# Introduction

The oil industry has expanded consistently over the last decades from land operations to inland waterways and then to offshore. Offshore barges for exploration began to be used in 1950, deepwater drill ships in 1956, and semi submersible rigs in 1964. In the 1980s, deepwater exploration meant water depths of 800 feet. Today, depths below 1,500 feet are considered shallow, between 1,500 and 7,000 feet is considered deepwater, and over 7,000 feet ultra deepwater.

Offshore crude oil production started in the 1940s and has grown from a modest 1 million barrels a day (mb/d) in the 1960s to nearly 25 mb/d in 2005 representing one third of world crude oil production. Conversely, onshore crude production needed six decades to reach 25 mb/d in 1963. However, unlike onshore oil production, offshore production has never experienced sharp downward fluctuations and has grown consistently over the years. In fact, it has been the main source of growth for world oil production as the onshore has essentially remained at plateau for more than two decades. In 2005 the Persian Gulf/Middle East topped the list of offshore producers, followed by the North Sea, West Africa, the Gulf of Mexico (US and Mexico), Asia/Australasia, Brazil, China, Caspian and Russia/Artic. Of the total world offshore crude, shallow water accounted for 20.3 mb/d and deepwater 3.5 mb/d. Other liquids such as natural gas liquids (NGls) totaled 1.6 mb/d, mainly from the shallow offshore.

**Historical global oil production split by offshore and onshore (kb/d)**



**Largest offshore oil producing regions in 2005**

| | Production Start-up | Daily Production (mb/d) | Cumulative Production (Bb) |
|---|---|---|---|
| Crude oil | | | |
| Persian Gulf/ME | 1957 | 5.3 | 51 |
| North Sea | 1975 | 4.7 | 45 |
| West Africa | 1969 | 3.5 | 25 |
| Mexico GoM | 1960 | 2.6 | 20 |
| Asia/Australasia | 1960 | 2.1 | 21 |
| U.S. GoM | 1947 | 1.6 | 24 |
| Brazil | 1973 | 1.5 | 6 |
| China | 1980 | 0.6 | 2 |
| Caspian | 1950 | 0.4 | 1 |
| Russia/Artic | 1999 | 0.05 | 0 |
| Others | | 0.8 | 2 |
| Total NGls | | 1.6 | 7 |
| World Offshore | | 25 | 204 |

Persian Gulf/ME: Egypt, Iran, Iraq, Neutral Zone, Kuwait, Qatar, Saudi, UAE
North Sea: Denmark, Norway, UK
West Africa: Angola, Cameroon, Congo, Equatorial Guinea, Gabon, Ivory Coast, Nigeria
Asia/Australasia: Australia, Brunei, Indonesia, Myanmar, Malaysia, New Zeland, Thailand, Vietnam
Caspian: Azerbaijjan, Kazhakastan, and bordering countries
Others: mainly Argentina, Canada, Germany, India, Nertherlands, Trinidad, Tunisia, Lybia
NGLs: mainly Australia, Egypt, EQ, Iran, Nigeria, Norway, Trinidad, UAE, UK, US
Source: IHSE, OPEC

Up through 2005, a total of 503 Bb (455 of crude oil and 48 of NGLs) have been discovered offshore of which 204 Bb have been produced leaving the estimated remaining reserves at nearly 300 Bb. The most important offshore oil discoveries have been made in the largest producing regions. Offshore China, Caspian and Russia/Artic exploration has been relatively limited, whilst in other producing areas exploration has only yielded relatively limited success. In terms of undiscovered or yet-to-find (YTF) reserves, the only institution to have published undiscovered global estimates for oil that segregates offshore and onshore is the USGS. The USGS world petroleum assessment (WPA 2000) puts the estimate for undiscovered crude oil offshore at 306 Bb and NGLs at 95 Bb, representing 47% of total undiscovered oil in the world.

Looking ahead, global offshore production with no doubt will play a leading role in global oil supplies. E&P activities in several shallow water provinces including offshore China and Caspian are just beginning to result in production increases. Deepwater oil production is expected to double over the next five years driven by projects in the US GoM, Brazil, West Africa, Australia, and Malaysia. Ultra deepwater production remains constrained by a number of complex factors, but the industry is working hard to migrate into this frontier as soon as possible. Offshore production in Russia/Artic is taking off with new fields in Sakhalin, Pechora and Barents Sea. In fact, E&P activities in these and other areas are at record levels whilst efforts to expand and understand better frontier provinces continue to increase. In contrast, supply growth from onshore is expected to come primarily from the Canadian tar sands, Orinoco, eastern Russia, China, Middle East and North Africa; all other onshore basins around the world appear to be very mature.

From a resource and production perspective the importance of the offshore is paramount. However, most research fails to discern or disaggregate between offshore and onshore. More over, it also fails to discern trends in mature and emerging shallow offshore, deepwater, non-OPEC onshore (excluding the FSU), Western and Eastern Russia, onshore Middle East, etc. Although, recently significant efforts are being put to understand better non-conventional sources. But still, many prefer to look at the world as a single system split by OPEC and non OPEC, leading to fuzzy conclusions. For instance, there is no doubt that the growing significance of global offshore activities merits a reassessment of the classical Hubbert model predictions. This model is solid and handles adequately severe events such as sharp production fluctuations, new large discoveries, EOR, etc. In fact, the world crude oil (onshore and offshore) decline linear trend line has shifted its course after 1995 following the impact of offshore production. Eventually a new trend line will develop once the offshore effect reaches steady state, some time in the distant future. However the result of pooling production from different types of provinces - mature onshore with a strong emerging offshore – with distinct histories introduces interpretative distortions which inevitably lead to off beam estimations of world oil resources, depletion, and maximum oil supply estimates.

The objective of this report is to:

1) Provide an overview of the geological setting of the main offshore oil producing regions by studying the setting of giant offshore oil fields

2) Highlight key E&P trends in the offshore

3) Show estimates and to estimate the potential of the world's offshore oil provinces using an analogy of the size distributions of the giant onshore and offshore fields discovered to date

4) Provide a medium term production forecast for global offshore.

# Geological setting of offshore oil producing regions

It is no coincidence that the world's largest offshore oil producing regions are also blessed with rich onshore petroleum systems. The Persian Gulf/Middle East is the world's largest oil producer and has the largest concentration of reserves. West Africa primarily produces hydrocarbons from two large offshore provinces but the region also has significant onshore reserves and production. The Gulf of Mexico (US and Mexico) is a world class province surrounded by two countries with significant onshore petroleum systems. Asia/Australasia is a large region comprising several countries, but the petroleum resources are found in tectonically linked basins that originated in the same process (i.e. Sunda). Oil production in this complex region is primarily from offshore basins but it also has onshore oil provinces. The North Sea and Brazil are in a class of their own as most oil reserves are in offshore settings, but Brazil also has onshore systems. The regions of China, Caspian, and Russia/Artic share the following characteristics: a) are well endowed with onshore oil reserves and production, b) offshore oil production is presently either low or growing rapidly, c) limited number of offshore oil discoveries and exploration activity to date, and d) large petroleum systems.

**Largest oil producing regions in 2005**

| | Daily Offshore Production (mb/d) | Daily Onshore Production (mb/d) | Cum. Oil Discovered Offshore (Bb) | Cum. Oil Discovered Onshore (Bb) |
|---|---|---|---|---|
| Crude oil | | | | |
| Persian Gulf/ME | 5.3 | 13.6 | 158 | 784 |
| North Sea | 4.7 | na | 61 | na |
| West Africa | 3.5 | 1.5 | 65 | 36 |
| Mexico | 2.6 | 0.7 | 32 | 25 |
| Asia/Australasia | 2.1 | 0.7 | 38 | 85 |
| US | 1.6 | 3.6 | 30 | 235 |
| Brazil | 1.5 | 0.2 | 28 | 4.2 |
| China | 0.6 | 3.0 | 6 | 52 |
| Caspian | 0.4 | 1.4 | 25 | 42 |
| Russia/Artic | 0.05 | 9.2 | 4 | 257 |
| Others | 0.8 | 14.0 | 9 | 318 |
| Total Other Liquids | 1.6 | 13 | 48 | Inc. in Crude |
| Total | 25 | 59.3 | 503 | 1838 |

For Regional codes see Table 1

Others: as table 1 + rest of the world

Other liquids: include NGLs, non conventionals, processing gains; does not include biofuels

Source: IHSE, OPEC

Since the 1970s the setting of the giant fields has been studied with the objective of understanding the geographical and geological settings of the world's petroleum systems. In one of the most comprehensive studies of this type, Mann, P., et al (2003), reviewed the setting of 877 giant (> 0.5 bn) oil and gas fields for the world representing two-thirds of the petroleum resources and found that these were not only located in few geographical regions, but also concentrated in few tectonic settings. The three types of settings are: passive margins (304 giants), continental rifts (271 giants) and collisional margins between two continents (173 giants).

That study and the USGS WPA (2000) also concluded the following regarding the known petroleum systems of the world: a) the typical depositional environment of reservoir rocks is non-marine to marine (43% of the known reserves) and shallow marine (36%); b) less than 11% of the reservoir rocks have been deposited in deep marine environments (turbidites); c) the age of the reservoir rocks is commonly Mesozoic (65%) and Cenozoic (20%); less than 13% of the known reservoirs are Paleozoic or older; d) regarding trapping mechanisms, the most common traps are structural (71%); only 5% of the resources have been found in pure stratigraphic traps.

For the world giant offshore fields only, no similar assessment has been made. This study provides an assessment based on the classification proposed by Mann, P., et al (2003) and USGS WPA (2000) using an updated database of 67 giant offshore oil fields representing 211 Bb (41%) of the total oil discovered offshore (Appendix 1). A synthesis for each region is provided in the table below. No doubt that many observations can be made, but the intension is to show the similarities and differences that the offshore petroleum systems share between them and with the broader petroleum systems of the world. Some discernable observations about offshore giants are: the tectonic setting is commonly passive margin (45 giants); the depositional environment of the reservoir rock is dominated by non marine to marine sands (43 giants) and the age of is Cenozoic (33 giants) and Mesozoic (29 giants). Accumulations in deepwater giants are exclusively associated with turbidite reservoirs (26 giants) of Cenozoic age. The typical trap is structural (34 giants) and a combination of structural and stratigraphic (31 giants).

**Geological setting of largest offshore oil producing regions**

| | No. Offshore Giants | URR Giants (Bb) | % of Total Offshore Oil Discovered | Typical Tectonic Setting | Reservoir Rock Depositional Enviroment | Typical Reservoir Rock Age | Typical Trap |
|---|---|---|---|---|---|---|---|
| Persian Gulf | 14 | 109 | 69% | Passive margin | Marine | Mesozoic | Structural |
| North Sea | 12 | 26 | 42% | Continental rifts | Non marine | Mesozoic | Structural |
| West Africa | 15 | 11 | 16% | Passive margin | Turbidites | Cenozoic | Combination |
| Mexico GoM | 2 | 24 | 75% | Passive margin | Marine | Mesozoic | Combination |
| US GoM | 5 | 3 | 11% | Passive margin | Non marine/ turbidites | Cenozoic | Combination |
| Asia/Australasia | 3 | 3 | 8% | Strike slip/passive margin | Non marine to marine | Late Mesozoic / Cenozoic | Structural |
| Brazil | 7 | 9 | 33% | Passive margin | Turbidites | Cenozoic | Combination |
| China | 2 | 3 | 45% | Passive margin | Non marine to marine | Cenozoic | Combination |
| Caspian | 2 | 17 | 68% | Collisional margin | Non marine | Cenozoic | Structural |
| Russia/Artic | 1 | 1 | 20% | Continental rifts | Marine | Mesozoic and older | Structural |
| Sakhalin | 2 | 3 | 94% | Strike slip | Marine | Cenozoic | Structural |

For data on giant fields see Apendix 2

Combination: structural, growth faults, stratigraphic, salt domes, ect

North Sea mainly central graben

Mexico GoM main area around Cantarell complex

Asia/Australasia mainly Australia Bass Strait, Sunda

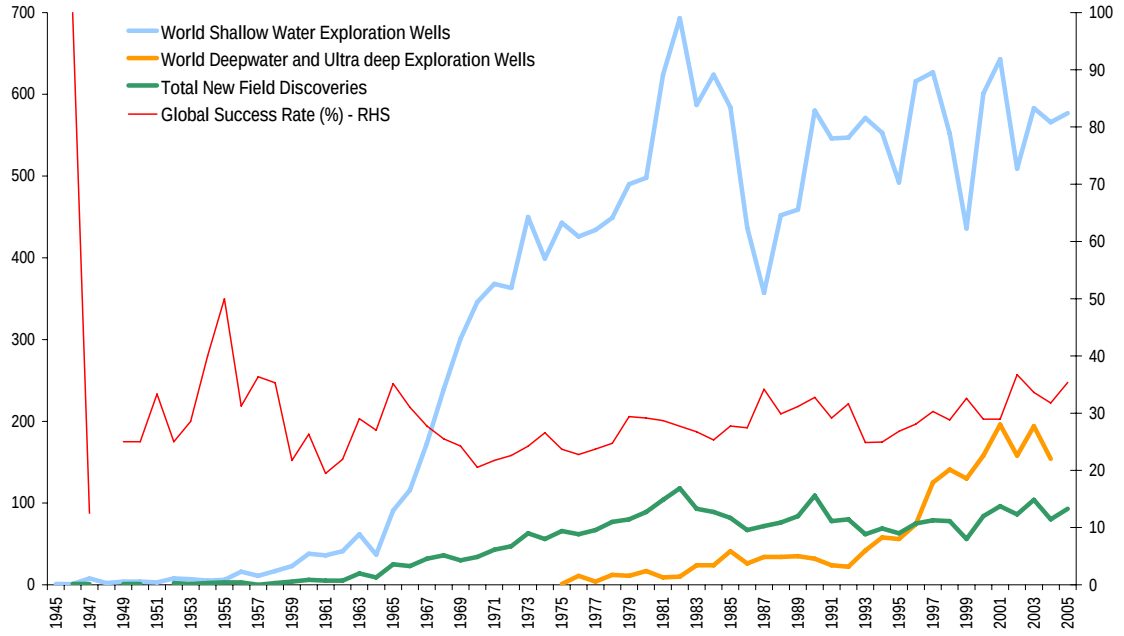
Russia/Artic mainly Barents Sea

Source: IHSE, OPEC, USGS, Mann, P., et al (2003)

# Global offshore E&P trends (oil)

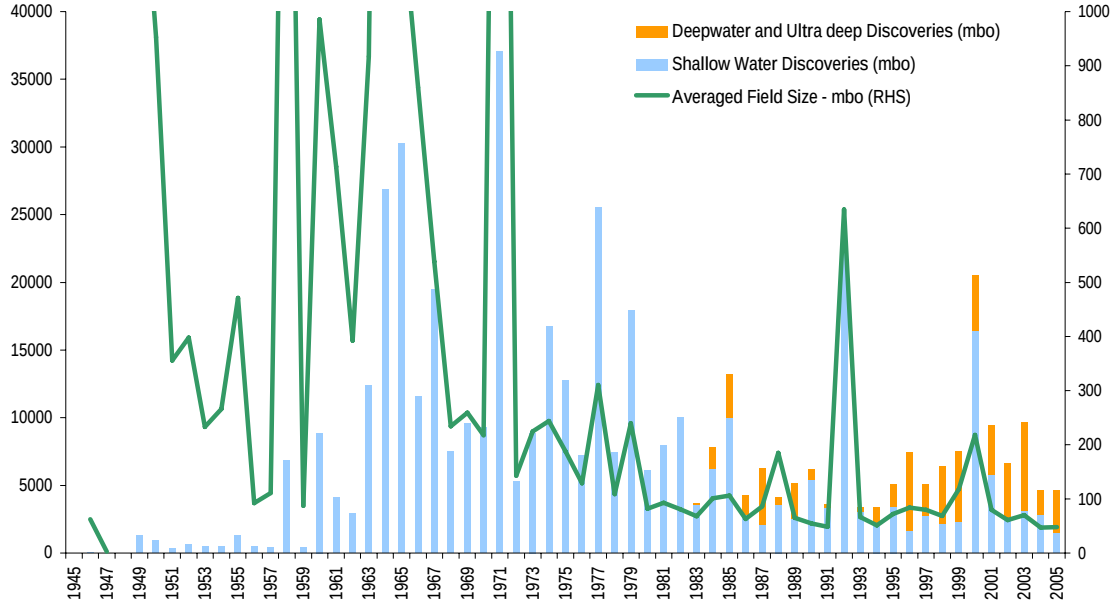
Since offshore exploration began in the 1940's some 17,700 exploration wells have been drilled in shallow water resulting in 2,500 new oil discoveries. In deepwater, exploration began in the late 1970s, and since then nearly 2000 exploration wells have been drilled resulting in 400 new oil discoveries. In the last 25 years, nearly 500 exploration wells per year have been drilled in the shallow water; the level has remained stable within a range of 500 and 650 per year except when oil prices dipped in the mid 1980s and 1998-99. In contrast the number of deepwater wells has been increasing steadily and since 1997 it has exceeded over 100 wells per year. In this long period, the average number of new offshore oil discoveries has remained close to 80 per year; the highest number was recorded in 1982 at 118. Two other record years include 1990 with 109 new oil discoveries and 2003 with 104 new offshore oil discoveries.

**Offshore exploration wells drilled and new oil discoveries**




The above efforts have resulted in the discovery of 500 Bb of oil in three exploration phases. The first identifiable phase is from the 1940s to 1972. This phase is characterized by the first offshore discovery made in the US GoM in 1947, the discovery of the super giants in the Persian Gulf, the first discoveries in West Africa and in the later part of the period, the first giant discoveries of the North Sea. Elsewhere, two giant discoveries were made in Australia and one in China. During this initial phase, the cumulative oil discovered was 198 Bb, the yearly average discoveries totaled 8.2 Bb and the average discovery size was 720 mbo.

**Offshore yearly oil discoveries and average field size**




The second phase is from 1973 to 1990. This phase is characterized by giant discoveries in the North Sea, Mexico, Caspian, Russia/Artic and the first deepwater discoveries in the US GoM (1983) and Brazil (1984). There are also two notable giant discoveries outside the previous regions: Bombay High in India and Hibernia field in Canada. Elsewhere, discoveries continued to be made in West Africa, Asia/Australasia and shallow US GoM. During this phase the cumulative oil discovered was 171 Bb, the yearly average discoveries totaled 9.5 Bb and the average discovery size was 140 mbo.

The last phase began in 1991 and extends to today. This phase is characterized by giant deepwater discoveries in Brazil, West Africa, and US GoM. However, several giant discoveries were made in other regions including the North Sea, Caspian and China; smaller discoveries in Asia/Australasia, shallow water West Africa, and the Persian Gulf. During this recent period the cumulative oil discovered was 120 Bb, the yearly average discoveries totaled 8 Bb and the average discovery size was 120 mbo. Of the total oil discovered, deepwater and ultra deepwater fields accounted for 44 Bb (average 3 Bb per year).

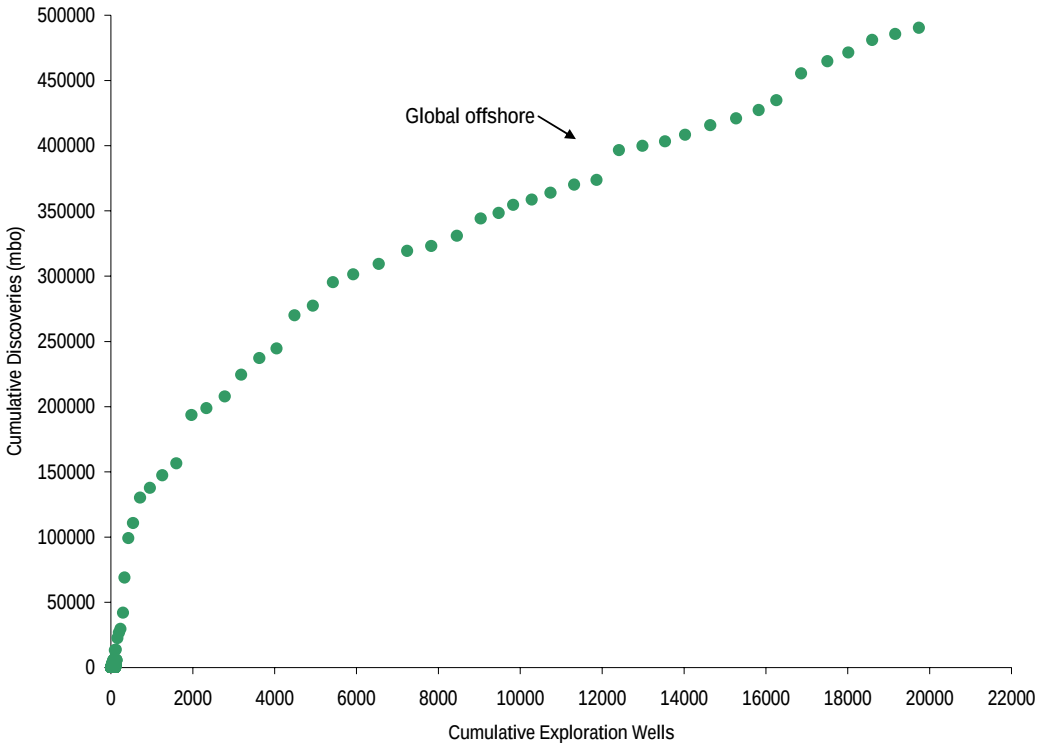
**Offshore exploration phases**

| | Phase 1 (until 1972) | Phase 2 (73-90) | Phase 3 (since 1991) |
|---|---|---|---|
| No. Expl. Wells | 2333 | 8986 | 8419 |
| No. of New Oil Disc. | 330 | 1454 | 1183 |
| Vol. Oil Discovered (Bb) | 198 | 171 | 121 |
| Av. Yearly Vol. Oil Disc. (Bb) | 8.3 | 9.5 | 8 |
| Av. Disc. Size (mbo) | 777 | 135 | 116 |

Regionally, the most explored areas (measured in terms of cumulative exploration wells drilled and wells per squarer kilometer of sedimentary basin) have been the US GoM, North Sea, Persian Gulf, Australasia, and West Africa whilst the least are Mexico, China, Caspian, and Russia/Artic. There are other offshore regions that have seen very limited exploration and some successes such as North Africa and eastern Canada, whilst there are others that literally have not seen any exploration such as the Red Sea, Pacific, and North Atlantic.

China is an interesting example of a country with several offshore provinces that have seen little exploration for their size. Over 700 offshore exploration wells have been drilled, but the level of exploration activity that has taken place in the South China Sea is six times less than the level of activity in the US GoM, despite the fact that the prospective area is eight times larger. Geological studies suggest that the country's offshore petroleum resources are located primarily in the Bohai Sea and South China Sea (Western and Eastern parts) at water depths of less than 1200 feet. Only two giant oil fields have been discovered (Shengli in 1963 which is onshore/offshore and Peng Lai in 1999), but there have been a number of medium and small size discoveries around. If we compare China's offshore exploration history with Russia/Artic, it can be noted that many more wells have been drilled in China, but more giant discoveries have been made in Russia/Artic, whilst the latter is comprised of several larger provinces. The figure below shows the cumulative offshore exploration wells drilled (x axis) and oil discoveries (y axis) for the world. As can be seen, it does not show the signs of a mature exploration play.

**Global offshore – cumulative exploration wells and oil reserves**

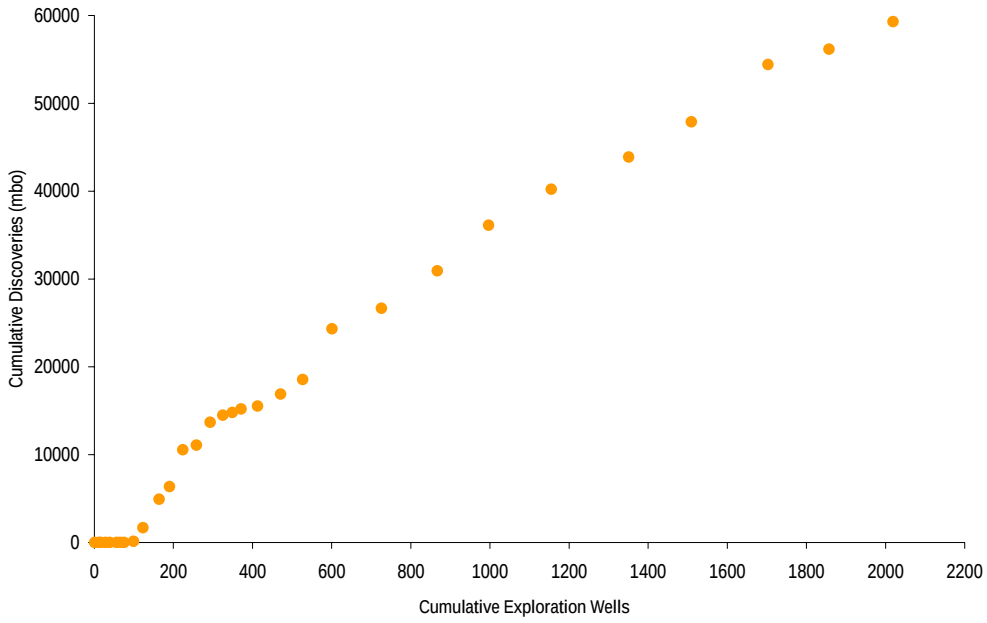


Looking at the deepwater and ultra deep, over 80 basin tests have been made globally, but the Big four provinces (i.e. US GoM, Brazil, Angola and Nigeria) account for nearly all of the exploration wells drilled and oil reserves discovered. The first oil discovery in deepwater was made in 1983 in the US GoM, the second in Brazil (Campos basin) in 1984, whilst in West Africa, serious exploration only began in the early 1990's and the first oil discovery was made in 1995 in Equatorial Guinea.

Despite the challenges of drilling in deepwater and ultra deep, the average commercial success rate has been better than on shallow offshore (except in the US GoM and Brazil which have seen lower success rates), similar to places where geological knowledge is higher and rewards are lower. The success rate in deepwater peaked in the late 1999s and since then it has remained below the average. The 5-year period to the end of 2005 key exploration parameters - success rate, discovery size, and reserves per well - showed a deteriorating trend in the Big 4, except in Brazil which has seen some significant successes outside the Campos basin. But these could be due to a number of non-geological factors such as a large number of ongoing deepwater development projects, new exploration strategies, etc. In addition, during period of high prices the industry tends to focus more on appraisal and development activities rather than on exploration.

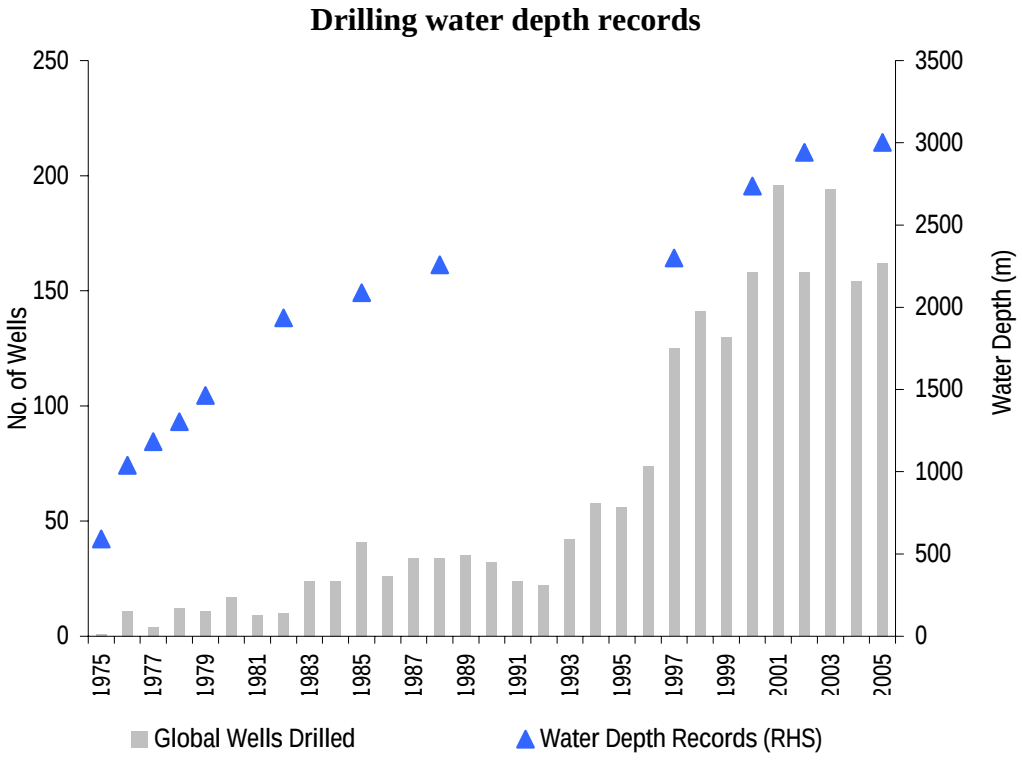
In terms of maturity, it may still be too early to draw strong conclusions but the geological evidence to date suggests that the deepwater is a play with limited prospectivity within the context of the global offshore, primarily due to the fact that the best quality reservoirs are exclusively associated with turbidities. The conclusions of several studies is that the potential of global deepwater provinces may not exceed by much what has already been found whilst others suggest that the remaining potential is large (>100 Bb). Whichever the case might be there is still relatively plenty of oil to be found even if the low range is considered, and on this basis the play may still be considered immature. The figure below shows the cumulative deepwater exploration wells drilled (x axis) and oil discoveries (y axis).

**Global deepwater– cumulative exploration wells and oil reserves**



It should be noted that deepwater Mexico is considered the single largest prospective province remaining in the world. It has seen no exploration whatsoever with only 3 wells drilled in established areas. Other countries with deepwater provinces outside the Big 4 have seen some successes (i.e. Australia, Malaysia, Mauritania, Ivory Coast, China, etc) but the global impact has yet to be seen.

The ultra deepwater play has been much discussed following the recent 'Jack' well in the US GoM. No attempt is made in this paper to address its potential worldwide, as there is simply not enough information and history to do so. So far 7.5 Bb have been discovered (2 Bb in US GoM and 5.5 Bb mainly in Angola and Brazil) resulting from an extension of deepwater plays. However two points are worth making. First, the global distribution of ultra deepwater oil prospectivity is very unique to geological settings only so far known in limited areas of the US GoM, Brazil, West Africa and North Africa. Second, having the technology to go to ultra deep does not mean you can go to any water depth to explore. In most parts of the world at 12,000 feet of water depth is touching the edge of the continental shelf and there will not be any more sedimentary rocks to look for. Therefore, regardless of its potential it is likely to be smaller than deepwater plays which appear to benefit from a wider geographical distribution and less restrictive geological settings.




Overall, the industry has been able to make each year as much discoveries in the offshore as in the early exploration phase. The average field size has remained broadly unchanged since the 1970s; this is in great part due to technology which has allowed for the visualization and discovery of different types of plays. The previous facts combined with conclusions of different geological studies, including this one, clearly suggest that the global offshore has remained highly attractive for exploration and more importantly, there is now doubt that it has significant upside.

# Estimating the global offshore oil reserve base

## *What we know today…*

The reserve base is the sum of cumulative production and remaining reserves; these two combined with an estimate for undiscovered potential or YTF give the ultimate recoverable reserve (URR). Estimates for the first two can be obtained from IHS Energy. IHS uses a consistent bottom up approach to compile technically recoverable estimates (2P) for individual discoveries, but these numbers are also subject to uncertainty. Estimates for undiscovered oil (crude and NGLs) in offshore provinces are only available from the USGS WPA (2000). The USGS methodology is based on assessments of a total petroleum system (TPS) of known and frontier provinces, which is a less restrictive measure than field by field estimates. The table below shows the global offshore reserve base and URR at the end of 2005 based on a combination of these two sources adjusted for discoveries and type of liquid. But can we get a second opinion?

**Offshore oil resource estimates at 2005, Bb**

| | Cumulative Production | Remaining Reserves | Total Discovered | % in Giants | Adjusted Undiscovered USGS | Composite URR |
|---|---|---|---|---|---|---|
| Crude | | | | | | |
| Shallow offshore | 190 | 205 | 395 | 41% | na | na |
| Deepwater | 7 | 45 | 52 | 40% | na | na |
| Ultra deepwater | na | 7.5 | 7.5 | | na | na |
| Total crude | 197 | 258 | 455 | 40% | 251 | 706 |
| Total NGls | 7 | 41 | 48 | 46% | 95 | 143 |
| Total Liquids | 204 | 299 | 503 | | 346 | 849 |

USGS Undiscovered has been adjusted to reflect discoveries in the 2000-05 period

Composite URR = total discovered + adjusted undiscovered URR

Source: IHSE, USGS, OPEC

## *Alternative 1: the decline curve*

The world had consumed/produced one trillion barrels of crude oil over the last 150 years**.** Roughly 800 billion barrels came from onshore oil fields and 200 billion from offshore, a review of the cumulative production growth patterns of each genre are remarkably similar except for the phase lag in development. Offshore production started 40 years later. Characteristically the cumulative production curve begins growing exponentially up through the half-life point of the reserves (Q = K/2); thereafter it reverts to an exponential decline pattern, finally approaching asymptotically the value K - the ultimate reserves of the field. Overall it resembles a somewhat S-shaped curve which is best represented by the logistic equation:

$$\boxed{Q = \frac{K}{\left(1 + ae^{r_0 t}\right)}} \qquad (1)$$

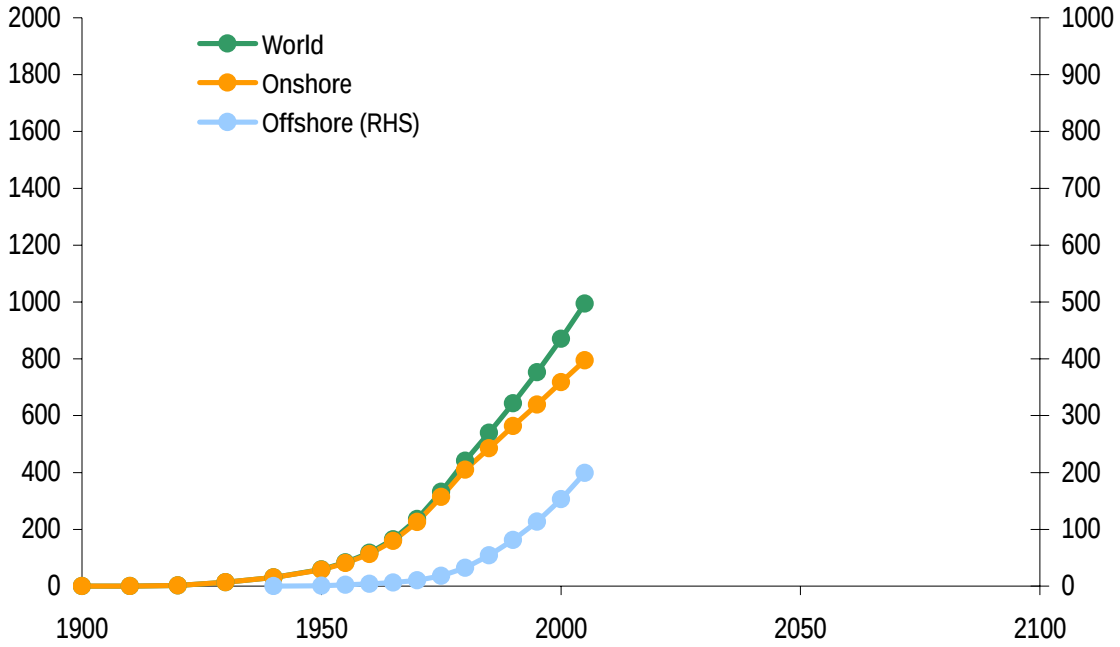
Q is the cumulative production, K the ultimate reserves, $r_o$ the initial growth rate constant, and the constant *a* which has no physical significance. Unfortunately it is not possible to curve fit equation (1) and obtain a unique set of values for the three constants. However, the derivative of equation (1), namely:

$$(dQ/dt)/Q = r_o (1 - Q/K) \qquad (2)$$

defines a straight-line relationship between production decline, (dQ/dt)/Q, and Q. This constraint allows the establishment of definitive values for K and $r_o$.

Generally the straight line trend would kick off after a substantial volume of oil has been produced – at least 25% of the ultimate reserves. This has been the observed decline behavior of oil production in several regions. *However, global offshore production is still in its early exponential growth stage and this precludes the use of production decline analysis to establish its K-value.*

**World cumulative crude oil production growth, Bb**




Laherrere developed an elegant parabolic fractal distributions approach to estimate the K-value for a region with only few estimates about the size of the largest fields, a condition very akin to the offshore environment which is in a nepionic stage of development. The methodology however assumes that the discovery of large fields has peaked and that no additional fields will be discovered which would be a bold assumption to make given what we have already discussed. The parabolic fractal method moreover requires the determination of three free constants, none of which has any physical significance; a physical tie would normally allow obtaining independent anchor values.

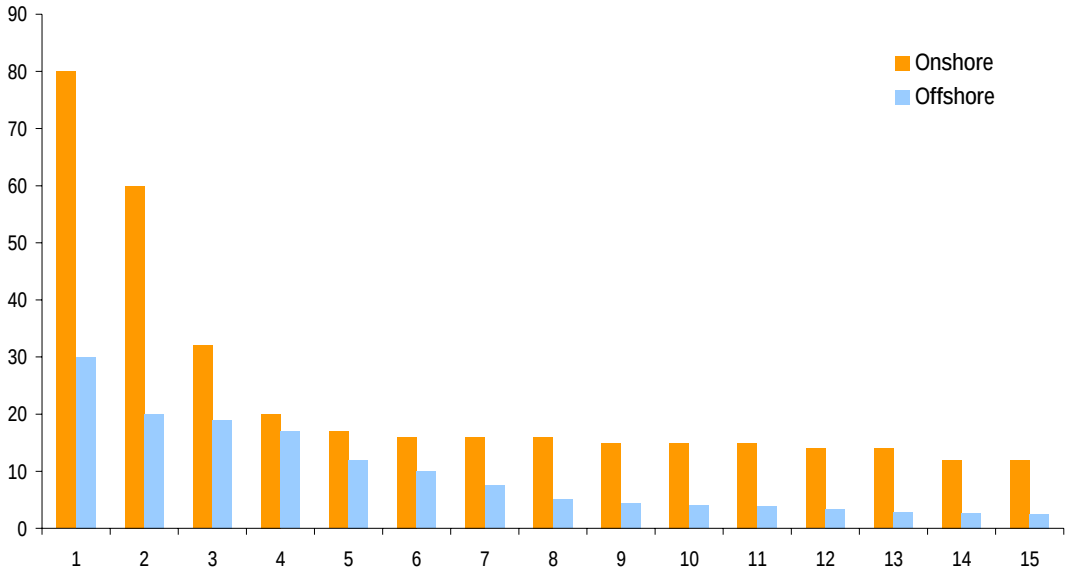
## *Alternative 2: exploration by analogy*

In order to establish a second estimate for the global offshore crude oil reserve base a heuristic approach is proposed, using an assumed analogy of the size distributions of the giant oil fields discovered to date in both the onshore and offshore environments. The basis for the analogy stems from the premise and observation that oil fields are often found together in the most important hydrocarbon provinces or petroleum systems. Therefore, the results of this methodology tend to be less restrictive compared to field by field estimates.

This methodology requires knowledge of the global onshore reserve base for comparative purposes. IHS Energy estimates that the world onshore reserve base at the end of 2005 (cumulative production + technically remaining) is 1838 Bb. A second estimate was obtained in this study by decline curve analysis, the results of which indicate that the global onshore reserve base is approximately 1777 Bb (Appendix 2). It should be made clear that both estimates are solely for the known reserve base and exclude undiscovered oil potential (YTF) and reserve growth.

The figure below compares the size distributions of the fifteen largest onshore and offshore oil fields discovered to date. The largest onshore giants range in size from 80 Bb to 12 Bb of ultimate reserves. In comparison, the offshore giants range in size from 30 Bb to 2.5 Bb. In general, the mean size of the onshore giants is three times that of the offshore giants, 24 Bb versus 8 Bb. Consequently, the expected value of the offshore crude reserves base would be around 600 Bb corresponding to one-third of the known onshore reserve base.

**Size distribution of largest 15 onshore and offshore oil fields, Bb**




Onshore fields: 1. Ghawar, 2. Burgan, 3. Bolivar, 4. Rumalia, 5. Ahwaz, 6. Kirkuk, 7. Marun, 8. Daqing, 9. Romashkino, 10. Gachsaran, 11. Tengiz, 12. Aghajari, 13. Samotlor, 14. Abquaiq, 15. Berri

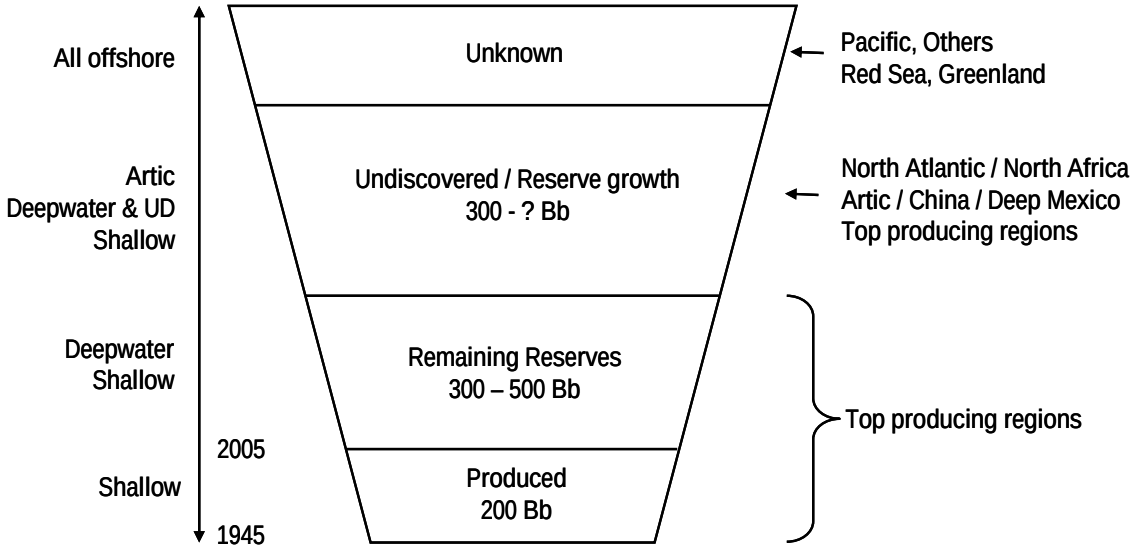
Offshore fields see Table 5

Using the tail-end values of the offshore size distribution it is also possible to obtain a range of values. The high end corresponds to the oil fields of the Persian Gulf. They are the largest offshore oil fields in the world, varying in size from 30 Bb to 4 Bb. Their onshore counterparts are also the biggest in the world. The size ratio of onshore to offshore fields is estimated at 2.5. At the low tail-end of the distribution are the giant oil fields discovered in the Gulf of Mexico. With the sole exception of the fields in Mexico, the largest fields discovered in the GoM to date tend to be relatively small, less than 1 Bb and averaging 0.5 Bb and less. The onshore fields contiguous to the GoM also are relatively small. The ten largest onshore oil fields in the lower US states have sizes varying from 6 Bb to 1.4 Bb with an average of 2.5 Bb. The size ratio for the onshore GoM is 5 which is twice that for the Persian Gulf. These size ratios would indicate that the offshore reserve base can range from 720 Bb to 360 Bb.

Worth noting is that the heuristic methodology shows that the average estimate for the global offshore oil reserve would be closer to 600 Bb, which is nearly 30% more than the IHS estimate; considering the difference in the approach the proximity of the results is reassuring. In addition, the heuristic methodology may not apply to unexplored regions with known reserves and potential (i.e. China, Caspian, deep Mexico and Russia/Artic, etc). Therefore it can be concluded that additional offshore reserves must exist over and above this new estimate.

By combining the average result of the heuristic approach with the USGS WPA (2000) estimate for undiscovered oil, the URR for the global offshore could be closer to 1000 Bb, of which just 200 Bb have been produced.

**Global offshore oil reserve base and URR**

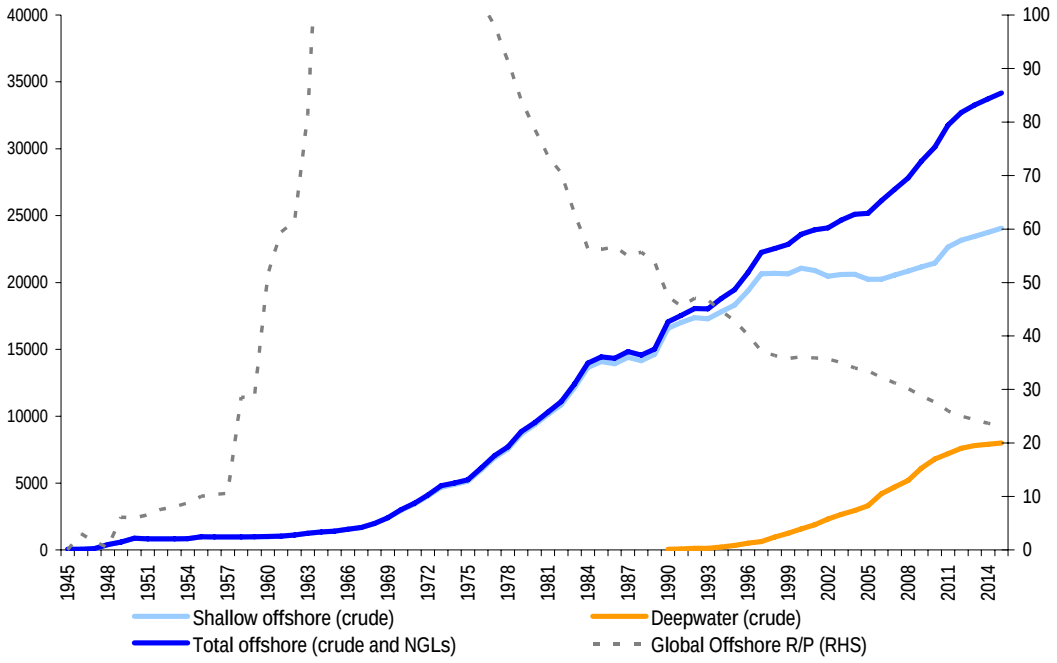


# World offshore oil production potential

Shallow offshore oil production in several under-explored hydrocarbon rich provinces including China and Caspian is just ramping up; it may be a slow ramp up but the fact is that it is increasing and there is medium term project visibility. The shallow offshore is expected to continue to grow at a slower pace to the end of this decade, until the pressure from declining North Sea oil is reduced. At least three super giant fields in the shallow offshore will contribute significant volumes in the medium term – ACG, Manifa, and Kashagan; however, over additional 200 fields will be developed. On the other hand, deepwater oil production will double over the next five years underpinned by more than 60 projects globally. It is very possible that with the rapid rate of increase, deepwater will reach its maximum level in the medium term due to the nature of turbidities reservoirs. However, this scenario remains uncertain due to the potential impact of technology and unexplored deepwater provinces, both of which could extend the growth and certainly the post peak production level. Ultra deepwater oil production will remain constrained but in five year there will be several producing fields in the US GoM, Angola and Brazil. Offshore production in Russia/Artic is also just taking off with new production from Sakhalin, Pechora and Barents Sea.

The figure below shows historical and modeled future world offshore oil production. Deepwater is included separately given the importance of this source. The near to medium term has been modeled with known projects and assumed decline rates. The model has also been calibrated so that projected R/P ratios remain stable.

**Global offshore production outlook, kb/d**



There is no doubt that global offshore oil production will continue to grow strongly in the medium term; in fact various tests shows that this could be the case until past 2020 (not show). Long term, once the R/P ratio reaches 10-15 and cumulative production exceeds 50% of the URR, it is expected that production will start to level off and then decline. The current global R/P is over 32, and by 2015 it will be 23. Using an URR of 1000 Bb, we have produced so far 20% and by 2015 we would have produced 35%. Given that there are uncertainties about the timing of new oil, impact of potentially large discoveries and deliverability issues, the long term is not modeled here, but there should be no doubt that offshore production will continue to grow. The potential contribution of the largest offshore producing regions over the next few decades is provided below along with the expected key drivers.

**Potential incremental offshore oil supply by region**

| | 2005 Offshore Production (mb/d) | 2005 R/P | Potential New Production (mb/d) | Potential to Add New Reserves | Main Drivers |
|---|---|---|---|---|---|
| Crude oil | | | | | |
| Persian Gulf | 5.3 | 55 | 3+ | High | Saudi, Iran, Qatar |
| North Sea | 4.7 | 9 | Loss of (3 to 2) | Low | |
| West Africa | 3.5 | 31 | 3 to 4 | High | Angola, Nigeria |
| Mexico GoM | 2.6 | 13 | 2+ | High | Deepwater, KMZ |
| Asia/Australasia | 2.1 | 21 | 1 | High | Deepwater |
| U.S. GoM | 1.6 | 10 | 1 to 2 | High | Deepwater, Ultradeep |
| Brazil | 1.5 | 40 | 2+ | High | Deepwater, Ultradeep |
| China | 0.6 | 20 | 1+ | High | Shallow, Deep |
| Caspian | 0.4 | 162 | 3+ | High | ACG, Kashagan, Iran, Shallow |
| Russia/Artic | 0.05 | 192 | 2+ | High | Pechora Sea, Barents, Shakalin |
| Others | 0.8 | 23 | 1 | Low | Canada |
| Total NGls | 1.6 | | 3+ | | Persian Gulf, Australia, North Sea |
| World Offshore | 25 | 32.0 | 17+ | High | |

For Regional codes see Table 1

New reserve potential includes discoveries, reserve growth

# Conclusions

The performance of the global offshore has been remarkable. Globally, a total of 500 Bb of oil have been discovered in the offshore, of which 200 Bb have been produced. The URR for the global offshore could be near 1000 Bb. Over the decades, E&P trends have remained highly encouraging, particularly the reality that both yearly discoveries (~8 Bb per year) and average field sizes have remained the same over the last three decades.

Giant offshore fields represent 41% of the total oil discovered and these are located in several regions albeit in few geological settings. A heuristic approach developed in this paper based on exploration by analogy suggests that there could easily be 30% more oil than what is currently estimated. Additionally there is a large undiscovered oil potential, in the range of 300+ Bb, as several regions remain under explored and others have not been explored at all. To note are offshore China, deep Mexico, Russia/Artic, Red Sea, North Atlantic, Pacific and North Africa. Offshore is the next frontier in global oil supply. It's amazing what $50 oil will do!

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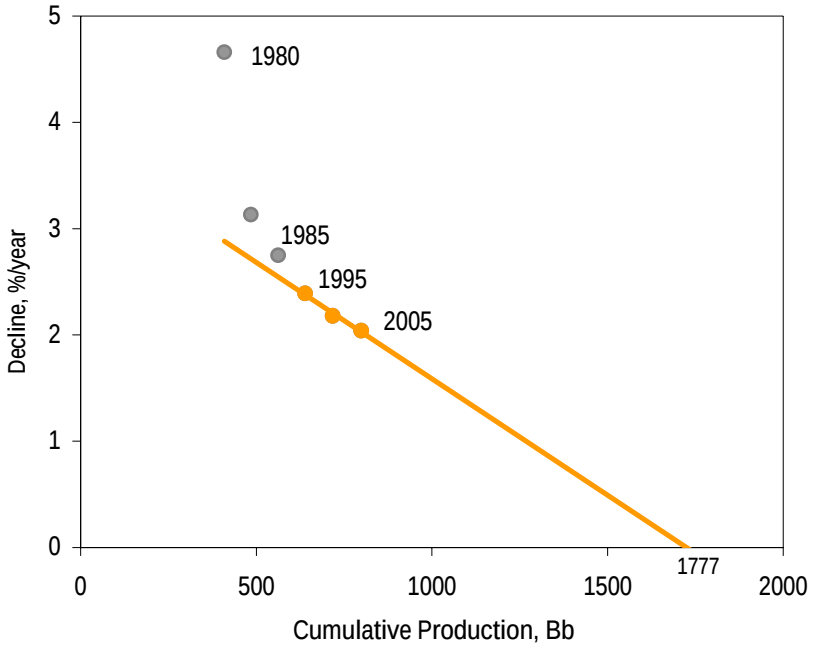
## *Appendix 1: Giant offshore oil fields*

## *Appendix 2: World onshore oil decline curve analysis*

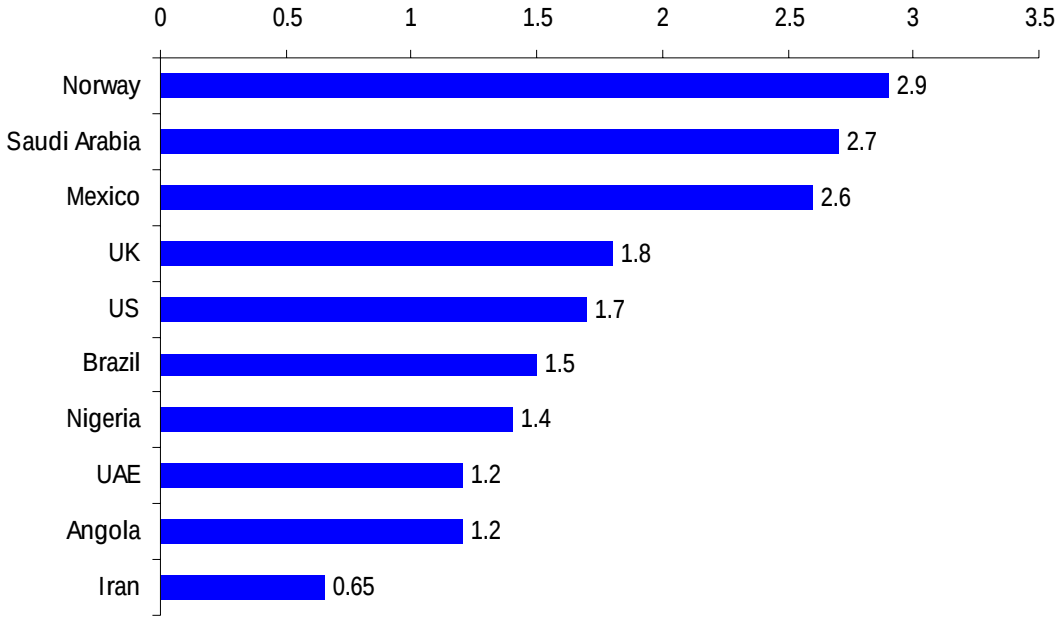
The oil production decline performance for global onshore crude since 1980 is shown in the figure below. The linear trend line starts in the early 1990s and extrapolates to a K-value of 1,800 Bb, thus indicating that onshore production would reach its half life in the next six years at current production rates. The least squares-fitted trend line has a correlation coefficient of 0.984.

**Production decline trend – world onshore crude oil**

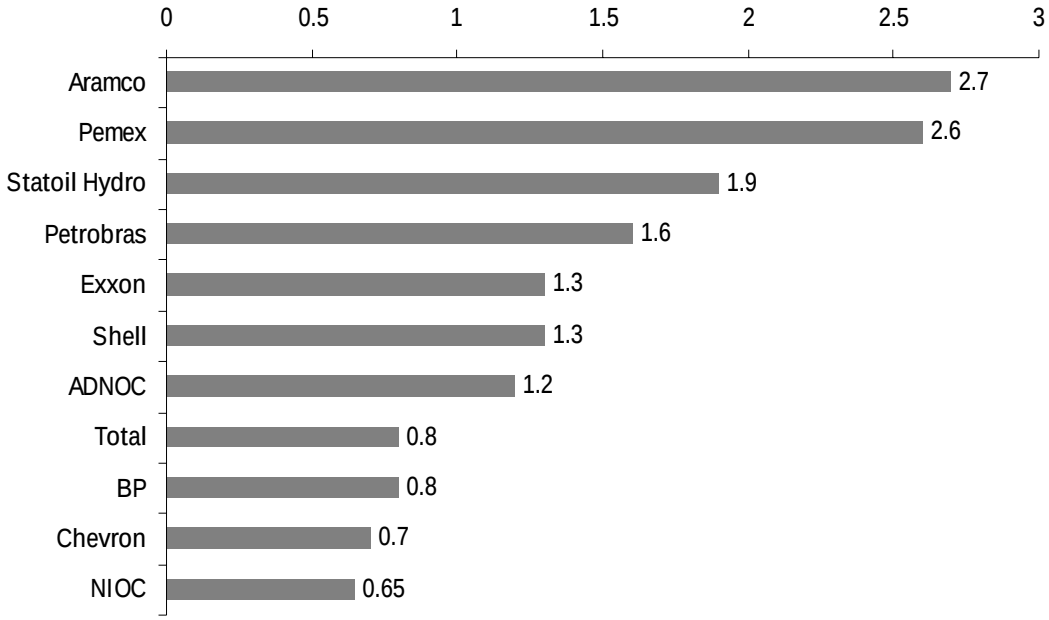


## *Appendix 3: Top offshore oil producers (mb/d)*

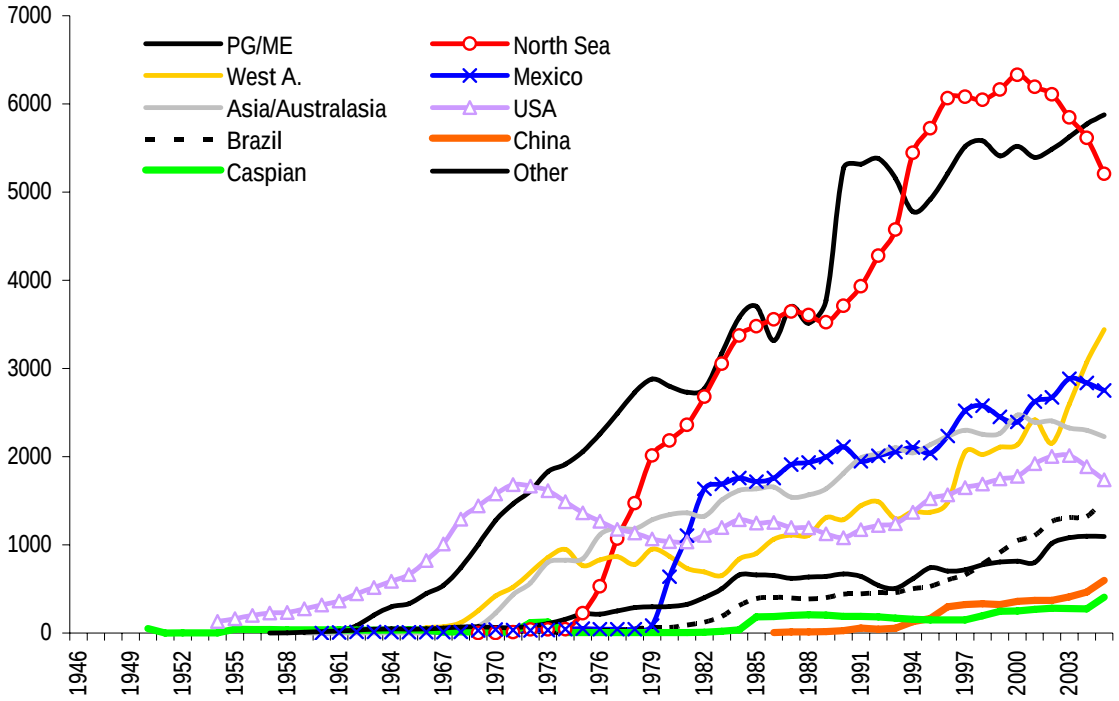
**Countries**




**Companies**



## *Appendix 4: Regional offshore oil production (kb/d)*



# Biographies

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