Oil and Natural Gas Resource Assessment: Production Growth Cycle Models  
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"Our ignorance is not so vast as our failure to use what we know." M. King Hubbert

Abstract - Oil & gas modeling has for goal to forecast future production, and the aggregation of these future productions represents reserves. Oil has to be discovered before being produced. Discovery (i.e. reserves) and production need to be studied together. A model has to be represented by the simplest equation which fits the best the past discovery and production starting when the volume is significant. The value of a model is mainly the value of the data. Some modeling may be ignored, not because of the model, but because the data is poor or incomplete. There is no theoretical justification for any model, only the fit between the model and the past data justifies its value.

- Quality of discovery and production data

First, oil production has several problems of definition. Oil is not produced but extracted, except when synthesized from coal or natural gas by chemical reactions. The term "oil" can represent crude oil only (including some lease condensate for some countries as the US) totaling 65 Mb/d (25 Gb/a) for the world supply, or the demand for all liquids (including synthetic oil, condensate and natural gas plant liquids and refinery gains) totaling 75 Mb/d (28 Gb/a). Oil can be reported in volume (cubic meter or barrel) or in weight (tonne); making the world total difficult to estimate when density is badly known or ignored. Furthermore some oil is lost (2 Gb during the Gulf war), stolen or unaccounted for when cheating because of the quotas. The bad reporting by the IEA in 1998 led to the "missing barrels" (600 Mb) between supply and demand, giving a false abundance of oil and the low price of 10 $/b. Only scout companies (as Petrologistics) can give a fairly right volume of the oil being shipped on the seas.

Models need to study the past reserves with time. Reserves are in fact the addition of all future productions until the end. The production of today was part of the reserves of yesterday. It is imperative that reserves and production represent the same product. In fact they do not. The most often used databases are the Oil & Gas Journal (OGJ) published every December, BP Statistical Review published every June, World Oil (WO) published every August, and OPEC. For the world oil, the discrepancy is striking, besides an unrealistic accuracy.

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<thead>
<tr>
<th>Reserves in Gb (OGJ)</th>
<th>Production in Mb/d</th>
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<tr>
<td>OGJ end 2002</td>
<td>1 212.880 852</td>
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<tr>
<td>BP end 2002</td>
<td>1 047.7</td>
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<td>OGJ end 2001</td>
<td>1 031.553 477</td>
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<tr>
<td>BP end 2001</td>
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<td>WO end 2001</td>
<td>1 017.763 1</td>
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<tr>
<td>OPEC end 2001</td>
<td>1 074.850</td>
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BP specifies that tar sands are not included in their reserves but that they are included in their production.
Most published data is incoherent and badly defined. It is obvious that the authors of these publications do not understand the assessment of accuracy and they do not want to define what is measured, as they do not know.

Oil discovery has to be carefully studied, but unfortunately the reporting of reserves to the public is a political act and operators are reluctant to tell the truth which can damage their image. Operators in the US have to comply with the SEC rules and to report only proved reserves, omitting probable reserves, when the rest of the world report proven + probable reserves (close to the mean or expected value). The SEC refuses the probabilistic approach for known reserves when the USGS 2000 largely uses probabilistic simulation to evaluate the undiscovered. The volume of proved reserves is left to the appreciation of what is a "reasonable certainty to exist" which can vary between 51% to 99% (the same definition of "reasonable certainty of no harm" is used by the FDA to allow the sale of a new product). The following graph plots the remaining oil reserves from political sources (being current proved) published by OPEC, BP Review, OGJ and World Oil (WO), completely different from the technical reserves which are the present mean values backdated to the year of discovery and are confidential. Statistically the mean (expected) values do not grow despite that some values will increase, but some will decrease. In contrary proved reserves are very conservative and thus designed to generate growth, which pleases everyone: the operator, the banker and the shareholder. Unfortunately, though in the past 25 years the US reserve additions come mainly from revisions of the past discoveries, as positive revisions were twice larger than the negative revisions, the last USDOE 2001 annual report indicates that negative revision were larger than the positive, MMS in the Gulf of Mexico were reporting the same things since 1998. USDOE published only in 1990 the "mean" estimate of annual discoveries from 1900 to 1988. These values were used, as well as the last annual new discoveries up to 2001, to get the present US mean values by growing them with a MMS reserve growth. It is a pity that such mean data which exists at the USDOE is kept confidential. It is also a pity that the US use an old method to evaluate their reserves compared to the better approach used by the rest of the world.

Figure 1: World oil remaining reserves from political and technical sources
The technical reserves decline since 1980, provided that discovery has ever since been lower than production, when in contrary the political reserves jumped in the second half of the 1980s by 300 Gb when OPEC quotas were decided upon the reserves. OPEC countries in few years have increased their reserves by 50% (except in the Neutral Zone owned 50/50 by Saudi Arabia and Kuwait as the two owners disagree on the year of increase) when no significant discoveries occurred during those years. Exxon-Mobil (Longwell 2002) publishes world oil discoveries that stand in very close agreement with the technical reserves displayed in the last graph, declining since 1980 as annual discovery became smaller than annual production. In fact Exxon-Mobil confirms and updates a graph already displayed by USGS for the WPC 1994 (Masters figure 6).

Last December OGJ increased Canada's reserves by 175 Gb to include the tarsands (extracted mainly by mining) which were excluded before as unconventional, as the Orinoco extra-heavy oils being produced now in very conventional ways. BP Review, which follows OGJ's for OPEC members, has refused last June to include this large increase for the tarsand reserves, despite that the oil from the tarsands was included in BP production.

For gas the situation is about the same, but since 1980 gas discovery matches the production and the technical remaining conventional gas reserves level is about flat.

Figure 2: World gas remaining reserves from political and technical sources
-How many models?
Model seem more reliable than production and reserve data. There is no theory to fully explain the best model to assess oil and gas discovery and production. The best approach is to deal with the most homogenous data covering the most natural area. In the past, exploration basins were explained in term of tectonics, now they are described as "petroleum system" it means in term of generation of hydrocarbons, since the most important factor is the source-rocks which have generated oil and gas. Gathering fields by large petroleum systems gives much better results than gathering fields by country. However, exploration activities depend strongly upon the country: opening of blocks, fiscal terms. It is better to deal with large areas such as continents. The data is also to be considered on the full life of exploration, for too many studies consider only the last decade or so. The best way is to study the past and to extrapolate with the best simple model towards the future. However, finding a good fit for a particular set of data does not mean that this model is the solution, maybe another model will provide a better solution. Comparing oilfield distributions can be done with different models as lognormal or parabolic fractal. Gulf of Mexico, Niger delta and the Saharan Triassic petroleum systems were compared (Laherrere 1998). Gulf of Mexico (GoM) is different on a lognormal model from Niger delta and Saharan Triassic which are similar, in fact this model considers mainly the frequency and the GoM is intensively explored looking for small fields, when in Niger and Sahara only the large fields are drilled. When comparing with a parabolic fractal model, GoM and Niger are similar as they are a dispersed habitat with many large fields of similar size, whereas Sahara is a concentrated habitat with few giants. Finding a solution with one model should not keep one from looking at other models to find another solution, as Nature is not linear and has several solutions.
The range of production and discovery models is large: creaming curve with hyperbola, cumulative production and discovery with logistic curve, annual discovery and production with normal curve or derivative of logistic (Hubbert curve), parabolic fractal for field size-rank in a log-log display, lognormal distribution, stretched exponential, and so on.

Each case is particular and cannot be generalized. Instead of speaking about the strengths and the weaknesses of each model, many cases will be shown in order to judge exactly how good the model is.

In fact the best model is using the correlation between production and shifted discovery, as the shift allows the forecast during the shift.

One of the most famous models for oil production is the Hubbert model which is a bell-shape curve which peaks at mid-point. Hubbert (1903-1989) was a brilliant geophysicist (Shell and USGS), but with a short temper. He is well known by geologists for his theory on hydrodynamics, tilting the water contact in oilfield when aquifer is strongly moving. He is well known also in the oil industry for his forecast in 1956 that the US oil production would peak in 1970. His theory was rejected when published, but acknowledged later as the US production peaked in 1970. Buzz Ivanhoe has created a Hubbert Center for petroleum supply studies at the Colorado School of Mines and issued a quarterly newsletter. Hubbert considered that oil has to be found first before being produced and that the production pattern will be similar to the discovery pattern.

-Hubbert curve: one peak?

Hubbert in his famous 1956 paper said that oil has to be found first before being produced and that the production pattern has to be similar to the discovery pattern. Production starts from zero, rises to a peak, declines back to zero, but he did not give any equation except the bell-shape curve. He said that the curve will be likely symmetrical. His Hubbert curve was obviously drawn by hand with an abacus and he was measuring the volume by the surface below his curve, taking as a unit a square in Gb in the corner of the graph. He did not show any graph with several peaks, despite that he did no dismiss them. His 1956 forecast was based on the assessment that the US oil ultimate could be 200 Gb giving a peak in 1970 (but also 150 Gb). It is only in the 1980s that he wrote that his curve was the derivative of the logistic function. The logistic function was introduced in 1864 by the Belgian mathematician Verhulst as a law for population growth (Laherrere 1999). The equation for the cumulative production CP for an ultimate U, where tm is the inflexion point (corresponding to the peak time for the annual production)

\[ CP = \frac{U}{1 + \exp(-b(t-tm))} \]

A population with a constant growth rate (as bacteria) displays an exponential growth until a point when the population reaches the limit of resources and start a constant decline to stabilize to a constant level. A constant growth is impossible in a limited universe. A bacteria doubling each half a hour will reach, without being constrained by the food resource, the limit of the solar system in a week and the limit of the Universe in 11 days. What goes up must come down.

The derivative of the logistic curve is a bell-shape curve very close to a normal (Gauss) curve. Its equation for the annual production P, peaking at a value Pm for the time tm

\[ P = \frac{2Pm}{1 + \cosh(-b(t-tm))} \]
When plotting the annual over cumulative production in percentage versus the cumulative production, if the production follows a derivative of logistics the plot is linear (Deffeyes 2002). Using the mean values for the US Lower 48 as indicated above, the plot is almost linear from 1937 to 2001. The linear extrapolation (in red) towards zero indicates an ultimate about 200 Gb. Hubbert was right on the peak in 1970 when he rightly used an ultimate of 200 Gb (a rounded up value as he knew that the accuracy was low). On the following graph the linear trend (in green) from 1938 to 1955 (at the time of the Hubbert forecast) already indicates this 200 Gb ultimate.

Figure 3: US lower 48 oil production: annual/cumulative versus cumulative

Hubbert was lucky that the real value was close to a rounded number. Plotting the annual mean discovery, it is easy to draw a Hubbert curve which fits the discovery data (smoothed on a 5 year period) and has an ultimate of 200 Gb. US discovery in the Lower 48 peaks around 1935 (East Texas the largest oilfield was discovered in 1930) at a level of 3.2 Gb/a. This Hubbert discovery curve shifted by 30 years fits the production curve perfectly.

Figure 4: US Lower 48: annual oil discovery and production
Why is the US 48 oil production as symmetrical in the rise as in the decline?
Plotting cumulative production versus time shows a perfect fit using one logistic curve with an ultimate of 200 Gb, when cumulative discovery needs two logistic curves, the first one with an ultimate of 150 Gb and the second one with an ultimate of 50 Gb.
US 48 oil production comes from over 22 000 producers which is a very large number and randomness has to be taken in account, as in the air where there is a very large number of molecules with a random Brownian move which gives a perfect law between pressure, volume and temperature. The Central Limit Theorem (CLT) states that, in probability, the addition of a large number of independent asymmetrical distributions gives a normal (symmetrical) distribution. The large number of US independent producers leads to random behavior and the aggregation of the very large number of fields is normal. On the above modeling of production by a bell-shape curve it occurs that the model seems wrong around 1930 (depression), 1950 (prorationing); 1980 (oil price) as well as when political or economic events oblige operator to act all in the same direction, become no more independent and therefore randomness cannot apply. It is amazing to find that the shoulders of end 1950s and 1980 occur at the same level, why? It is unexplained.

It is easier to work on cumulative discovery and production, as small details are smoothed. On the US Lower 48 the discovery can be well modeled with two logistic curves for an ultimate of 200 Gb when only one logistic fits the production well.

Figure 5: US Lower 48: cumulative oil discovery and production
Multi-cycles

But there are few places with such a large number of producers and a continuous activity for more than a century as in the US Lower 48. Most of other countries display several cycles of exploration activity and then of production. One good example is the almost depleted oil production in France. The graph of our 1995 "World Oil Supply 1930-2050" for France was shown in my article OGJ Feb. 1, 1999 "World oil supply- what goes up must come down, but when will it peak?" figure 6. The France oil production was modeled with 2 cycles fitting the past production (up to 1994) and forecasting then about 10 Mb/a in 2000. The following graph is an update and the real 2000 value was exactly 10 Mb. France oil production, if a new cycle (Mer d'Iroise?) is not found, will cease in 2010. The modeling of the production gives a good fit for 800 Mb ultimate when the ultimate from discovery is higher at about 950 Mb. Discoveries seems to be a little overestimated. But the fit between production data between Petroconsultants and USDoE is poor for the first half of the 90s, confirming the poor quality of published data.

Figure 6: France oil discovery and production
-Ultimate
Drawing a good model for oil production implies estimating the oil ultimate, such as 200 Gb for the US 48. The plot of annual/cumulative % versus cumulative needs to be linear in order to give a reliable value, but it is not always the case. The best approach is the creaming curve. This curve was "invented by Shell" in the 80s, displaying the cumulative discoveries versus the cumulative number of new field wildcats (NFW), in order to eliminate the up and down of exploration when plotting versus time. When NFW are not available, the plot versus number of discoveries (in time sequence) can give good results. Some economists call creaming curve the curve of cumulative discoveries versus the rank of the field by decreasing order (as in the fractal display), it is a wrong label and the curve varies with new discoveries as rank changes, this curve is of no interest and shows the poor knowledge of their authors.

-US
The creaming curve for the full US displays 3 cycles, well fitted to data with hyperbola curves. It is easy to recognize a first cycle for the Lower 48, a second cycle for Alaska and a third cycle for deepwater. Without a new cycle (where could it be?-Unlikely in very deep sediments as oil is converted into gas below 6 to 7 000 m), the US oil ultimate is about 225 Gb. The creaming curve represents the well known law of diminishing returns in mineral exploration. Big gold nuggets are found first and at the end the fine particles. The creaming curve indicates that finding an additional 10 Gb will require over 50 000 NFW.
Figure 7: US oil creaming curve
The plot annual/cumulative versus cumulative is almost linear from 1940 to 2001, confirming an ultimate around 220 Gb very far from the ultimate estimated by the USGS 2000 report which is an unrealistic 362 Gb, of which 83 is undiscovered, and 76 Gb of reserve growth.

Figure 8: US oil production: annual/cumulative versus cumulative giving an ultimate of 220 Gb
This annual/cumulative versus cumulative plot could be good in case of one cycle, but it could prevent from seeing the new cycle coming or the deviation from the logistic function. With an US ultimate of 220 Gb coming from the production trend, it is easy to plot a logistic curve for the cumulative production. But it is interesting to compare it with the cumulative mean discovery. This mean discovery comes from the 1990 EIA report and the last annual reports which are grown to get the mean. This estimate is questionable but it is striking to compare discovery shifted by 30 years to the production. Despite the jump due to Prudhoe Bay, the shifted discovery fits the production very well and the 30 years advance from discovery complete as good as a logistic curve the future production up to 2030. The published annual proved reserves plus cumulative production is plotted on this graph (in red) and in fact it follows roughly in parallel the cumulative production, and a linear extrapolation for the last 30 years will go to 280 Gb in 2030, much lower than the 2000 USGS with an ultimate in 2025 of 362 Gb (of which 76 Gb is for the so-called reserve growth), even the ultimate without reserve growth at 296 Gb looks too high. The proved reserves are a poor estimation of the future and should be replaced by the practice of mean reserves; as it is done for the rest of the world.

Figure 9: US cumulative oil production and shifted mean discovery

-World oil

The world cumulative conventional oil discovery and production are fairly well modeled with one logistic curve with an ultimate of 2 Tb but with different slopes. Again the USGS ultimate of 3012 Gb (what accuracy !) looks unrealistic in front of the past mean discovery, but removing the very questionable reserve growth it goes down to 2.3 Tb which is then more acceptable.

Figure 10: World cumulative conventional oil discovery and production
The cumulative discovery can be broken down by size of fields, separating the large fields over 2 Gb which makes about half of the total volume, the giants (500-2000 Mb), the major (100-499 Mb), the rest (0-99 Mb) and all curves can be modeled well with one logistic, the largest having reached close to the ultimate first. It is the principal of the creaming curve or the law of diminishing returns. Global results give simple model, as it smoothes the discrepancies.

Figure 11: World oil cumulative discovery by field size
The world natural conventional gas discovery needs two logistic curves plus an addition of 1500 Tcf corresponding to the reserves of the largest gasfield (combining North Field in Qatar and South Pars in Iran found in 1971) giving an ultimate of 10 Pcf. The huge size of the North Field-South Pars (it is a King!), more than 5 times the second gasfield which is Urengoi (it is still considered by some as the largest gasfield) disturbs completely the distribution as it represents 15% of the ultimate. For oil, the largest field Ghawar represents only 5% of the conventional ultimate.

In contrary the cumulative production (adding badly defined dry or marketed) is easily modeled with one logistic, but only one quarter has been produced. The USGS ultimate which is 15 401 Tcf looks, as always, too high, without the reserve growth the ultimate is then 11 741 Tcf, looking more reasonable.

Figure 12: World natural gas discovery & production

![World natural gas cumulative discovery & production with model](image)

The logistic model can also model the total primary energy consumption (unfortunately this data omits the muscular energy from human and animal (which built many empires)) with only two cycles with an ultimate (in fact a peak) of 12 Gtoe. The second cycle is associated to the demographic explosion

Figure 13: World primary energy consumption
When ultimate has been assessed, for the world liquids, as 3 Tb, the best way to plot the possible future production as being an addition of the OPEC Hubbert (ultimate 1.3 Tb) curve and the non-OPEC curve (ultimate 1.6 Tb), with the assumption that the production would not be constrained by the demand, but by the supply. A smooth curve is better than some scenarios as Wood 2002 from the USGS 2000 report, where many scenarios are drawn with a constant growth up to a peak followed by a constant decline. Such angular pattern looks unnatural. The peak could be about 90 Mb/d around 2015. It is likely that the demand will put down the supply curve as the official scenarios of oil production are all based on a constant growth corresponding to an economic growth of over 3%/a for the next twenty years, leading to a USDOE forecast of 120 Mb/d in 2025 (without any sign of peaking). This level of 120 Mb/d looks almost impossible to reach from the technical data.

If the demand stays at a level around 80 Mb/d (a bumpy plateau) the real decline will be after 2020. The supply could constrain the demand only after 2020. If the supply is high enough to satisfy demand during the next 20 years, oil price could be chaotic if OPEC does not succeed to keep its price-mechanism working. Low price will lead to more demand, then to lack of supply.

Figure 14: World liquids production & forecasts
For the natural gas our ultimate is 10 Pcf for conventional gas and 12 Pcf for all gas, giving a peak around 2030 and 130 Tcf/a. USDoE IEO 2003 forecasts 180 Tcf/a in 2025 with no sign of slowing down. It seems to come from another world! An ultimate with 9 Pcf will give a peak about 110 Tcf/a around 2020.

Figure 15: World natural gas production & forecasts

-Hubbert Peak, mid-point and constraints
In the media now, Hubbert symmetrical curve (and peak) is often found to describe the coming oil decline and many believe that the Hubbert peak arriving at the mid-point (when half of the ultimate is produced) is the rule. A single symmetrical curve occurs only on places where exploration and production are active, without any interruption and any constraints as in the US Lower 48 and likely in Norway. But if up to now there was no constraint from the oil supply (except for a short time as transport needs some time), there are many cases of constraint from the demand. Production was reduced in 1930 in Texas (creation of the Texas Railroad Commission which was the model for OPEC in 1967) as the discovery of East Texas oilfield led to the fall of the oil price from 1 $/b to 0.1 $/b), and mainly in 1979 as the demand fell because energy savings in front of the high oil price. The world oil production peaked in 1979 and it took 15 years to go back to the same level. Figure 14 shows the forecast if there is no demand constraint, but despite the official forecast of 90 Mb/d in 2010 and 100 Mb/d in 2015, the supply could offer only 90 Mb/d in 2010 and 2015, because of the coming problems in the world economy for the next decade, it is likely that the demand will constrain the supply as the potential of oil savings is huge in particular in the US where energy consumption is double than in Europe for a similar way of life. The supply will really constrain the demand only after 2020. Hubbert curves for a world liquid ultimate of 3 Tb are plotted first in H1 as fitting the quick rise from 1950 to 1979, giving a peak around 2000 for 140 Mb/d (it was the forecast of Hubbert as Halbouty in 1978), second H2 fitting the past 20 years giving a peak in 2012 around 80 Mb/d (but the model is too high before 1950) and a two cycles H3+H4 (in red) fitting the data since 1950 with a peak around 2020 at 90 Mb/d. Our forecast of figure 14 (coming from a long study and adding several Hubbert curves) gives a peak at 90 Mb/d about 2015, but the mid-point is reached only in 2019 as the global curve is not symmetrical. Figure 16: World liquids production with forecast and Hubbert curves for 3 Tb

-Parabolic fractal
Another way to assess the ultimate of a Petroleum System (taking only a part of the system will disturb the natural behavior) is to plot in fractal display the filed size versus the rank of the field by decreasing order in a log-log format. The linear fractal (power law) as developed by Benoit Mandelbrot is only a theoretical interpretation of the nature as every natural system (as the urban agglomeration in contrary to the political city boundaries) displays a curved pattern (Laherrere 1996), as the world earthquakes (the Gutenberg-Richter (power) law being only a tangent to the curve). Natural distributions are fractal, self-similarity is the rule of Nature. On a picture of a geological outcrop a scale is needed, being a hammer or a man, as geological events are similar what is the scale. Fractal equations are used in movies to create "natural background".

The study of the discoveries evolution, every decade, leads to the drawing of the parabola representing the ultimate in the ground. The yet-to-find can be deducted from the yet-in-the-ground with some economic and time constraints. The example for the Niger delta Petroleum System (covering 3 countries) shows that the 1960 pattern was quickly replaced by a pattern which did not change much the largest fields already found, and only smaller fields were added. The parabola in brown represents the ultimate in the ground gathering a large number of small fields which will be never discovered.

Figure 17: Niger delta oilfield size fractal display

The slope at the beginning (for the first 10 fields) characterizes the habitat, here it is a dispersed habitat as the slope is almost flat, in contrary a concentrated habitat (as the Saharan Triassic) shows a steep slope.

-Creaming curve
All the creaming curves I modeled were easily fitted with several hyperbolas, each representing a new cycle (as shown before for the US). The only problem is to guess if a new cycle is possible and only geologists could answer, by studying the geological potential. In the case of the Middle East, the last cycle is from 1974 to 2002 (28 years) corresponding to 2500 NFW having an ultimate of 50 Gb with 830 discoveries, when before (70 years) the ultimate was 820 Gb corresponding to 1400 NFW and 340 fields. It means that for the last 28 years the success ratio 33% but a potential of 120 Mb per discovery when before the success ratio was only 24% but the average field was about 600 Mb. It is obvious that for the last 28 years more fields were found but they were much more smaller. It is wrong to say as it is often done that the Middle East was poorly explored and has a huge potential. The only badly explored place is the Western Desert in Iraq, but the petroleum system is perfectly known and is mainly gas prone; the oil potential small. As for the deepwater, there is almost none.

Africa is another interesting example as the last cycle is recent, starting in 1992 with the deepwater and the Sahara discoveries of Berkine. The question is always: could geologists predict in 1992 the new cycle? The answer is yes. The deepwater discoveries in Angola and Nigeria are just the extension of discoveries on the shelf. The large discoveries of the Berkine area were predictable since the source-rock of the "petroleum system" is the Silurian (which provided the filling of Africa's largest oilfield, Hassi Messaoud, over 10 Gb), and in 1992 it was an obvious lack of large discoveries in the eastern part of the Silurian kitchen. Could a third cycle occur in Africa? It is unlikely in the eastern offshore, with no larger discovery, and the source-rocks are gas prone.
North America gas

If there is only one oil market as transport is cheap, there are three gas markets because transport is 6 to 10 times more expensive. The North America gas market has been supplied only locally. The mean gas discovery of US + Canada + Mexico is shifted by 20 years to fit the production which is plotted as raw, dry and dry minus unconventional (coalbed methane and tight gas).

This graph was done in 2000 (Laherrere 2000) when production was still rising. My forecast was then a soon coming sharp decline.

Figure 20: US + Canada + Mexico natural gas: production & shifted discovery
The combined US + Canada natural gas discovery is a perfect logistic curve for an ultimate of 1700 Tcf, but the USGS 2000 report gives an ultimate of 2118 Tcf as they assume that the reserve growth in the US will bring 355 Tcf, without saying how much in Canada. Removing this reserve growth the ultimate is then 1763 Tcf, in close agreement with our estimate. The production is following the same logistic curve with a shift of 33 years. It means that the future gas production is fairly settled for the next 30 years, except miracles!

Figure 21: US+Canada natural gas cumulative discovery & production
Taking this 1700 Tcf ultimate allows to fit a 3 cycles model to the annual gas production, confirming the sharp future decline.

Figure 22: US + Canada natural gas annual production with 3 cycles

This confirms that the best modeling is not a model but correlating the production with a shifted discovery, without any assessment of the ultimate, the part of the shifted discovery beyond present year is the best forecast.
-Other models and ultimate assessments

Albert Bartlett has written several papers on Hubbert peak, but he uses a normal curve for annual production instead of a derivative of logistic, which is better in theory, assuming the influence of random in countries where there is a large number of producers. But there are many countries with few producers. The cumulative production is then modeled by an integral of the normal curve which is more complex to handle than the logistic function.

Richard Duncan has developed a software (a kind of blackbox) modeling the coming peak, but since he has no access to the confidential discovery values, his model relies only on past production. He used the help of Walter Youngquist to get some geology into his modeling. He compares three different forecasts (Duncan 2003) by Campbell, Duncan and Smith, but the values of the three forecasts starting at 2000 are significantly different, meaning that they do not deal with the same product, leading to differences not due only to the models.

Michael Smith (2002) has published a report "Analysis of global oil supply to 2050" (now with Douglas-Westwood) which provides forecasts up to 2100 for every producing country based from an ultimate and a constant decline from the peak. The peak of conventional and unconventional oil is forecasted around 90 Mb/d in 2012. It is a very thorough work, updating a similar report written in 1994 (Campbell 1995).

Deffeyes has written a good book "Hubbert's peak", where he says that, despite having discussion and lunch many times with King Hubbert, he did not dare to ask him about the earliest roots of his prediction. As Deffeyes uses the plot annual/cumulative versus cumulative, Hubbert in 1956 could have done it also and as shown on figure 3, the trend 1938-1955 gives the same 200 Gb ultimate as used by Hubbert, as also 150 Gb. Hubbert was clever enough to use round figures, as he knew the poor accuracy of any oil data. But I guess that he used more his knowledge (his nose) on discovery than a plot on production.

The base of a production forecast is the ultimate (called often EUR = estimated ultimate recovery) and geologists have published their estimates for the world since 1942 and for the past 30 years have ranged from 1600 to 3000 Gb (with different definitions). In 1977 IFP used a Delphi approach by asking a large number of experts first with an individual enquiry, followed by a second enquiry after giving the results of the first enquiry. USGS used the Delphi process for their assessment of undiscovered for the WPC of 1984, 1987, 1992 and 1994.

The USGS 2000 report did a very good study by defining and describing the petroleum systems of the world with the help of the oil industry. But this industry help stopped when evaluating the potential of undiscovered reserves (because of confidentiality). Instead of using a Delphi process in front of the lack of experts, only one geologist was asked for each area to give on a single sheet of paper (called the seventh approximation!) only six values of the minimum, median and maximum of the number of the undiscovered fields, and of the size. Then Monte Carlo simulation were used to give a full distribution of the undiscovered reserves. It was the way that East Greenland was provided with 47 Gb of mean undiscovered oil.

A kind of poor model used by the industry is the R/P, being the ratio of the remaining reserves at the date versus the annual production of the current year. It is given as 40 years for oil, but his ratio is poor (Laherrere 2002) for two reasons: first, the reserves are the political data and not the technical data, and second, the model assumes that the production will stay flat for 40 years and dropped suddenly to zero on the 41st year, this model is far from the Hubbert model and from production reality.
-Conclusions

There is no theory to justify any model for oil or gas production. The best is to use the best data (for reserves, it has to be the backdated mean and never the proved value) on the longest possible period, on the largest possible area and to try the simplest model of second degree. Having modeled thousands of curves, it is amazing first to find that any event, and in particular annual discovery and production, can be modeled with several symmetrical bell-shapes curves (as a Fourier analysis for a permanent wave), that oil and gas cumulative discovery and production can be modeled fairly with several logistic curves versus time, and several hyperbolas versus cumulative number of new field wildcats.

But the best tool is to find the best fit between the shifted (by a certain number of years varying between 5 to 35) annual discovery and the annual production, and this shift allows to predict the future production by following the part of the discovery beyond to day. Reserve (future production) estimate depends mainly on the reservoir characteristics which are mainly geological, and it is why the recovery factor ranges from 3 % (fractured tight reservoir) to 85 % (very porous reef). But economy and technology cannot change geology. Do not underestimate the geology.

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