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Forecasting production from discovery

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-1956 Hubbert peak oil concept

King Hubbert (geophysicist with Shell and USGS) introduced in 1956 and forecasted in particular that US crude oil could peak in 1970 (or in 1965). He is considered today as being right. Let's study his concept and his forecasts.

-Strengths

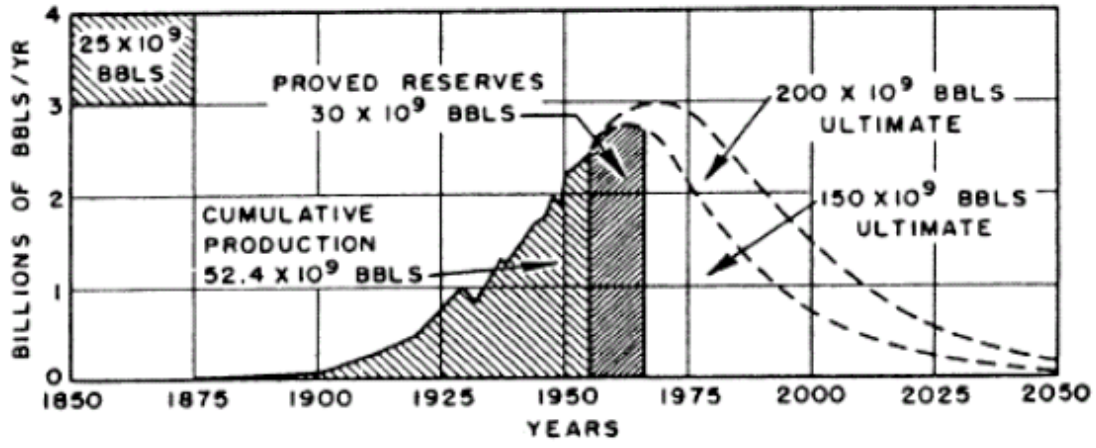
-natural: what is born will die
-based on past production, past discovery and a geological assessment of the **ultimate**
-uses one or two rounded ultimate estimates, recognizing uncertainty
-production mimics discovery with a time lag
-no equation, annual production drawn by hand with abacus and the area below the complete curve represents the Ultimate (counting the squares), the curve is not always symmetrical (coal) and in this case the peak is not the midpoint of depletion

-Weaknesses

-ignores backdating and mean values
-does not distinguish proven values and expected values as it deals only with ultimate(s), so it cannot compare discovery and production
-relies on outside ultimate estimates, creaming curves were not yet invented
-only one peak, when many countries exhibit "bumpy plateau" or two peaks (UK, France)
-ignores demand constraint (politics, economy)

Hubbert was right on one of his two forecasts, as the US crude oil peaked in 1970

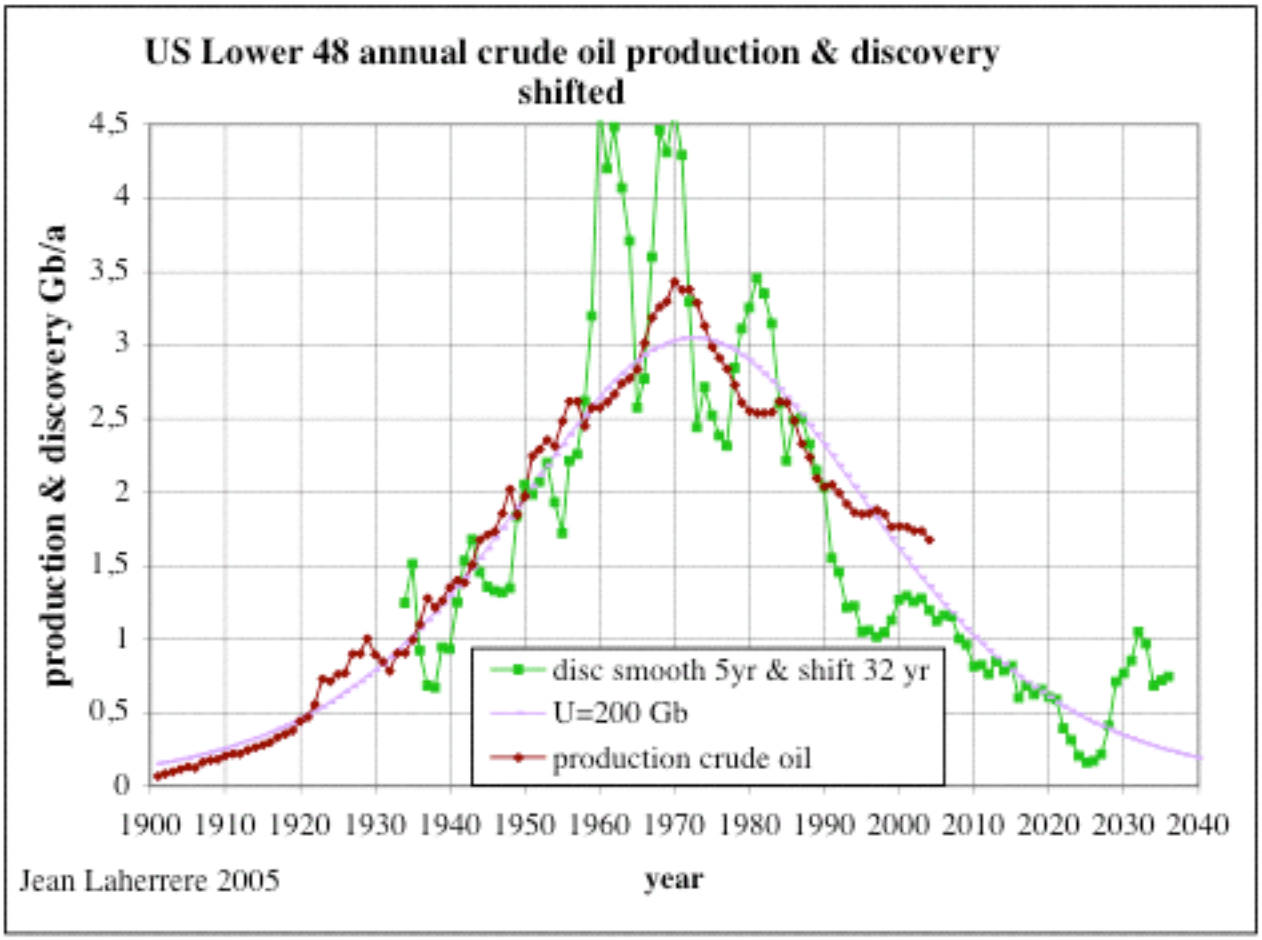
Figure 1: 1956 Hubbert's forecast for US crude oil called figure 21: Ultimate US crude oil production based on assumed initial reserves at 150 and 200 Gb



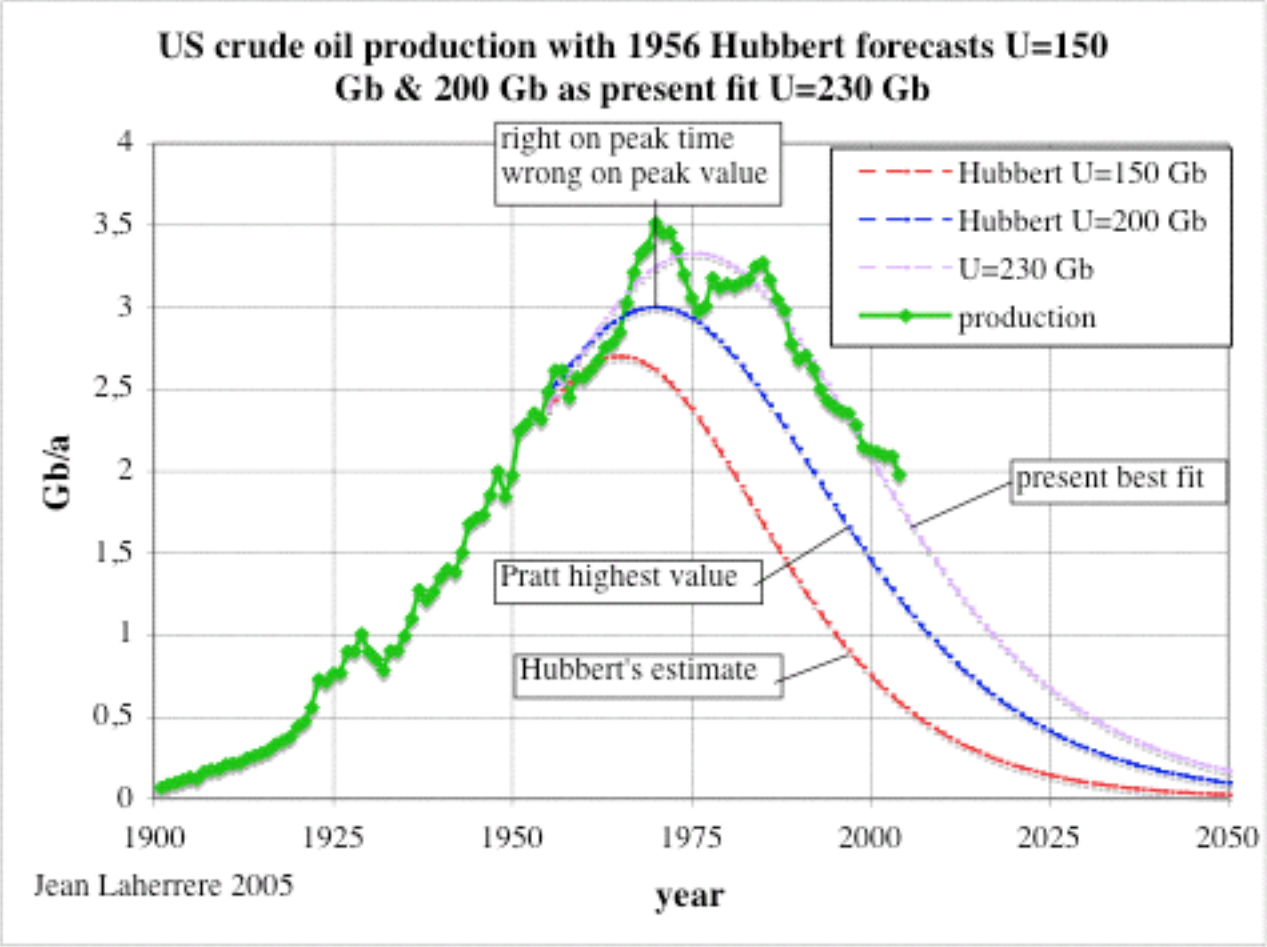
But he was wrong on several items

-his own US ultimate of 150 Gb (peak in 1965) was well under-estimated.
-his symmetrical curved occurs only for the US Lower 48 as there are over 20 000 producers acting in random, the aggregation is normal (Gauss curve = Central Limit Theorem) because the large number of independent players and the production is trending towards the round value of 200 Gb

Figure 2: **US L48 oil production and «backdated mean» discovery shifted by 32 years as model for 200 Gb**

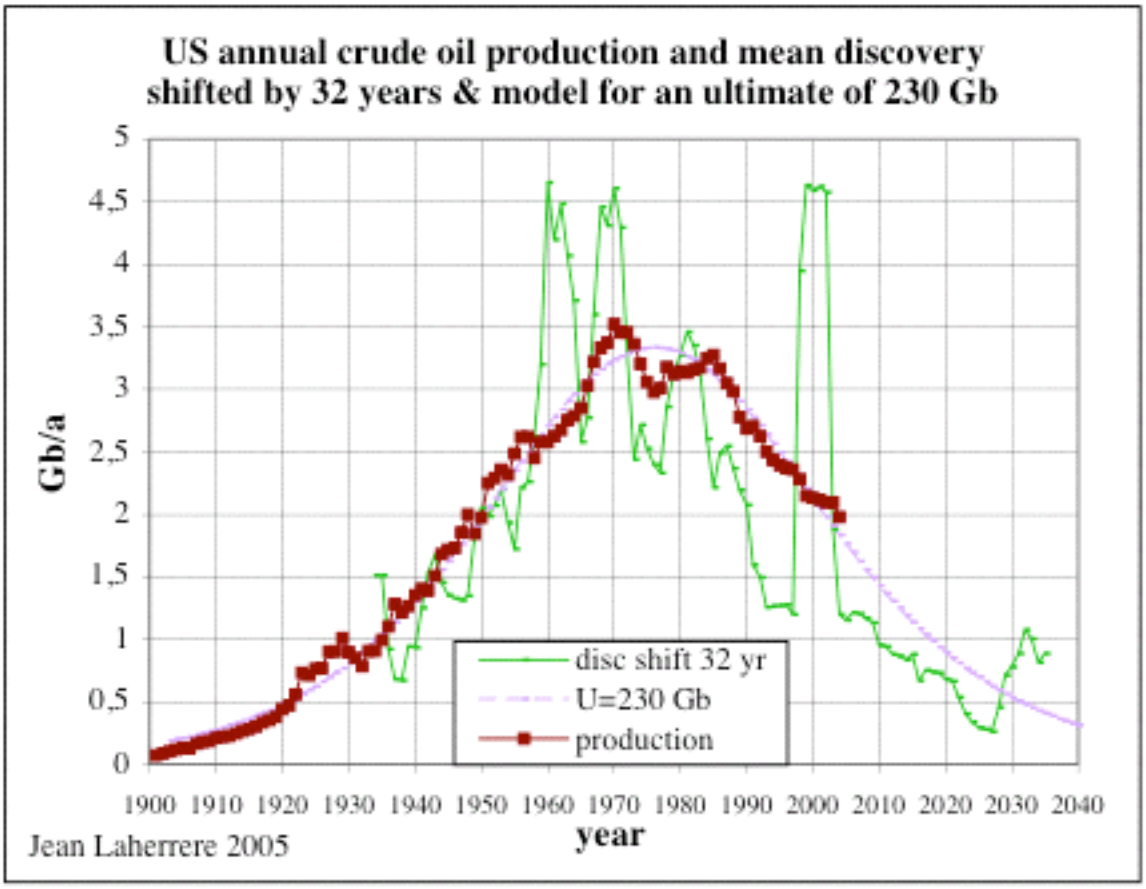


But Hubbert was wrong on the US crude oil ultimate Hubbert knew about Alaska oil discoveries starting 10 years before (1946 Umiat field in Naval Petroleum Reserve created in 1923) and was without any doubt including Alaska in his estimate.
The US crude production has a bumpy plateau, centred around 1975, fitting an ultimate of 230 Gb
Figure 3: 1956 Hubbert's US crude oil forecast and present data, & model for U=230 Gb

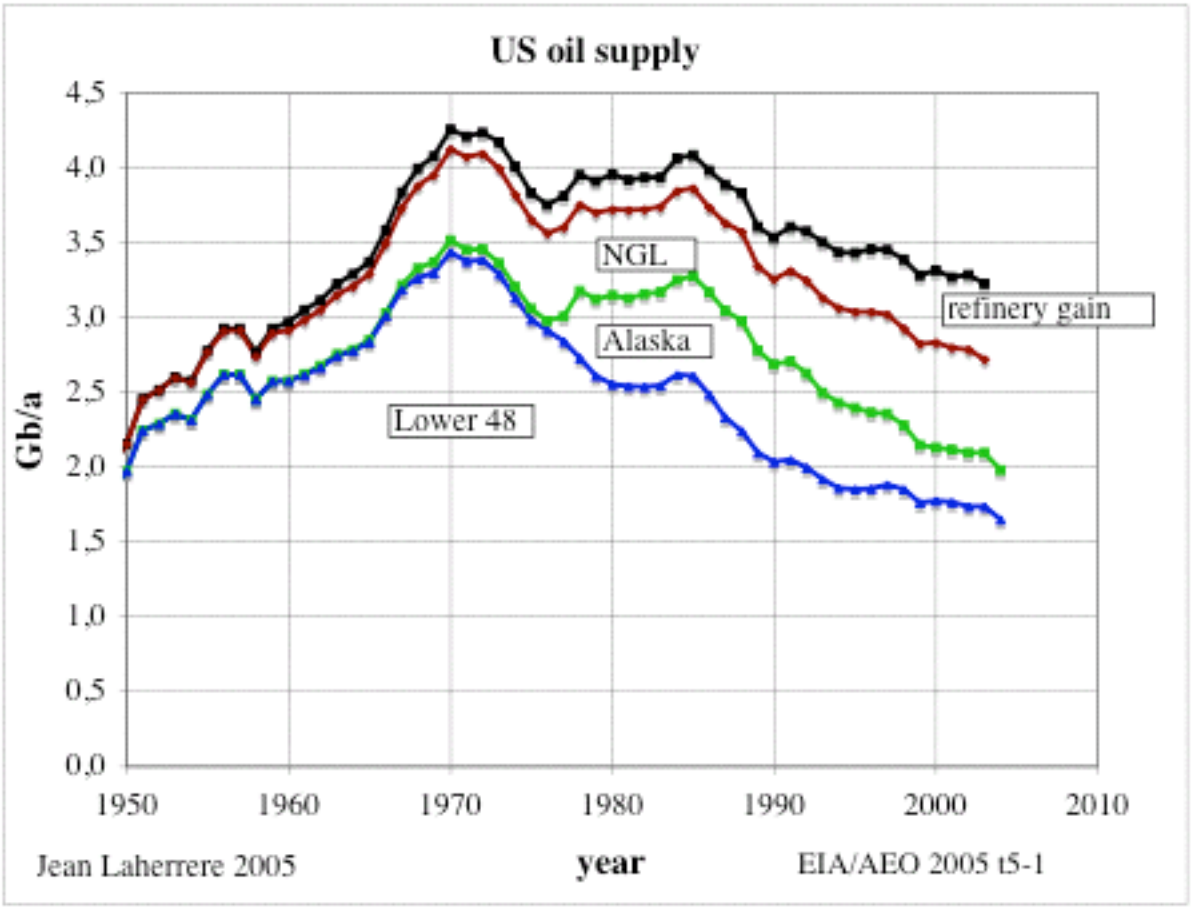


In fact the correlation between mean discovery and production for the entire US is not as good as the Lower 48 alone because the large addition of Prudhoe Bay when, for L48, the largest field East Texas, found in 1930, coincided with the peak of mean discovery. The best fit for mean discovery and production is achieved for a shift of 32 years, when the best fit for proved "discovery "is for 11 years as stated by Deffeyes ("Hubbert's peak" 2001 page 145)

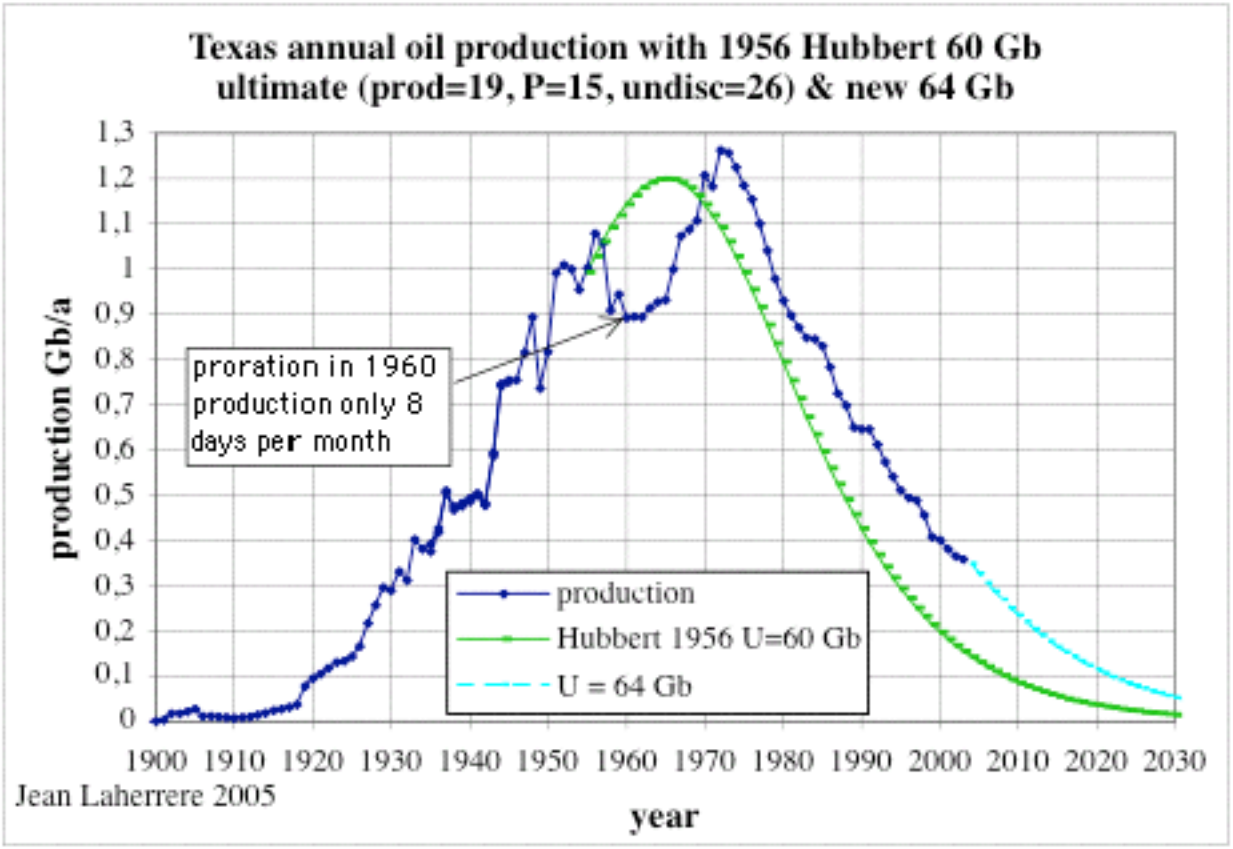
Figure 4: US crude oil production with shifted mean (smooth 5 yr) discovery & model U=230 Gb



Hubbert was wrong, as Colin Campbell and myself were wrong few years ago, by giving forecasts only for crude oil, when oil demand (equals to total oil supply for the world) is reported not for crude oil (73 Mb/d now for the world), but for liquids (84 Mb/d now). The US 2003 liquids production is at 8.8 Mb/a including crude oil at natural gas liquids 5.7 Mb/d, NGL at 1.7 Mb/a and other domestic supply (mainly refinery gains, coming also from imported crude) at 1.4 Mb/d. The US oil supply is far from symmetrical with a clear peak, but shows a bumpy plateau and the real decline starts around 1985
Figure 5: US oil supply as reported by USDOE showing a bumpy plateau and a real decline starting 1985

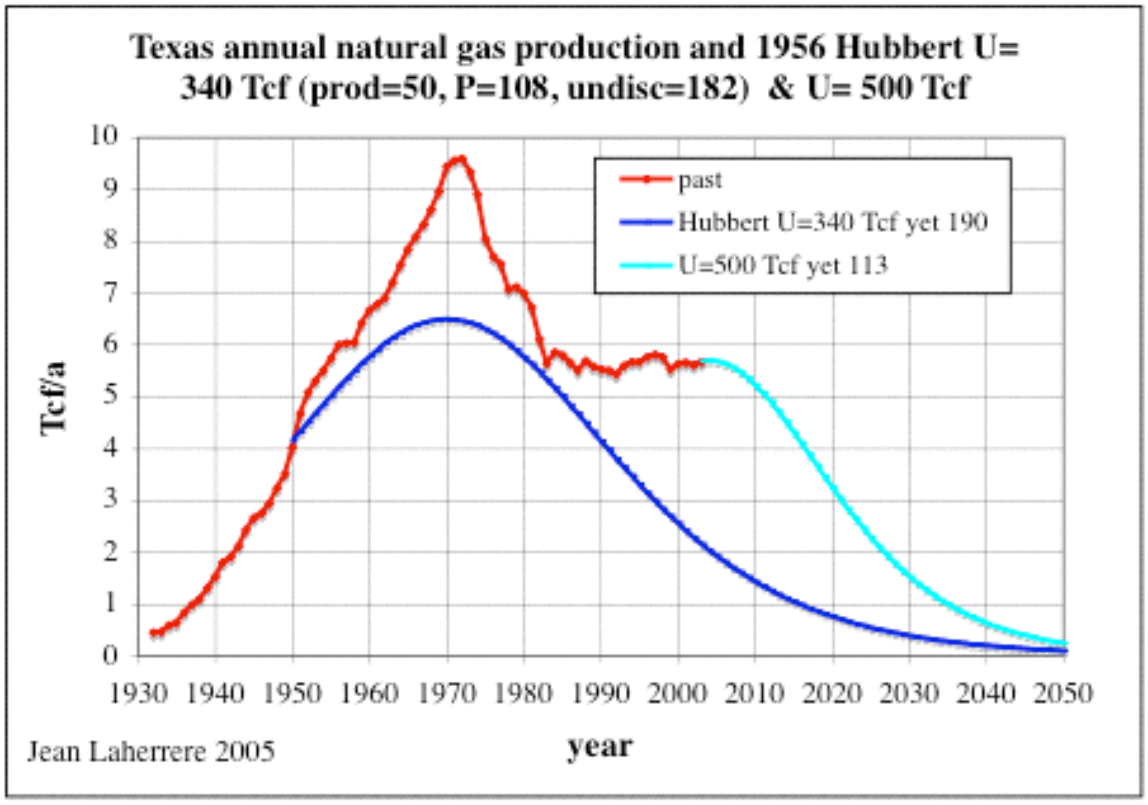


Hubbert's forecasts on Texas were good and poor on oil. Good as his ultimate was 60 Gb (with 26 Gb undiscovered) when the new estimate is about 64 Gb and his steep decline was parallel to the actual one. Poor as his peak forecast of 1965 was in fact a trough in a bumpy plateau with a drastic increase up to a peak in 1972. He failed to mention a possible demand constraint, as proration, which commenced in 1960 where production was allowed only 8 days a month.
Figure 6: 1956 Hubbert's Texas oil forecast U=60 Gb with present data & model U=64 Gb

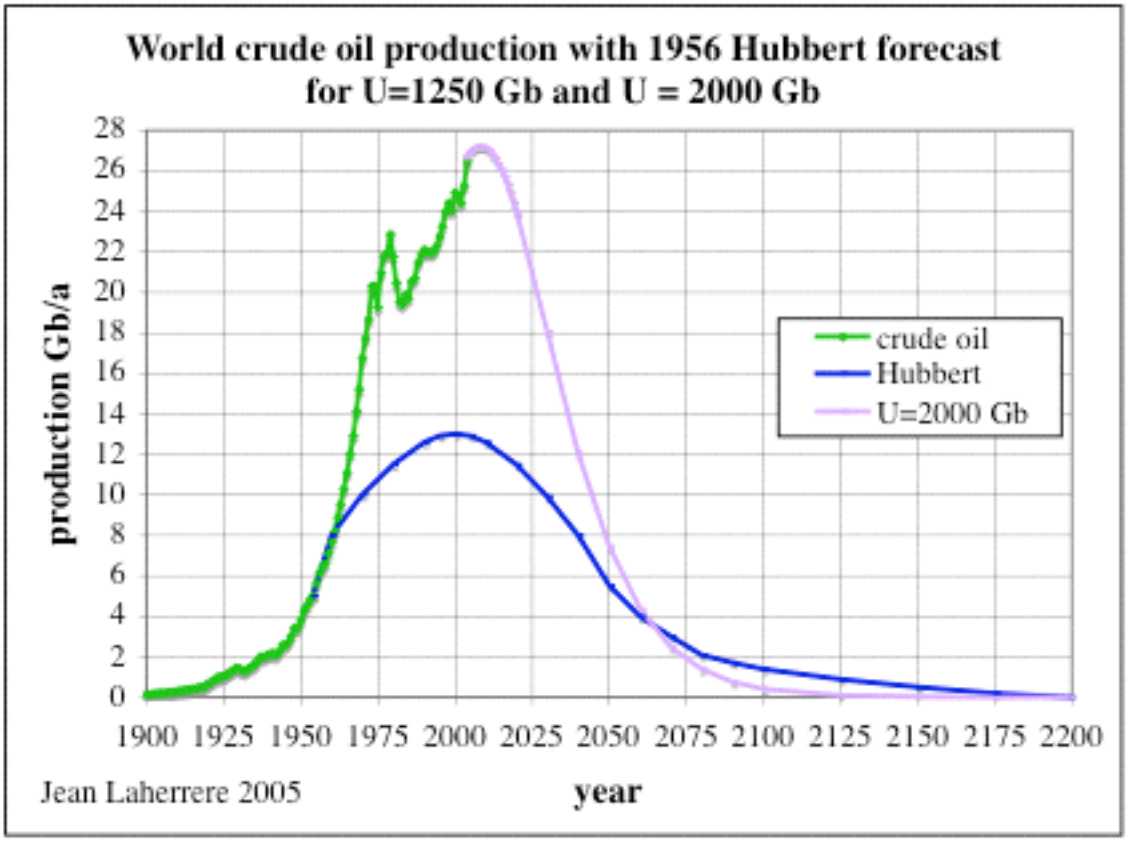


Hubbert's forecast (unsymmetrical) on Texas natural gas was poor as his ultimate was 340 Tcf when the likely estimate is now about 500 Tcf, but his gas peak was in 1970 at 6,4 Tcf/a. He was right on the date but wrong on the value, as it occurs in 1970 at 9.6 Tcf/a

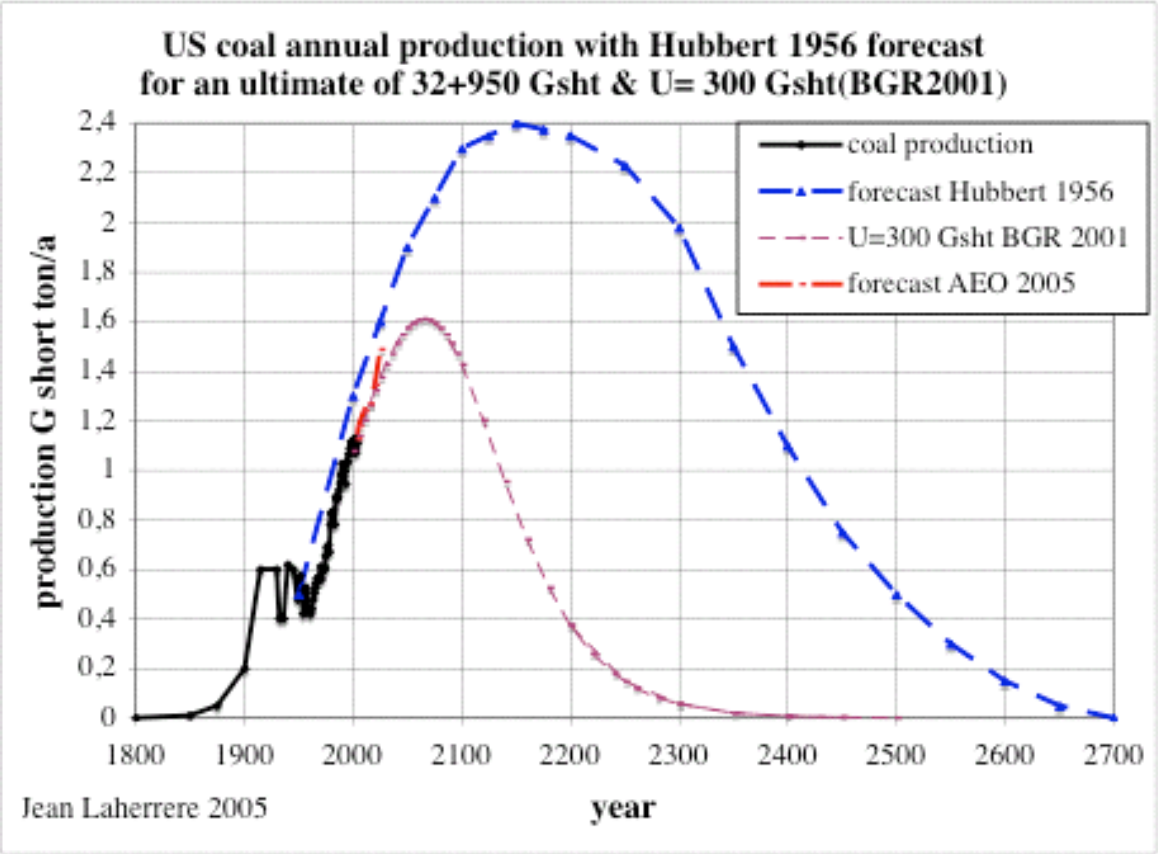
Figure 7: 1956 Hubbert's Texas natural gas forecast U=340 Tcf with present data as model U=500 Tcf



Hubbert's forecast on world crude oil for an ultimate of 1250 Gb (produced 90 Gb, P= 250 Gb, undiscovered =910 Gb) for a peak in 200 at 13 Gb/a (36 Mb/d) was quite wrong as my new ultimate is 2000 Gb with a peak around 2008 and the peak will likely being twice Hubbert's value
Figure 8: 1956 Hubbert's world crude oil forecast U=1250 Gb with present data as model U=2000 Gb



Hubbert's forecast on US coal was quite unsymmetrical ending in 2700, based on an ultimate of about 1000 billion short ton, when the last estimate by the BGR 2001 is about 300. The peak does not correspond to the midpoint (300 years of rise and 550 years of decline), but at less than 40%. Hubbert forecasted US coal peak for 2150 at 2,4 Gsht/a when using BGR ultimate the peak should be around 2060 at 1,6 Gsht/a? EIA/AEO 2005 forecast up to 2025 is in line which both forecasts.
Figure 9: 1956 Hubbert's US coal forecast U=1000 Gsht with present data as model U=300 Gsht



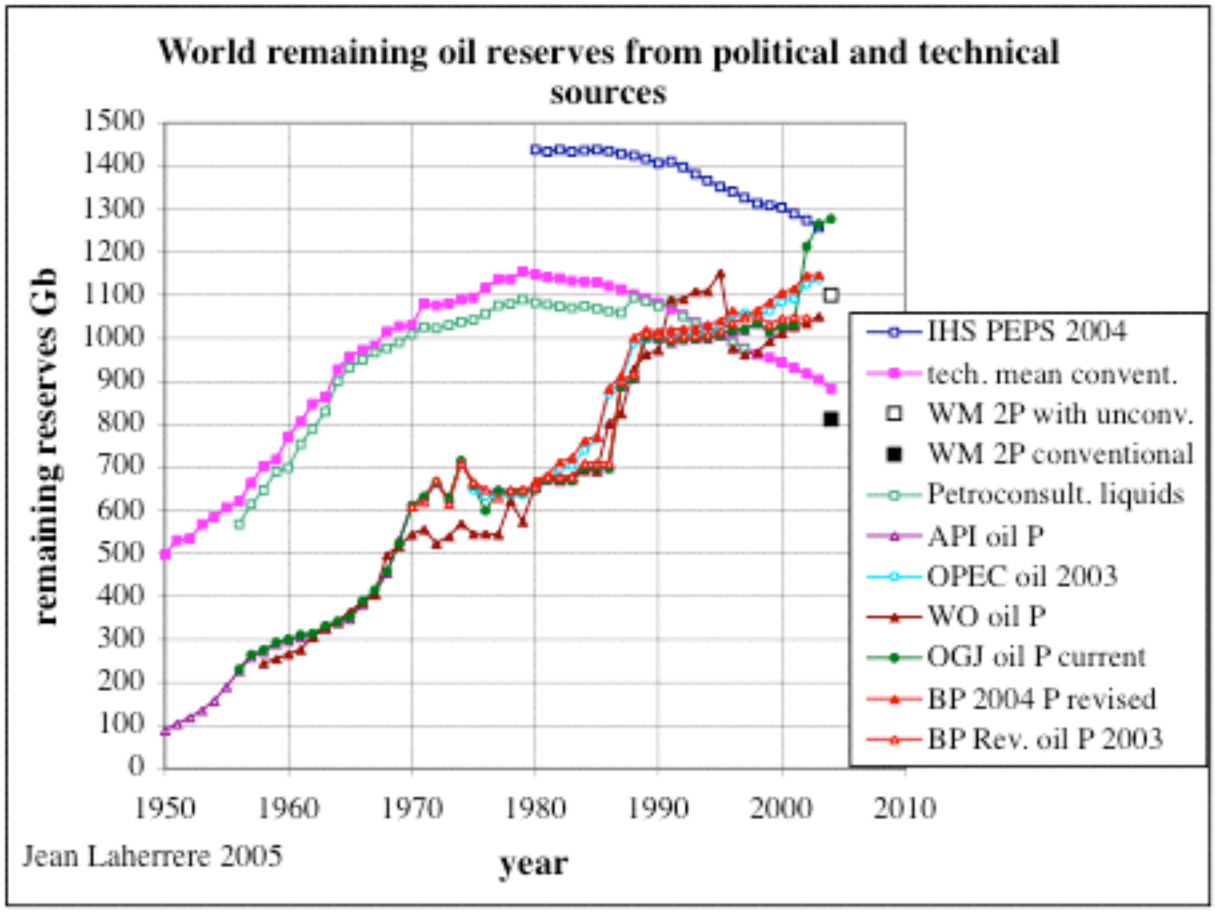
-**Discovery data**

Field reserves are assumed to report the cumulative production at the end of the field. The uncertainty of the estimates makes it desirable to report a range but the reporting usually prefer a single number which most of the times is the minimum (proved) or the median, when it should be the mean (expected value) has to be reported if only one. SEC rules to please bankers and shareholders oblige reporting only the proved values and omitting the probable values. SPE/WPC rules define “proven” value as being at least a probability of 90% to exist. I have shown already that the USDOE annual reports allow computing the probability of the proved estimates, which were for oil about 75% in the 70s, but trending towards 50% now, as in 2001 the negative revisions were larger than the positive revisions. The rest of the world report proven +probable (Canada starting to do so in 2003) so now the technical values are close to the mean values, except in the OPEC countries where quotas are based on reserves which became political with the increase from 1985 to 1990 of 300 Gb by OPEC countries without any significant discoveries. In the past there was only one worldwide source of field reserves, being Petroconsultants funded by a geologist (bought by IHS in 1999). Now IHS, who bought recently CERA, has lost its geological background and uses more and more political data. A new competitor Wood Mackenzie (WM), which uses more economical and technical data than IHS, is completing its country database and can be compared. The difference is very large, higher worldwide than the undiscovered estimate. The difference varies with the countries as seen below.

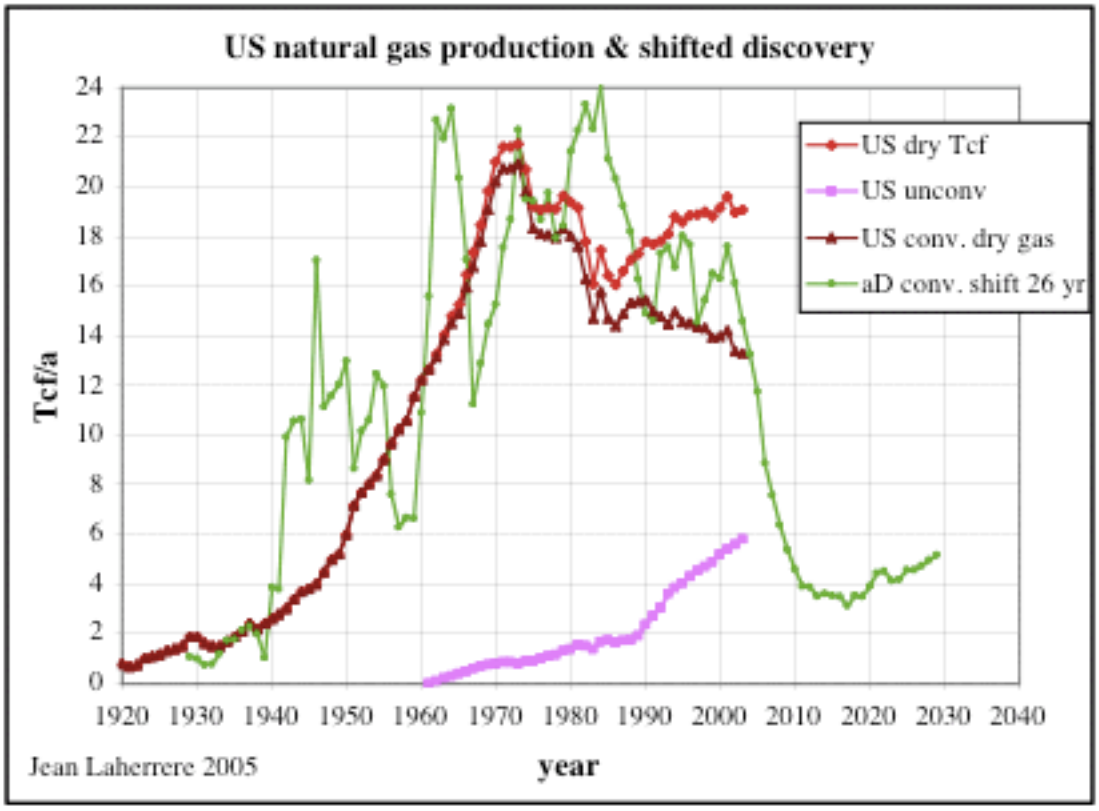
I am obliged to gather several field databases (over 25 000 fields outside US) and to correct them globally to the mean values to get a homogenous world database.

The result is that I call the technical data opposed to the political data as reported by the national oil companies.

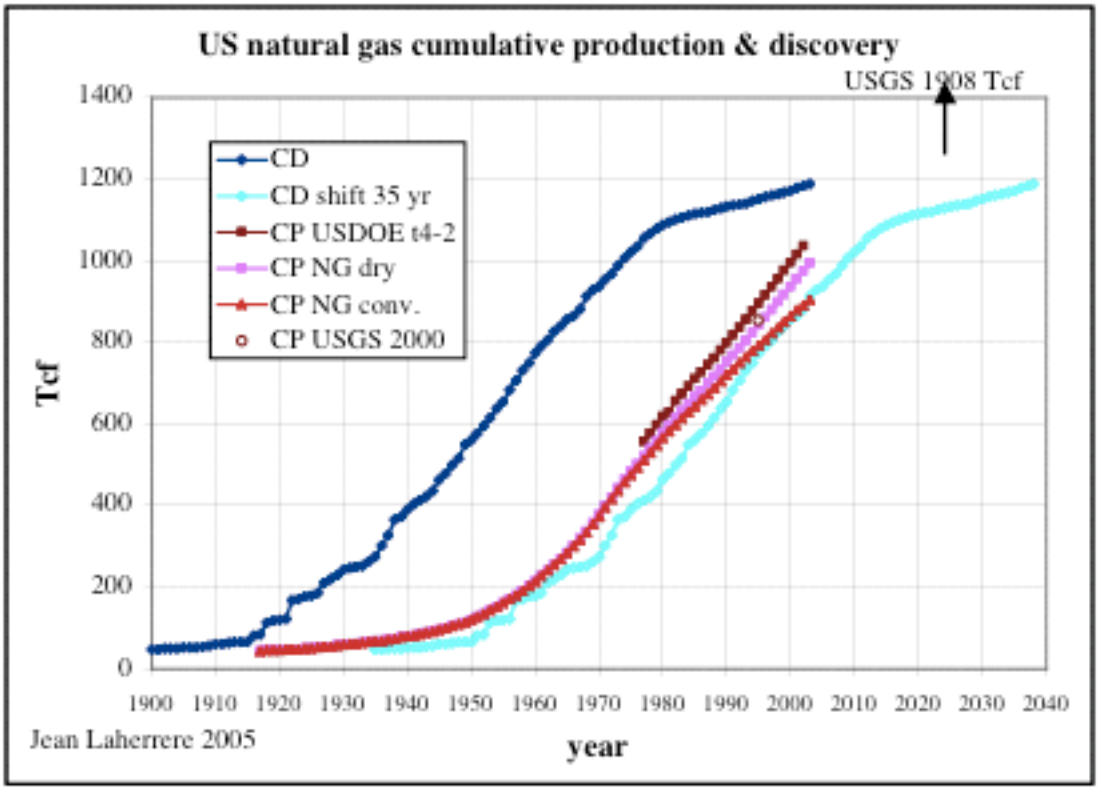
Figure 10: World remaining oil reserves from political and technical sources



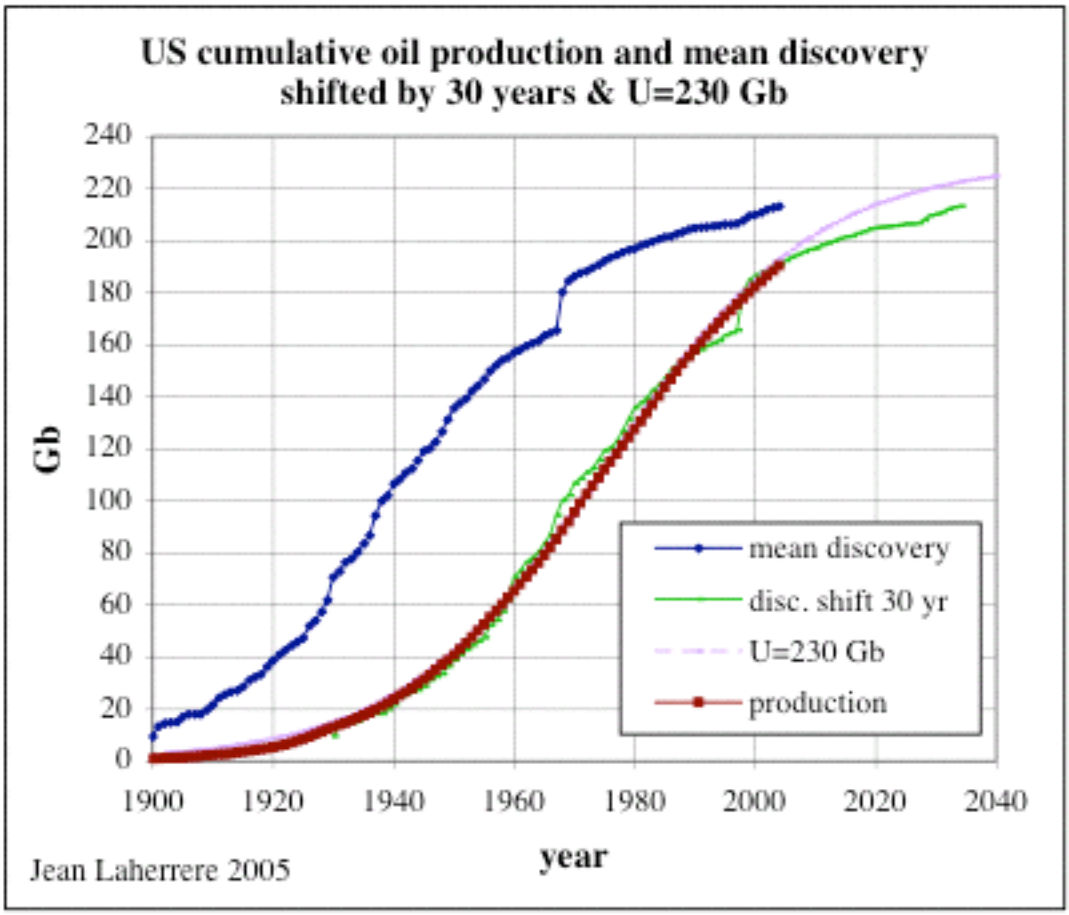
-**Forecasting production from past discovery by shifting to best fit**
In mature countries where there was little constraint on the demand production mimics discovery (mean values) with a certain shift and this shift provides a useful way of forecasting.
The shift of 26 years between US conventional natural gas production and discovery suggests a sharp drop in future production as unconventional gas is forecasted to peak in few years by USDOE
Figure 11: US conventional natural gas annual production and shifted discovery forecasting a drastic decline



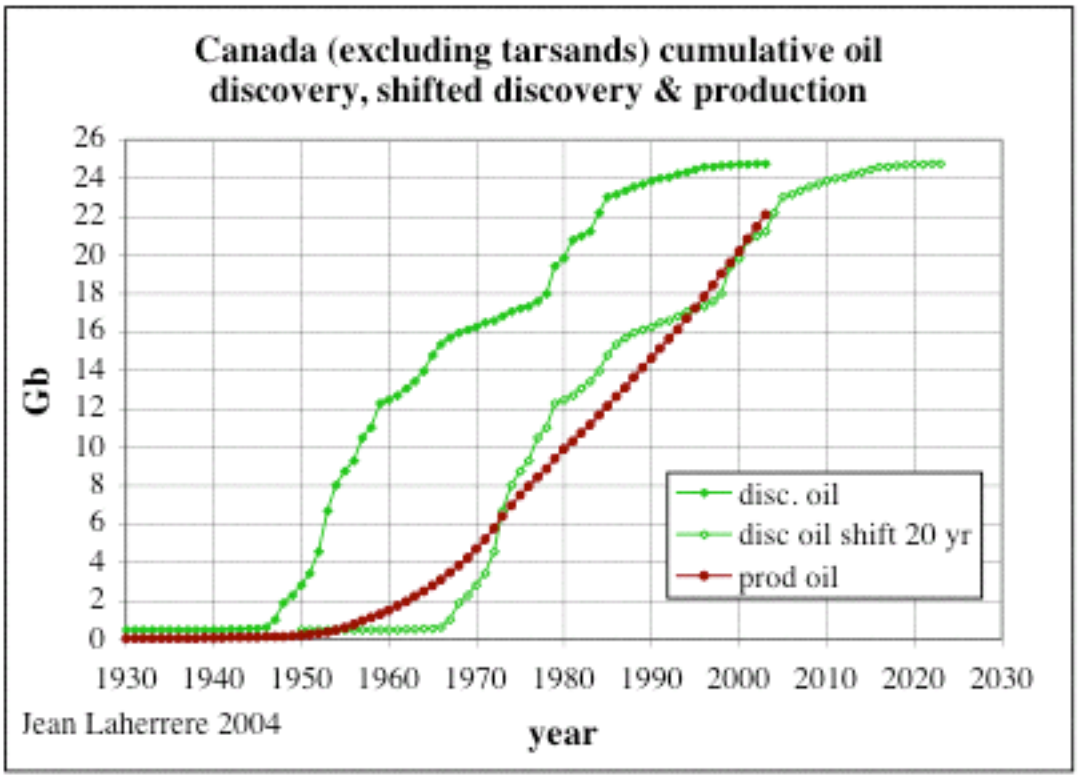
US cumulative conventional gas discovery displays an S curve (logistic function) as the production.
The 2001 USGS ultimate of 1908 Tcf looks overestimated!
Figure 12: US conventional natural gas cumulative production and shifted discovery



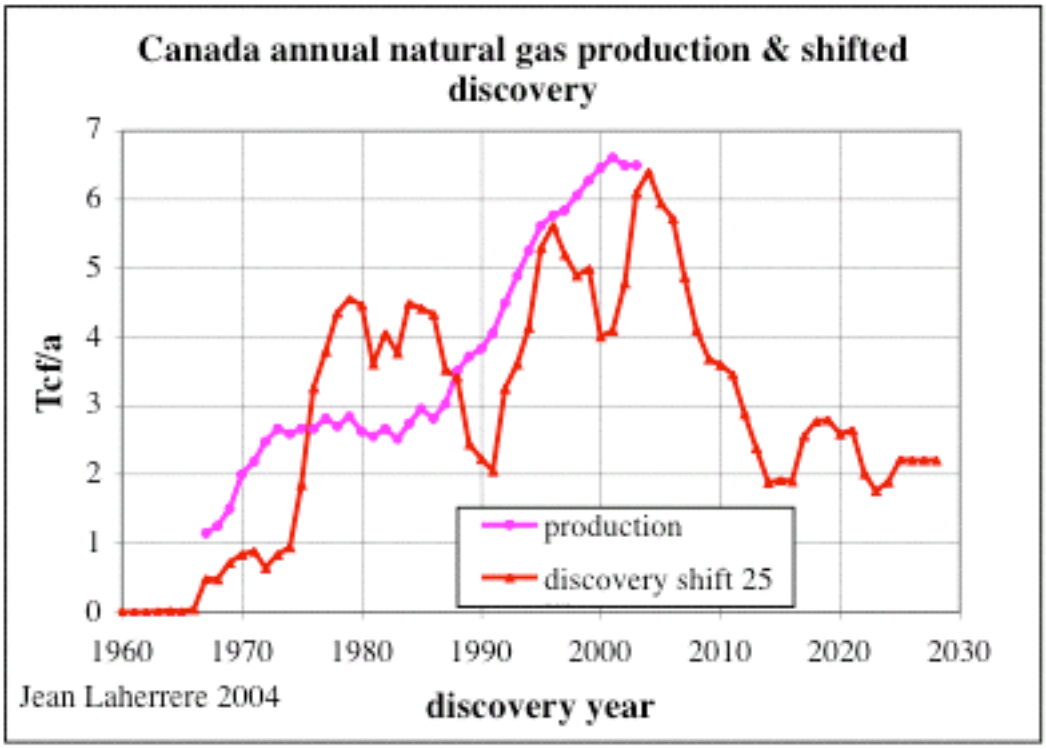
It is the same for US crude oil cumulative discovery and production with a shift of 30 years
Figure 13: US cumulative crude oil production and mean shifted discovery



For Canada, as the number of fields is much smaller, the cumulative discovery displays two cycles when oil production (excluding tarsands) has only one. The shift is about 20 years and a strong decline coming soon.
Figure 13: Canada cumulative crude oil production and mean shifted discovery



The shift of 20 years allows forecasting a soon coming sharp decline in gas production.
Figure 14: Canada annual natural gas production and mean shifted discovery



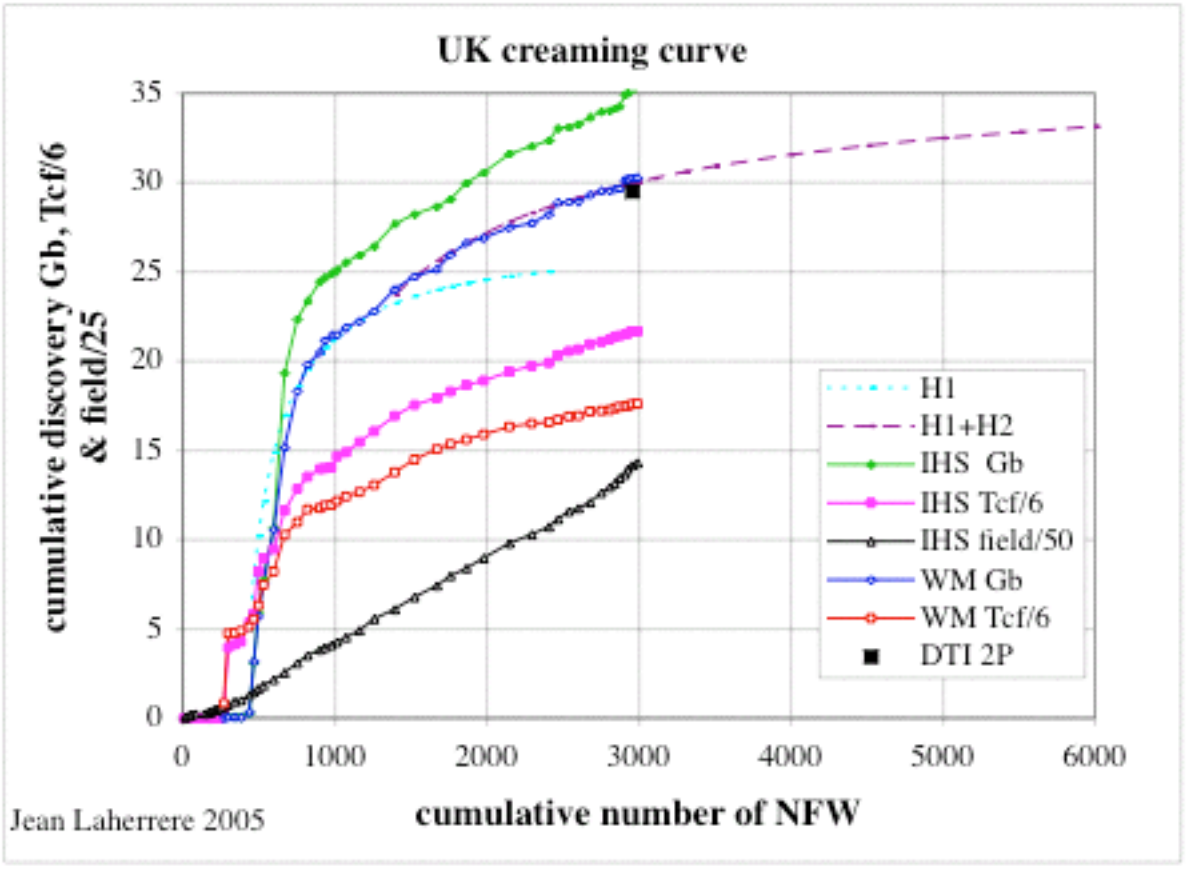
-Forecasting production by modelling from an ultimate coming from creaming curve
As Hubbert did it for the US oil using two ultimates coming from thorough studies by the most famous oil explorers: Wallace Pratt, L.Weeks and A.Levorsen. Forecasting country production needs to

estimate country ultimate. The best way to estimate ultimate is to draw creaming curves (cumulative discoveries versus cumulative number of new field wildcats =NFW), but discoveries have to be the mean values and not the proven values.
The main problem is to choose the right discovery value between several technical sources and several examples will illustrate how to choose, sometimes the help is from the past production (graph annual/cumulative versus cumulative).

-UK

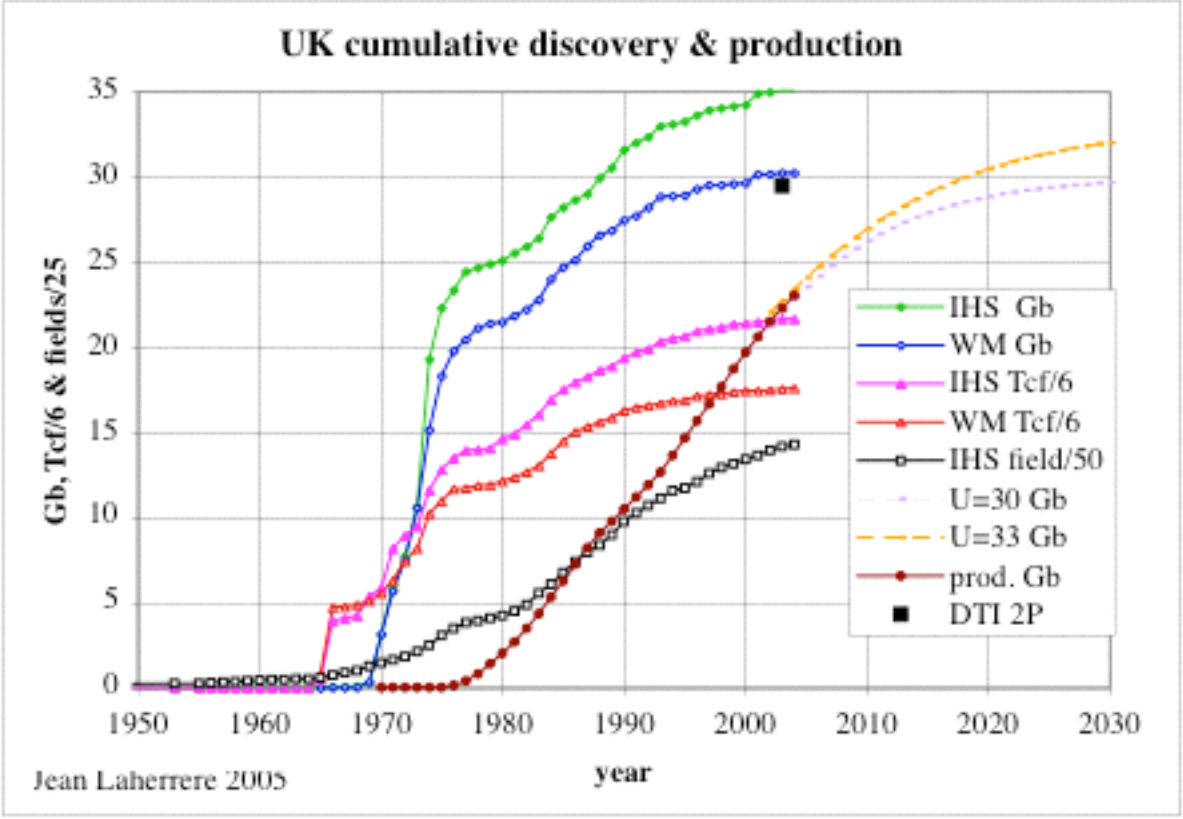
UK is with Norway (and the US Gulf of Mexico) the only countries reporting field values (proven+probable). It is however surprising to obtain divergent data from the two scout sources IHS and WM when reserves data are provided by DTI, because past annual field production allows estimating directly the field reserve. WM, which reports technical values, is in line with DTI when IHS reports every discovery even if completely uneconomical. The WM creaming curve can be modelled with two cycles giving an ultimate of 33 Gb.

Figure 15: UK creaming curve from IHS & WM with an ultimate of 33 Gb

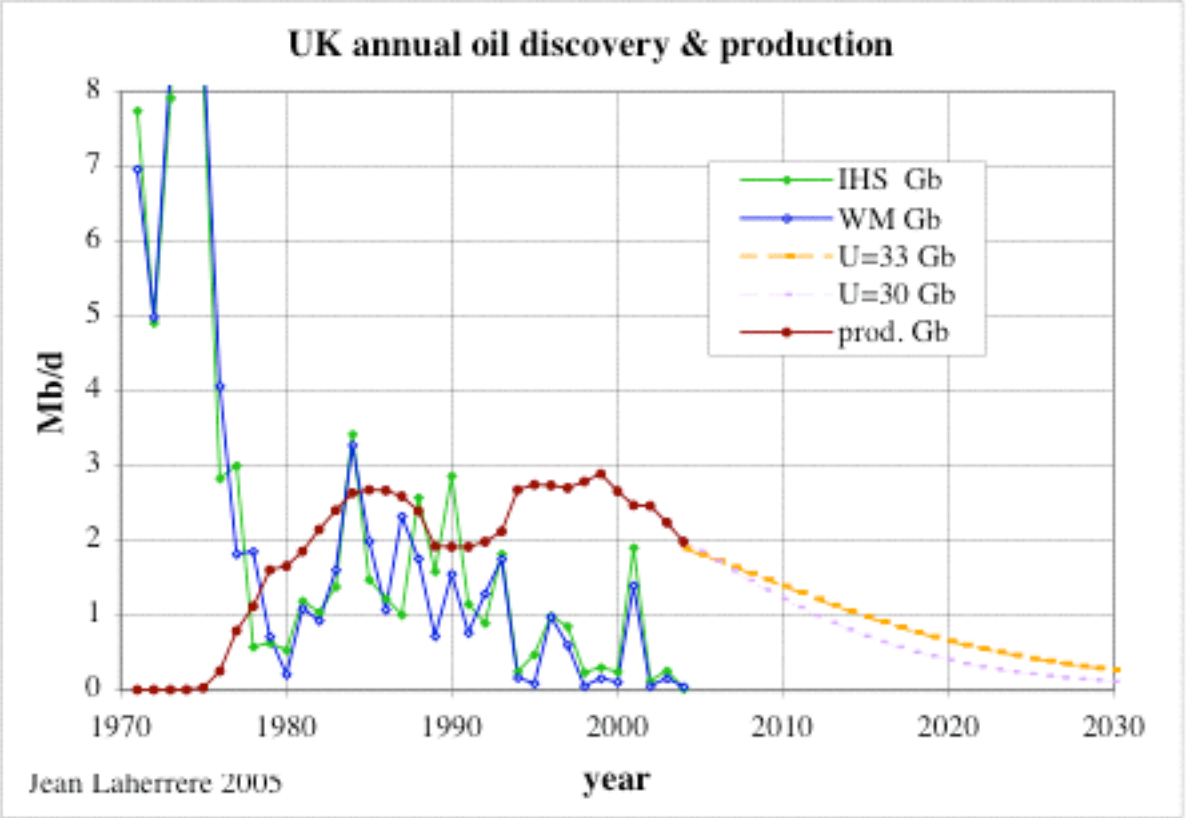


Cumulative oil production is modelled with U=30 and 33 Gb

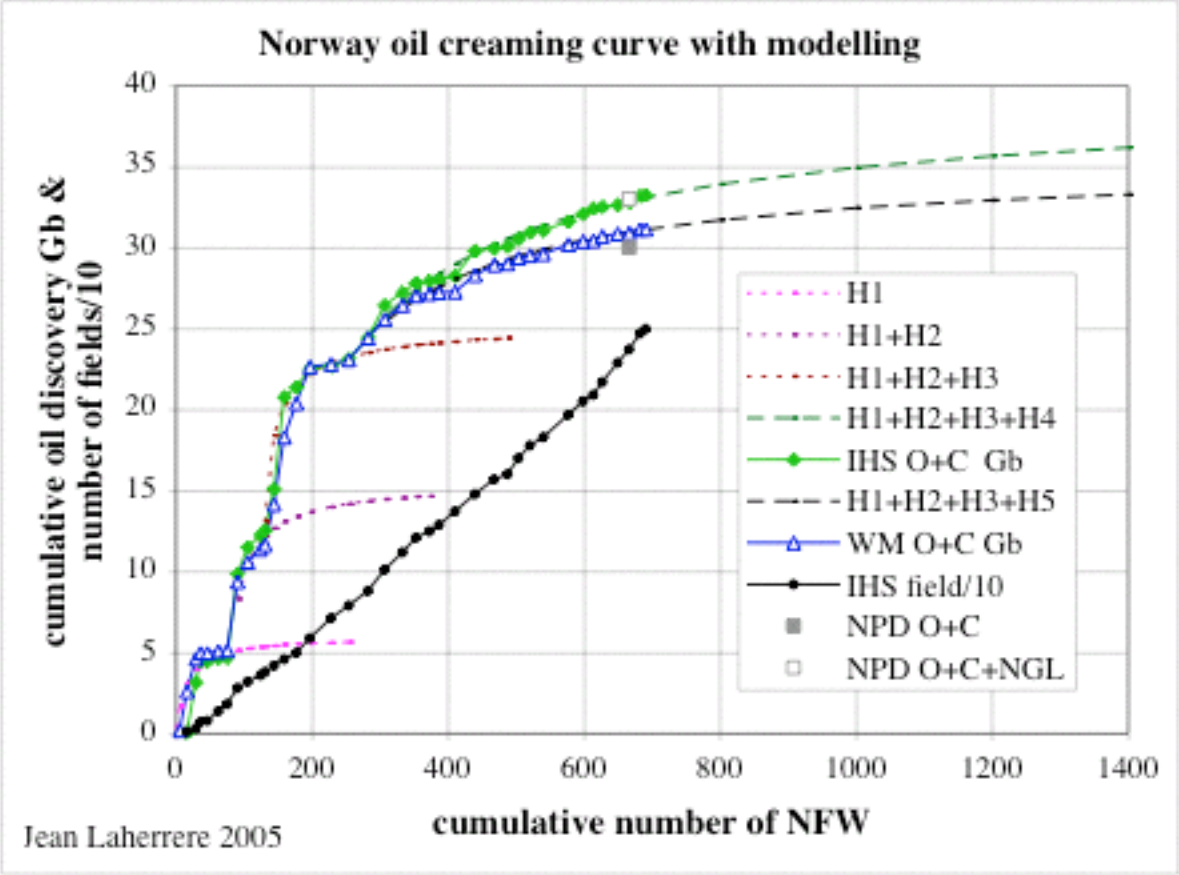
Figure 16: UK cumulative discovery and production U=30 & 33 Gb



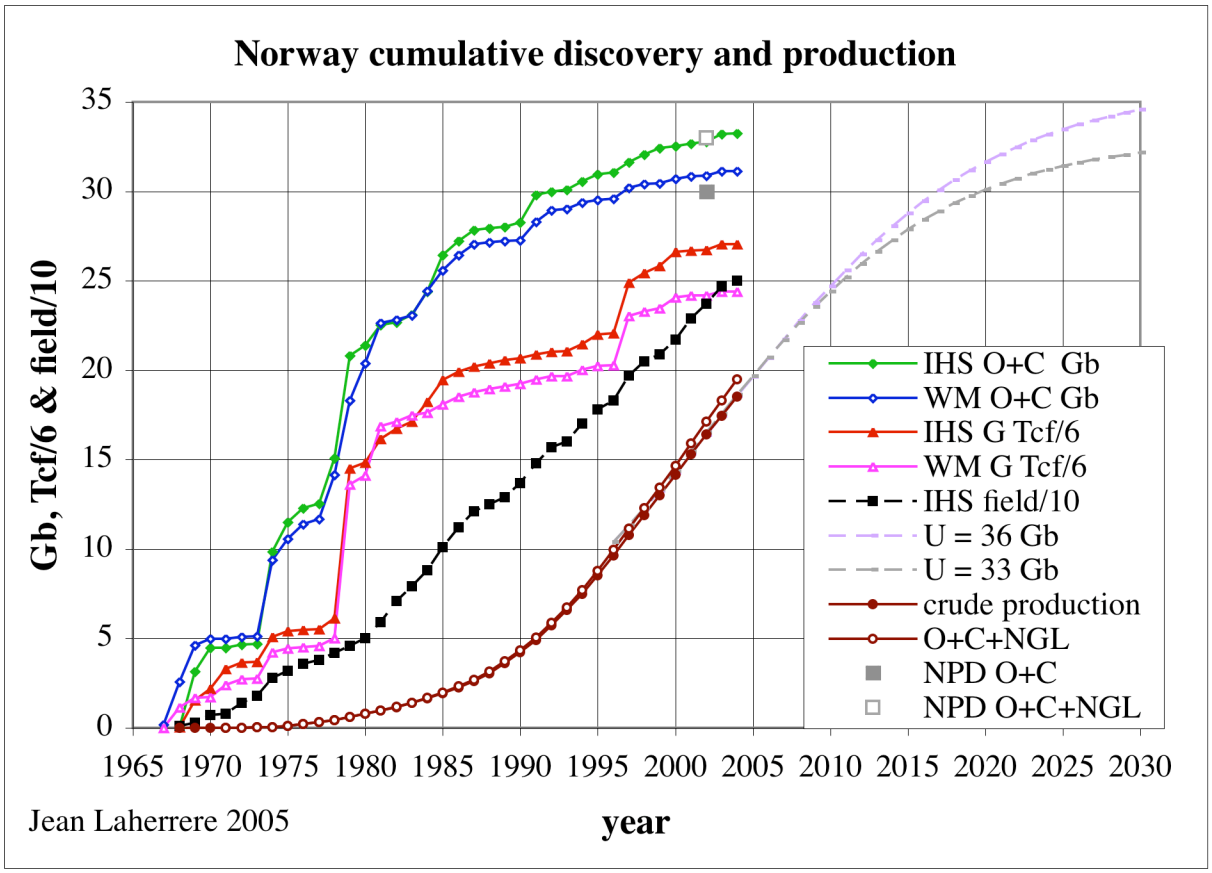
Annual production presently around 2 Mb/d will decline to 1 Mb/d around 2012
Figure 17: UK annual oil discovery and production U=30 & 33 Gb



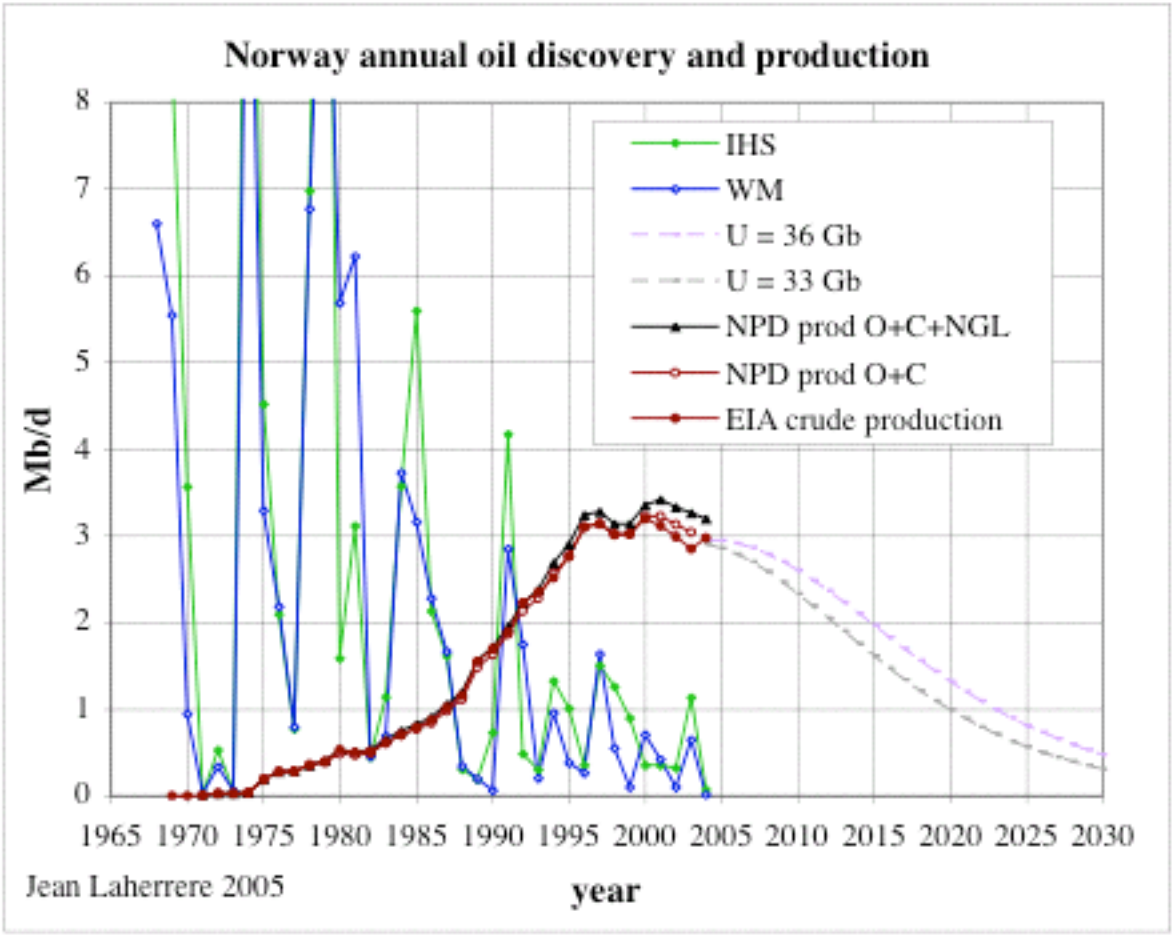
-**Norway**
Norway reports also field production and reserves. Again IHS is higher than WM.
The problem is that NPD reports separately NGL (in Mt = 1,9 M.m3) and condensate (in M.m3) when in close by fields UK reports only condensate (in Mt). USDOE reports NGPL for 2001 & 2002 more than 50% over NPD values? NGPL data reliability is another problem in liquids reporting.
Figure 18: Norway oil creaming curve from IHS & WM



Cumulative oil production is modelled for U=33 & 36 Gb
Figure 19: Norway cumulative discovery and production U=33 & 36 Gb



Annual oil production, which is about 3 Mb/d now, will decline to 1 Mb/d around 2020.
Figure 20: Norway annual oil discovery and production U=33 & 36 Gb

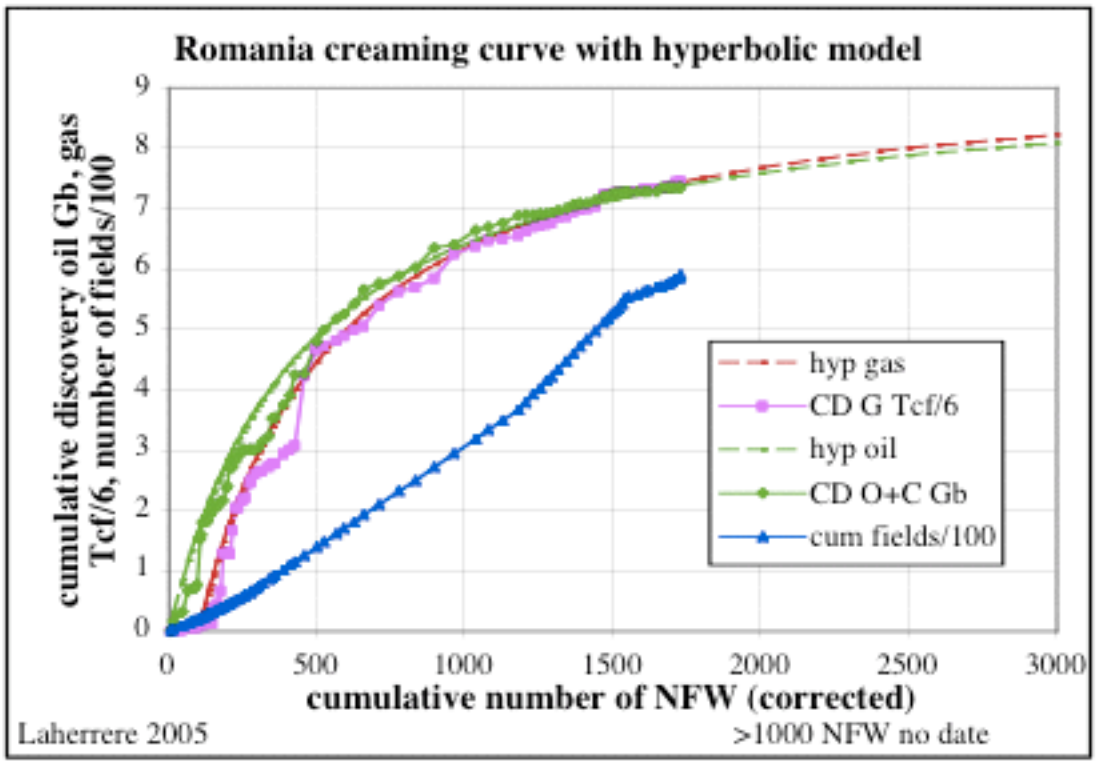


-Romania

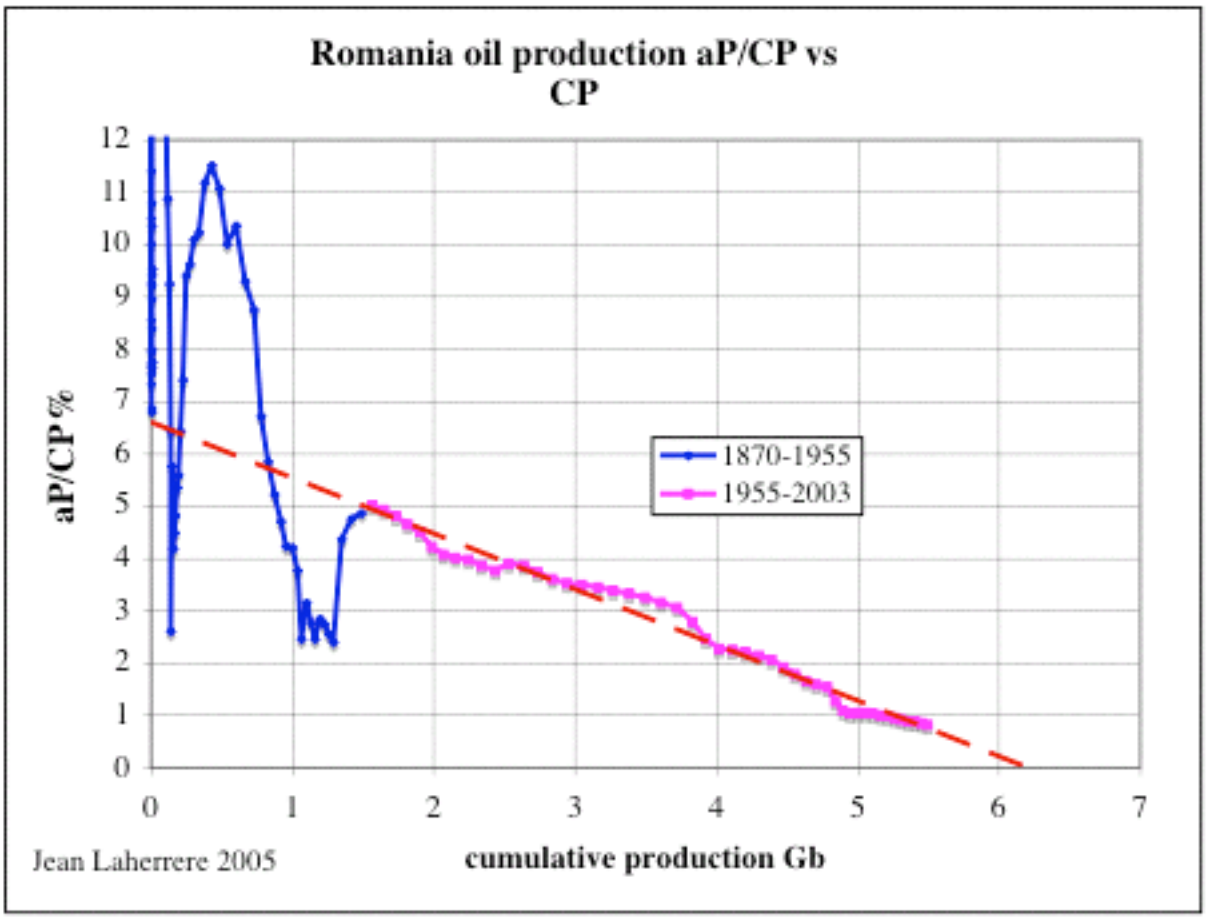
Romania is a mature country allowing to comparing discovery and production.

Only one source of reserves data as WM does not report Romania fields. Oil and natural gas have a similar discovery pattern in oil equivalent. There is only one cycle and a second is unlikely. The ultimate seems to be around 8 Gb.

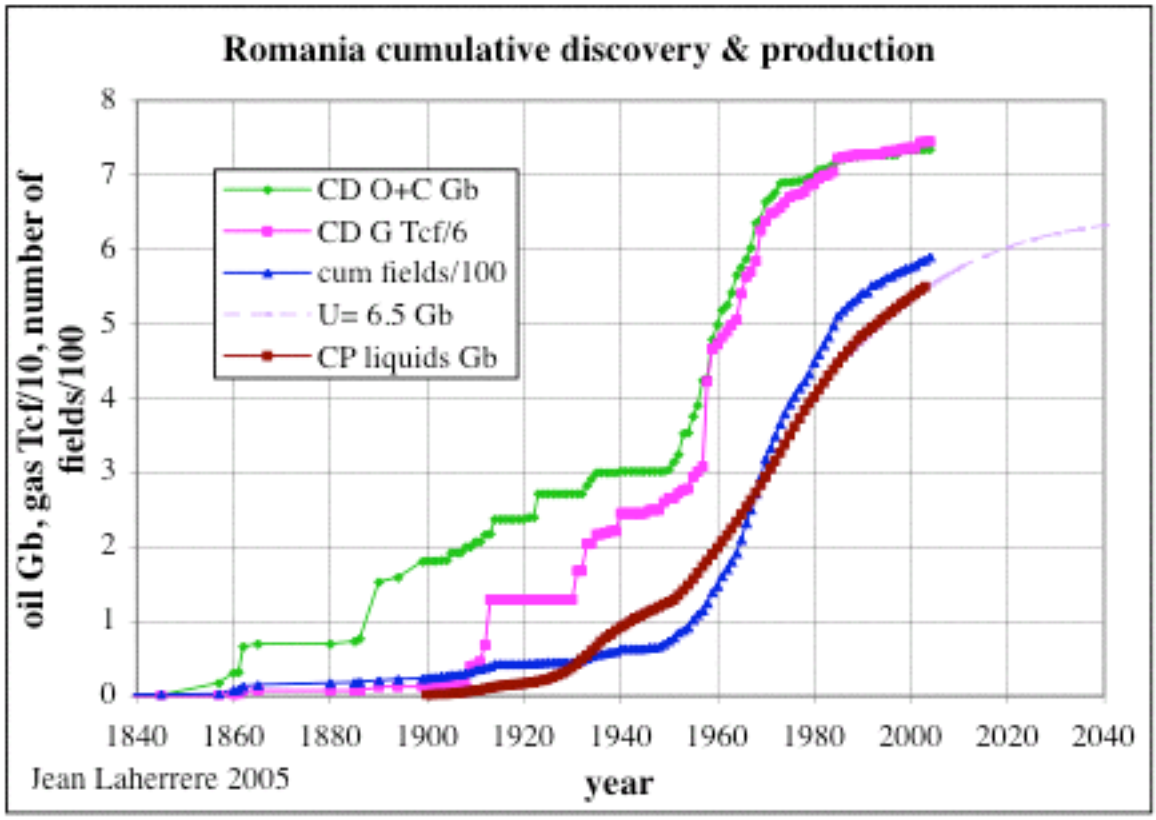
Figure 21: Romania creaming curve with U=8 Gb for oil



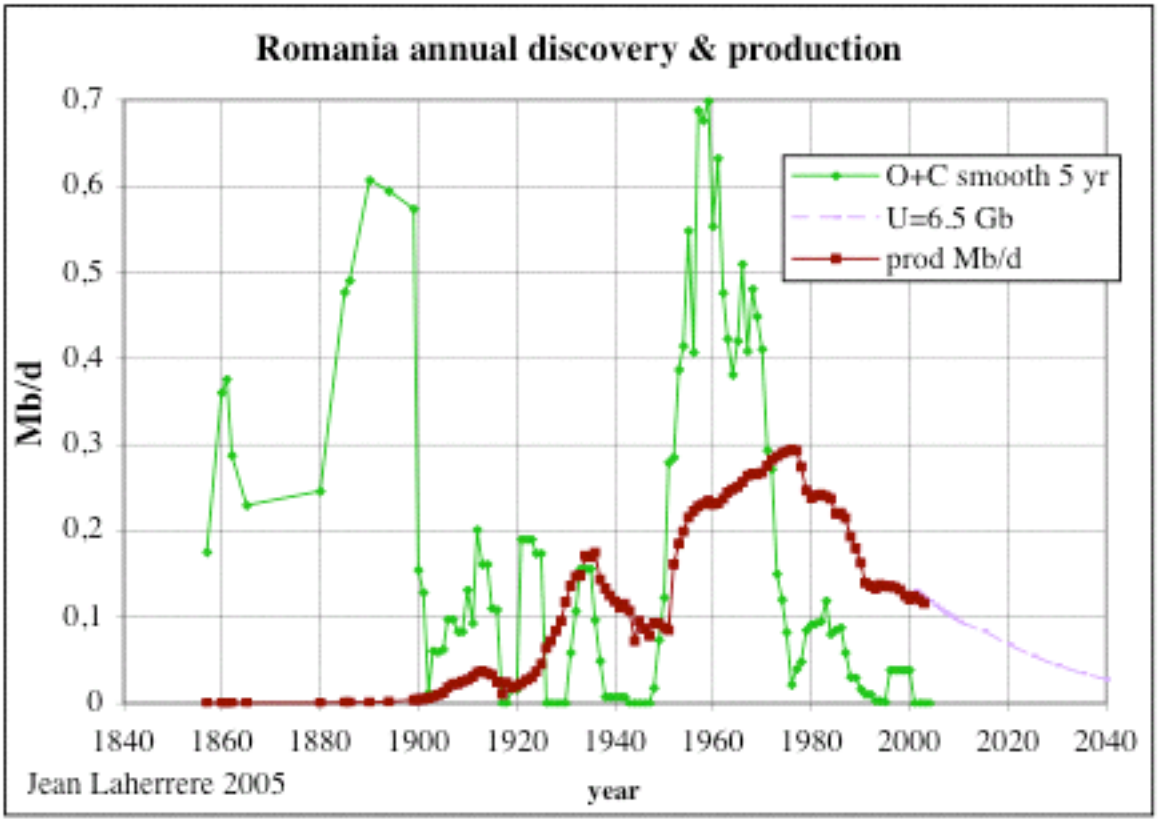
To check IHS values, the ultimate is guessed from production trend, which is only 6 Gb instead of 8 Gb
Figure 22: Romania oil production aP/CP giving an ultimate of 6 Gb



Cumulative production is modelled with U=6.5 Gb.
Figure 23: Romania cumulative discovery and production as model U=6.5 Gb



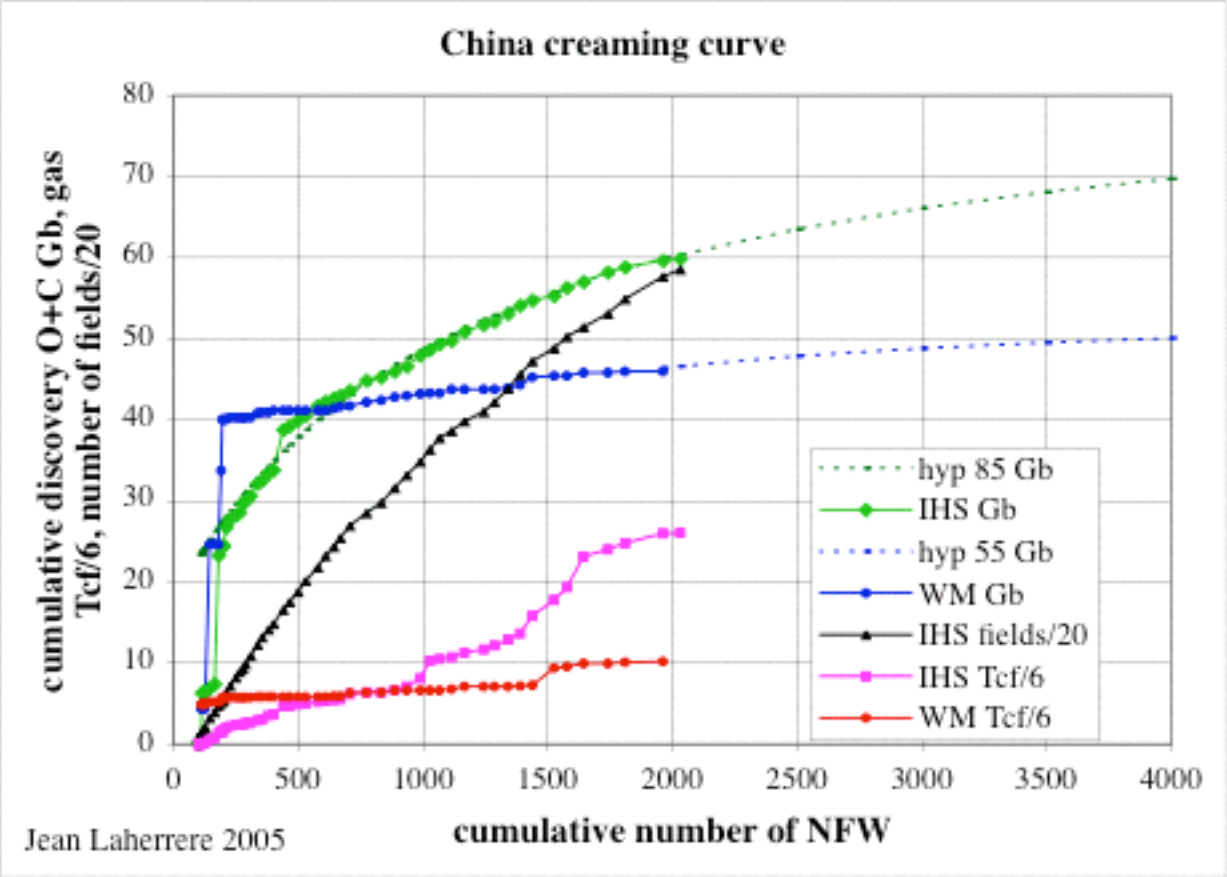
Annual oil production will continue to decline, as discovery since 1960.
Figure 24: Romania annual oil discovery and production as model U=6.5 Gb



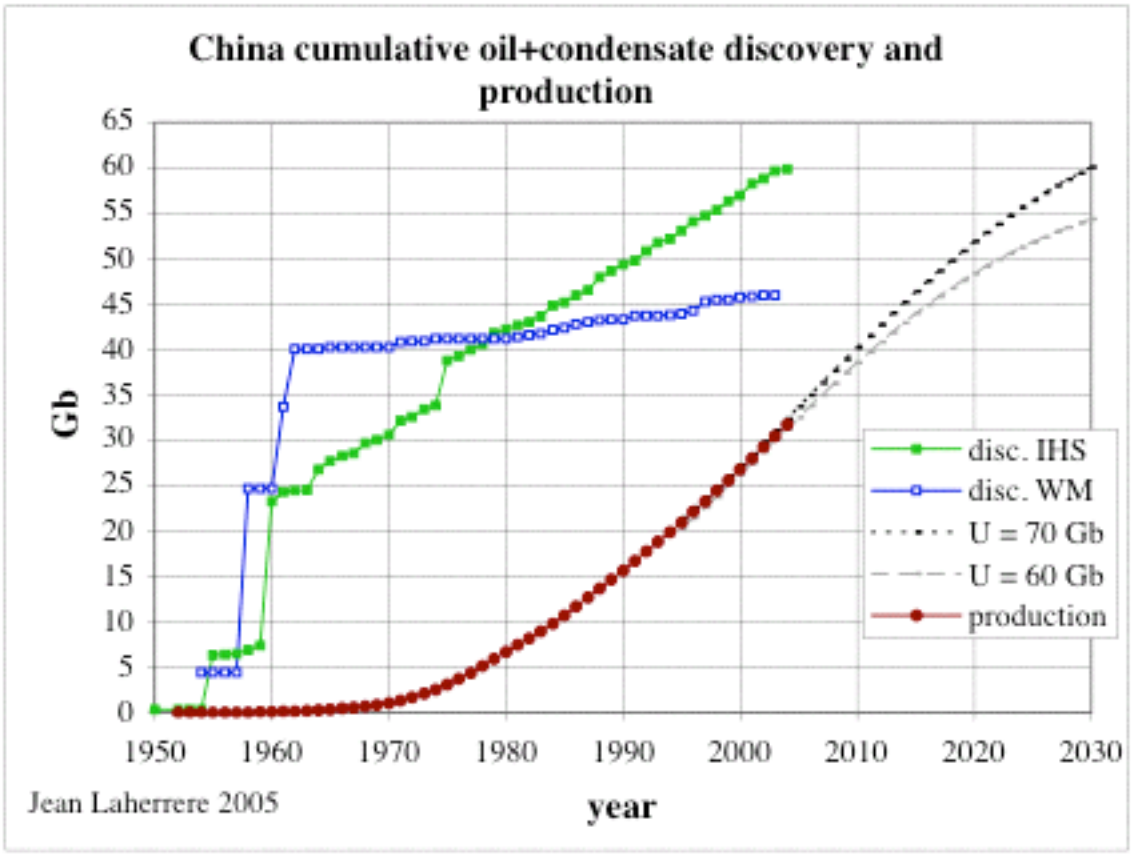
-China

IHS and WM shows different creaming curve patterns, as WM groups fields, but the ultimate could vary from 50 to 70 Gb (corresponding to doubling present cumulated NFW) when the asymptote is for 55 and 85 Gb.

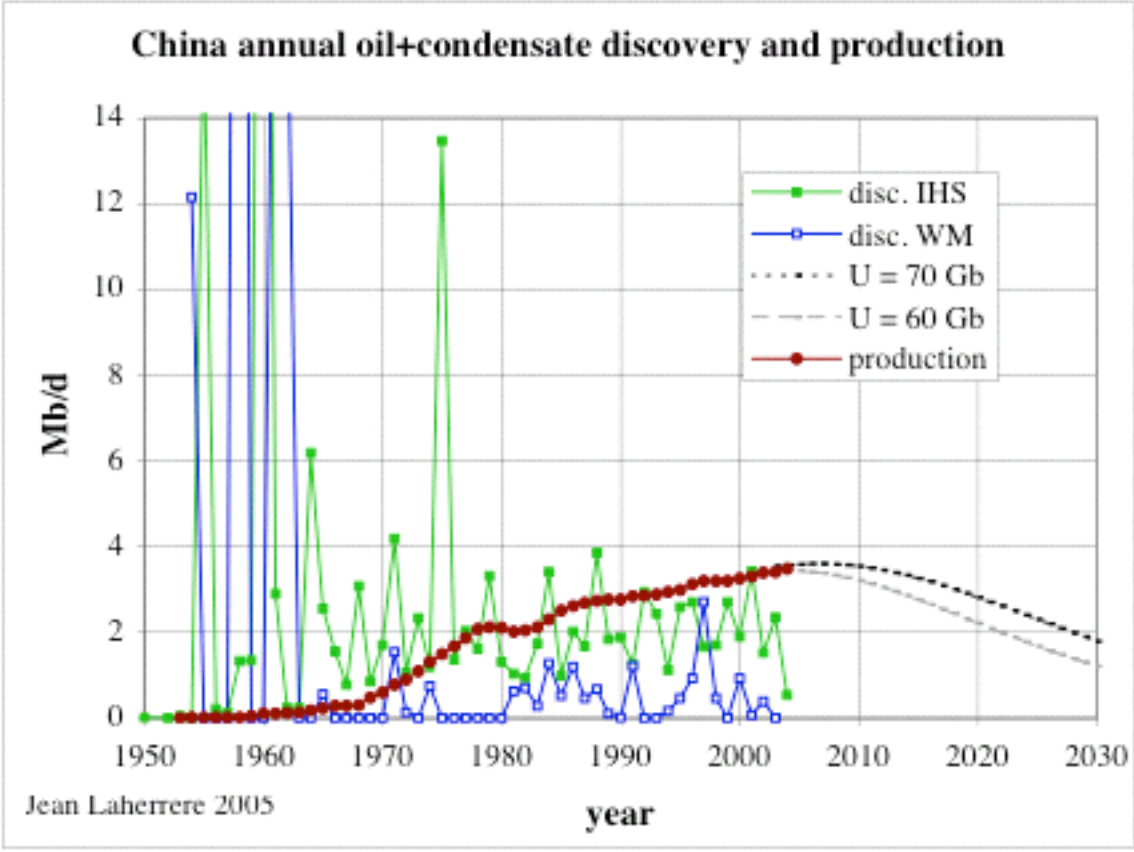
Figure 25: China creaming curve



Cumulative oil production is modelled for 60 & 70 Gb.
Figure 26: China cumulative oil discovery and production as models U= 60 & 70 Gb



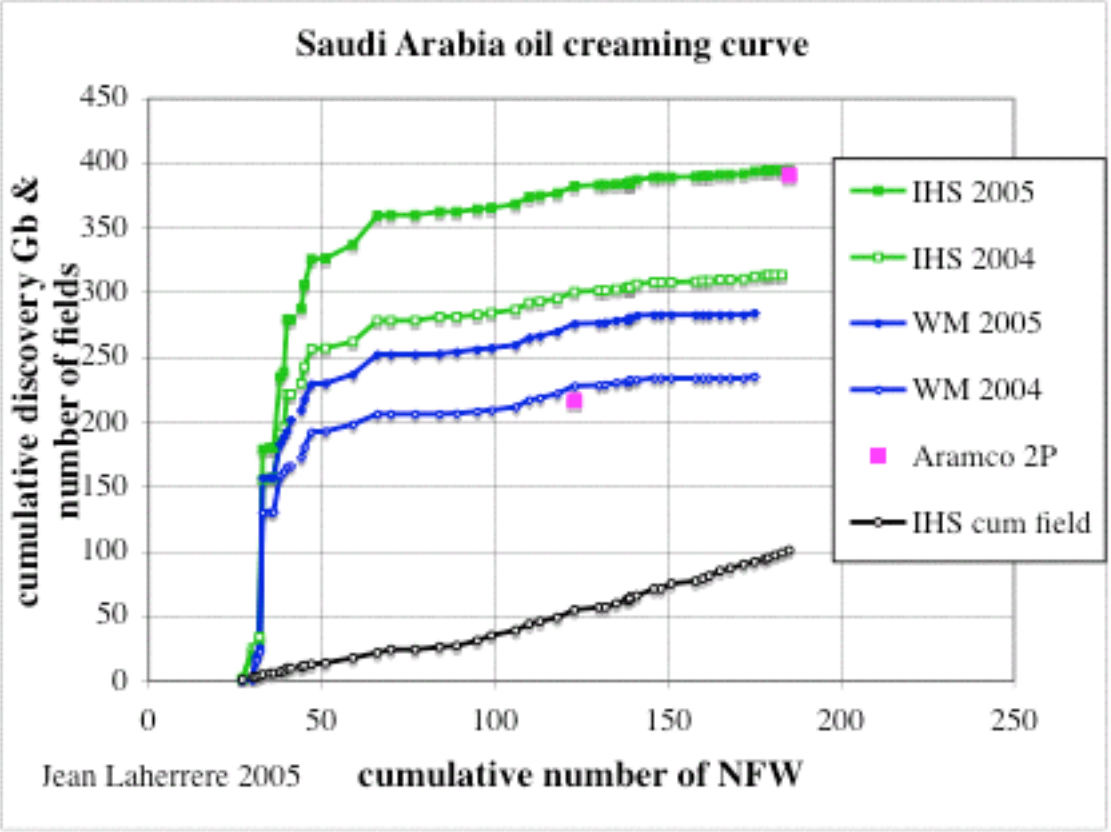
Annual oil production will decline soon.
Figure 27: China annual oil discovery and production as models U= 60 & 70 Gb



-Saudi Arabia

As Matt Simmons said Saudi oil is important as it is assumed to compensate the decline of many producing countries. But field reserves data are difficult to get. IHS added more than 80 Gb in the cumulative discovery from last year to this year in order to match the 2004 Aramco reported 391 Gb for 2P. WM added about 40 Gb but still about 100 Gb less than IHS. It is interesting to notice that WM 2004 value for 1980 was about 210 Gb which is the value reported in 1980 by Aramco ("Aramco and its world") before being nationalized. It is obvious that scout companies want to please the OPEC countries as the future important clients. This creaming curve shows very clearly that the country is not under explored because 90 % of the discoveries were found within the first quarter of NFW, the last quarter has found about nothing compared to the first quarter.

Figure 28: Saudi Arabia creaming curve



To increase the country cumulative oil discoveries by 80 Gb form last year to this year, IHS has increased the estimate of large fields by simply increasing the recovery factor. Ghawar last year IHS 60% was increased to 70% (from 122 Gb to 147 Gb), which seems difficult to get when knowing that the aquifer is inactive, but WM increase was from 108 Gb to 131 Gb. But Manifa field discovered in 1957 and which has been on production since 1965 and has produced only 0.3 Gb is now reported by IHS to have 23 Gb with 70 % RF (17 Gb last year with 52 %), but 4 Gb by WM.
The difference between IHS and WM is given below. For the country IHS has increased from 314 Gb to 395 Gb, when WM has increased from 196 to 239 Gb

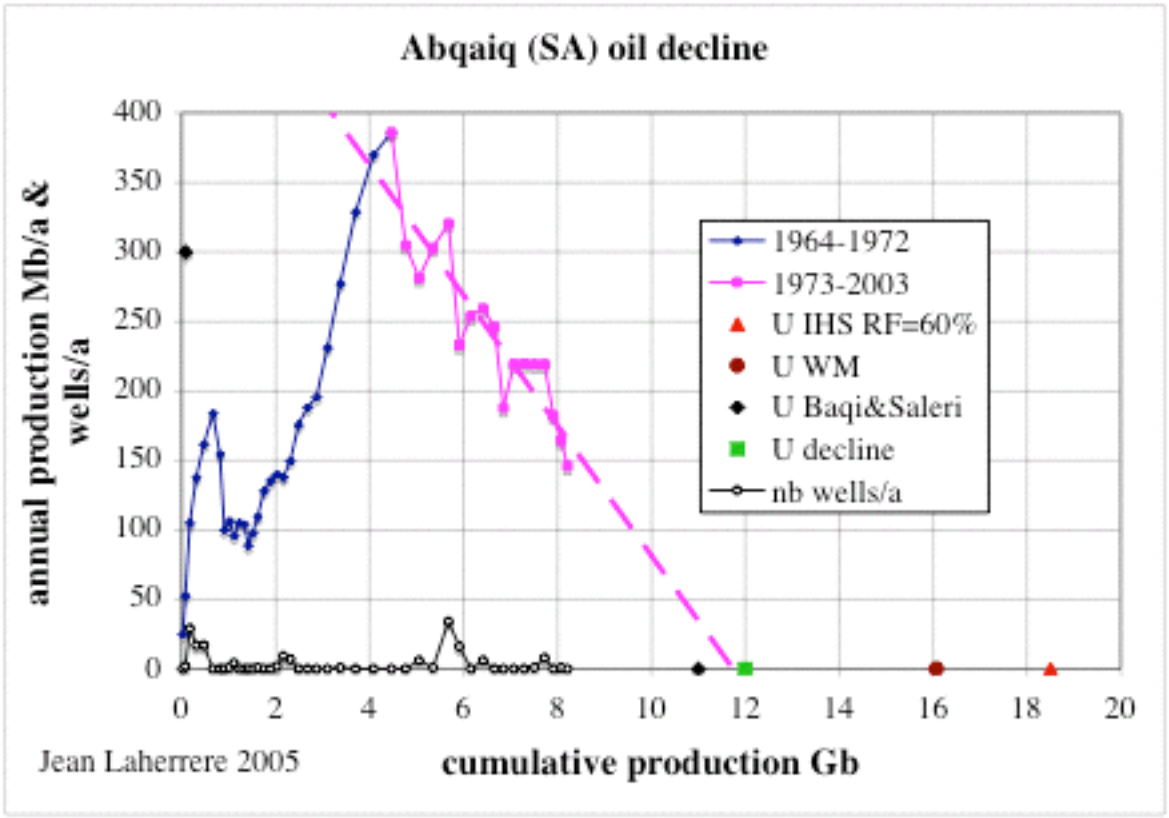
O+C Gb	Disc	**IHS**		RF	RF	**WM**	
Field		2005	2004	2005	2004	2005	2004
Ghawar	1948	147	122	70%	60%	131	108
Safaniya	1951	55	35	69%	54%	25	27
Shaybah	1968	22	15	70%	68%	14	7
Manifa	1957	23	17	70%	52%	4	4
Abqaiq	1940	19	22	60%	72%	16	15
Zuluf	1965	20	14	62%	43%	12	12
Berri	1964	18	13	59%	40%	8	8
Khurais	1957	17	9	47%	24%	9	0,2
Marjan	1967	10	4	67%	35%	6	4
Qatif	1945	10	9	50%	45%	7	6
Abu Sa'fah	1963	8	8	52%	52%	4	4
Khursaniyah	1956	4	4	55%	55%	3	1
12 fields		353	272			239	196
all fields		395	314			284	236

Baqi & Saleri Saudi Aramco Feb 2004 reported some field data by giving the percentage of depletion and cumulative production. Ghawar is given as 115 Gb compared to 147 Gb by IHS and 131 Gb by WM. For these 8 fields the total is 233 Gb for Aramco when 299 Gb for IHS and 217 for WM. It is obvious that IHS is now overestimating reserves, looking more to political data than to geological data.

Field Gb	CP	depletion	Ultimate	IHS	WM
Ghawar	55	48%	115	147	131
Safaniya	14	26%	54	55	25
Shaybah	0,9	5%	18	22	14
Abqaiq	8,2	73%	11	19	16
Zuluf	1,7	16%	11	20	12
Berri	3	28%	11	18	8.3
Marjan	0,8	13%	6	10	6
Abu Sa'fah	1,7	21%	8	8	4.3
Total	85		233	299	217

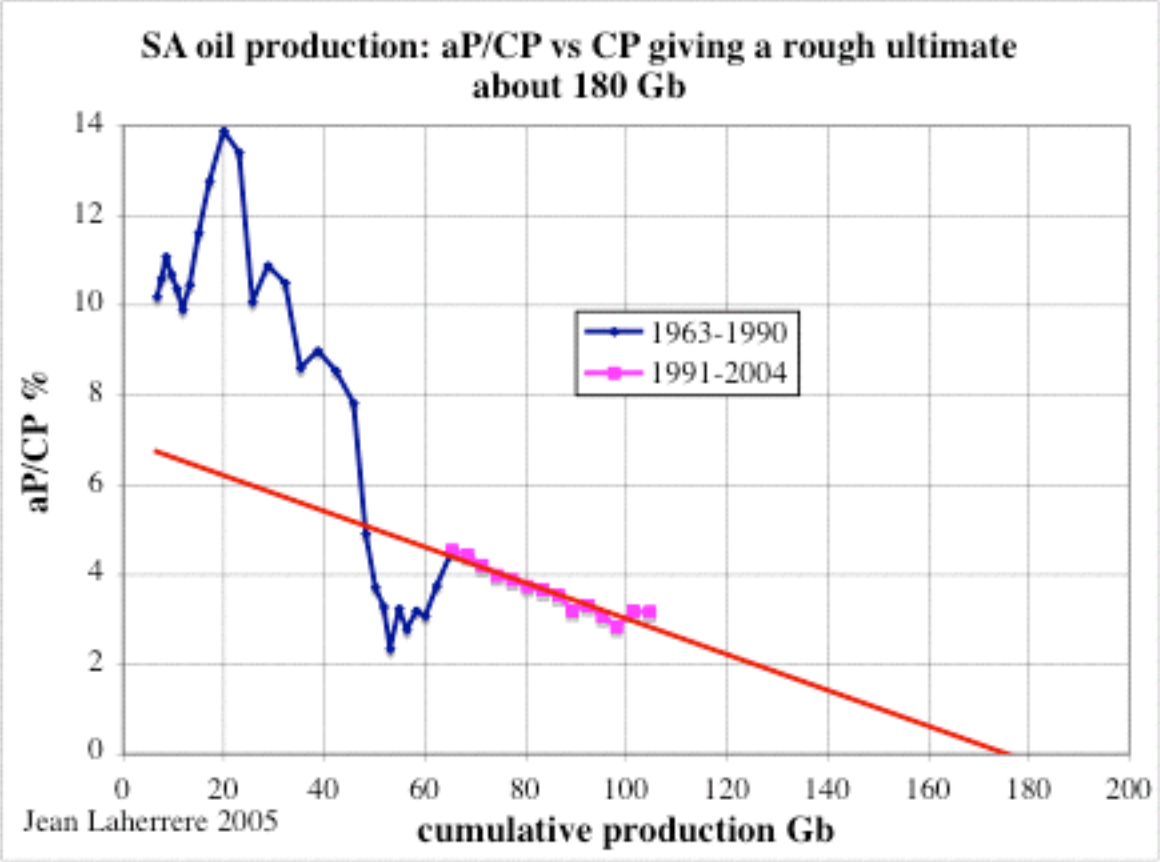
Abqaip (78 % depleted) is reported as 11 Gb when 19 Gb for IHS and 16 Gb for WM.
The oil decline of Abqaiq is obvious on the annual plot versus cumulative giving an ultimate around 12 Gb

Figure 29: Abqaiq oil decline



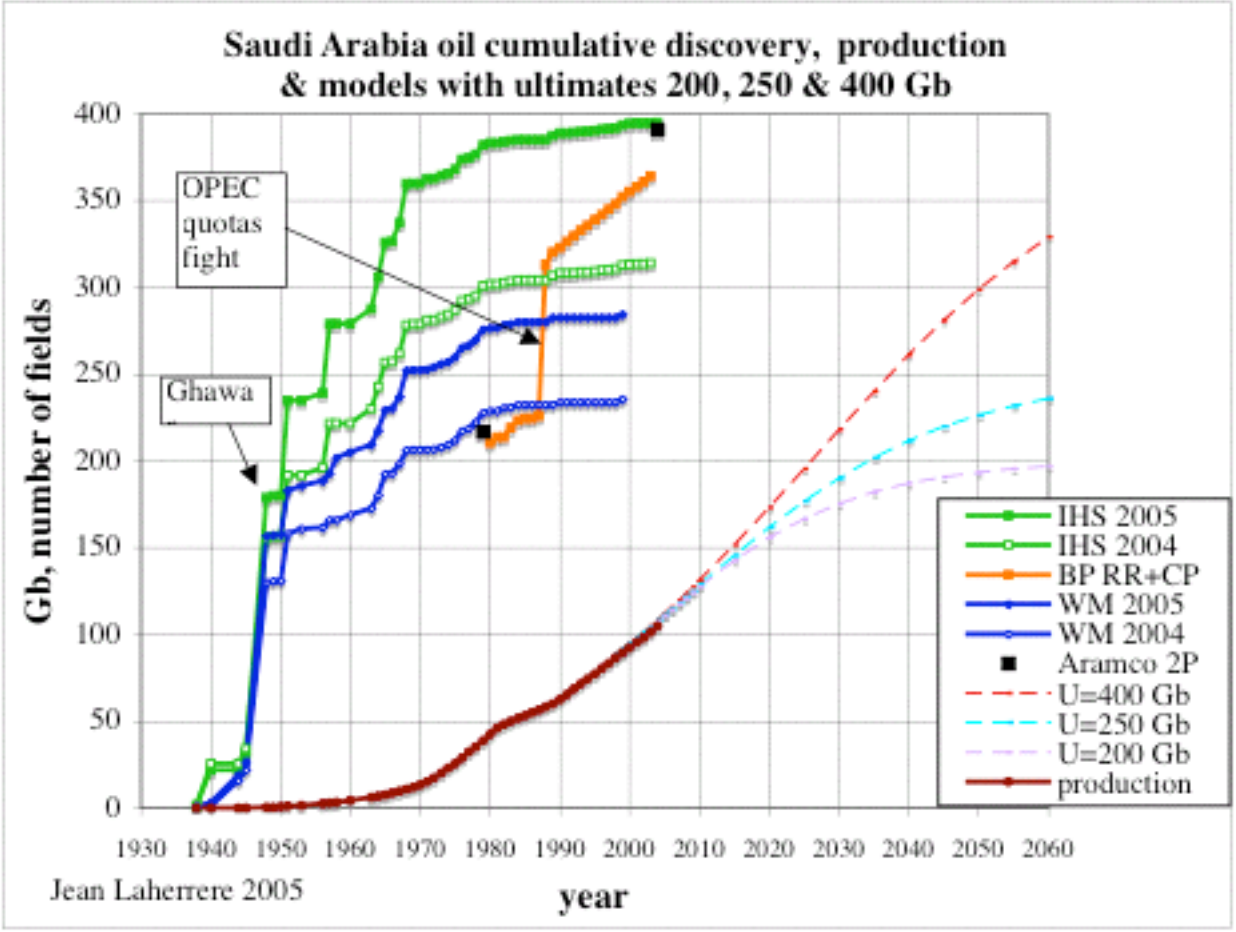
The plot of oil production aP/CP versus CP gives a rough estimate of 180 Gb by extrapolating the last linear trend from 1991 to 2004.

Figure 30: Saudi Arabia oil production: aP/CP giving an ultimate of 180 Gb

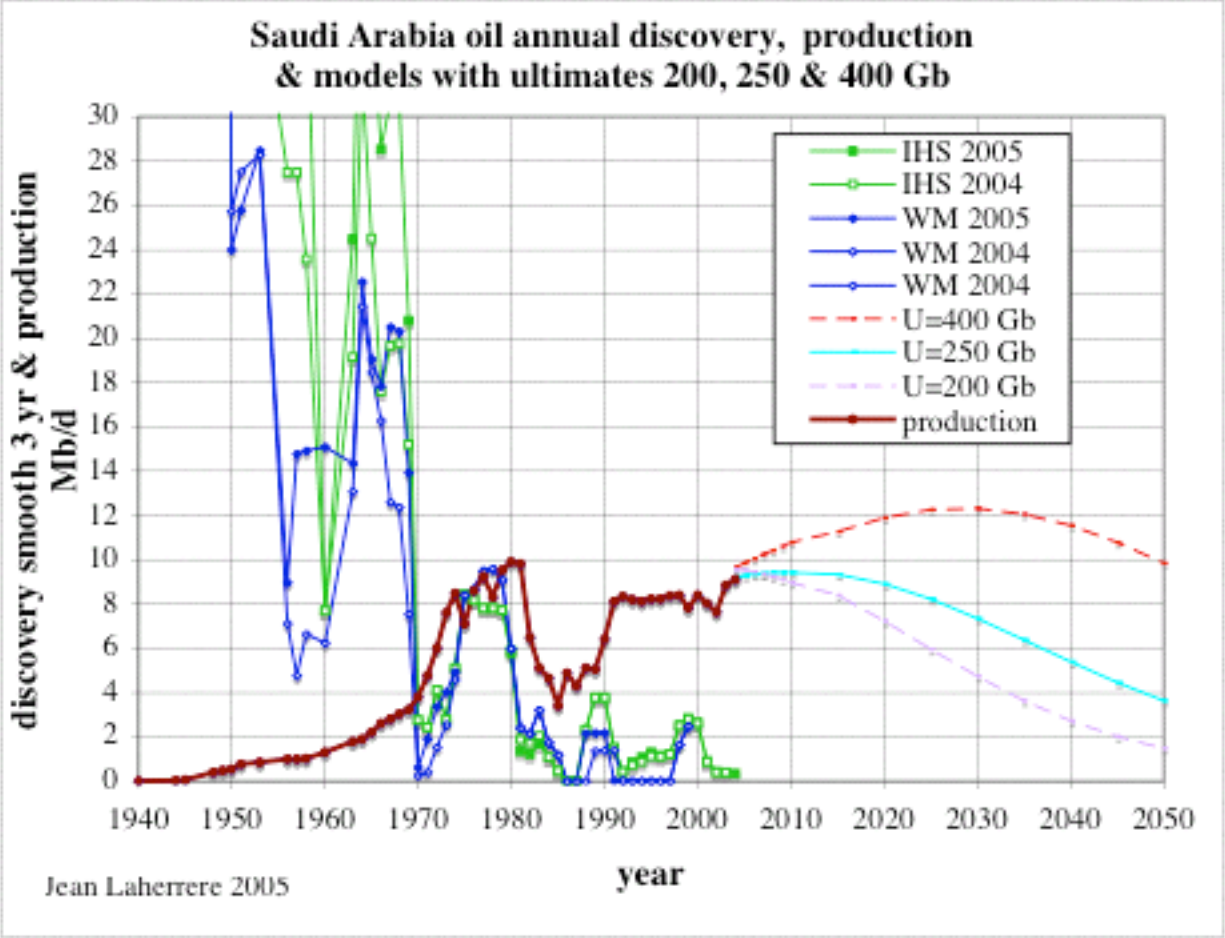


Cumulative production is modelled with ultimates of 200, 250 and 400 Gb. It is interesting to notice that the OPEC remaining proved reserves + cumulative production, which was in 1980 at 210 Gb (close to 2P Aramco 1980 and WM 2004) and it is now rising towards the Aramco 2004 2P. Proven is going, as in the US, towards proven +probable.

Figure 31: Saudi Arabia cumulative oil discovery and production as models U= 200, 250 & 400 Gb

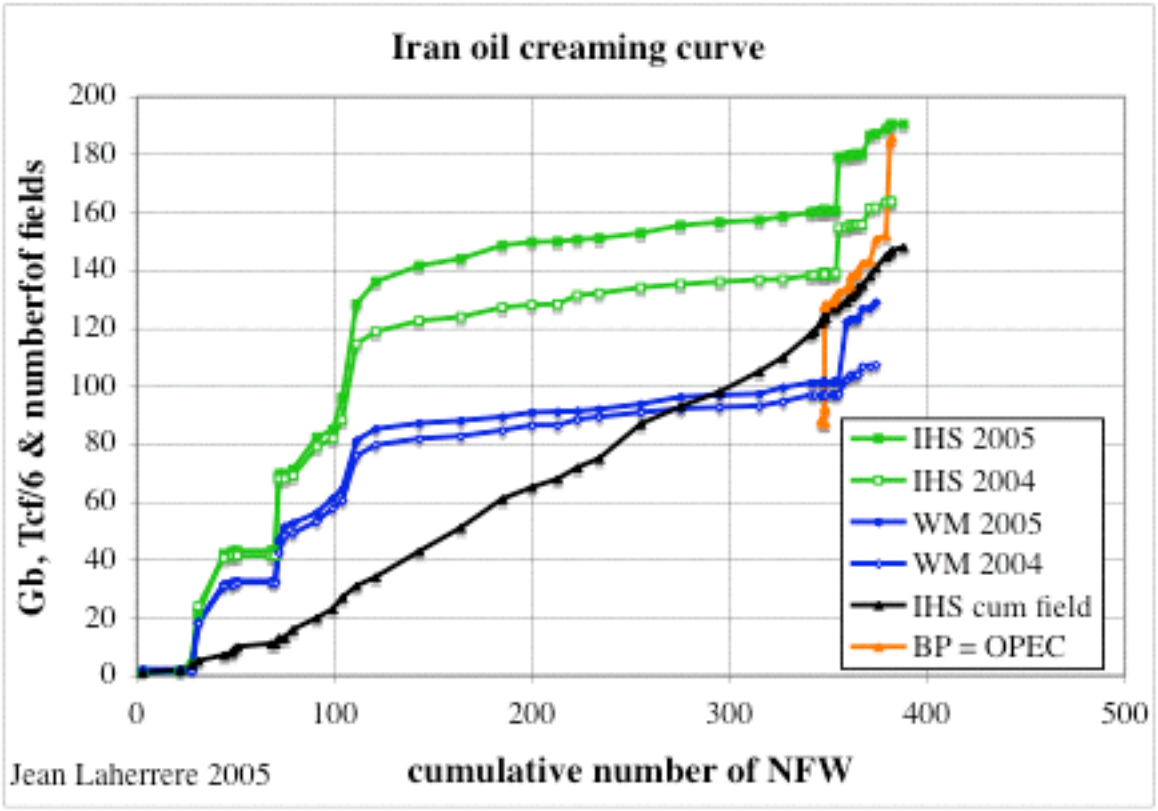


Annual production is forecasted with the three ultimates from 200 to 400 Gb but even it is difficult to justify the promised 15 Mb/d during 50 years. The 400 Gb peaks at 12 Mb/d for less than 20 years
Figure 32: Saudi Arabia annual oil discovery and production as models U= 200, 250 & 400 Gb

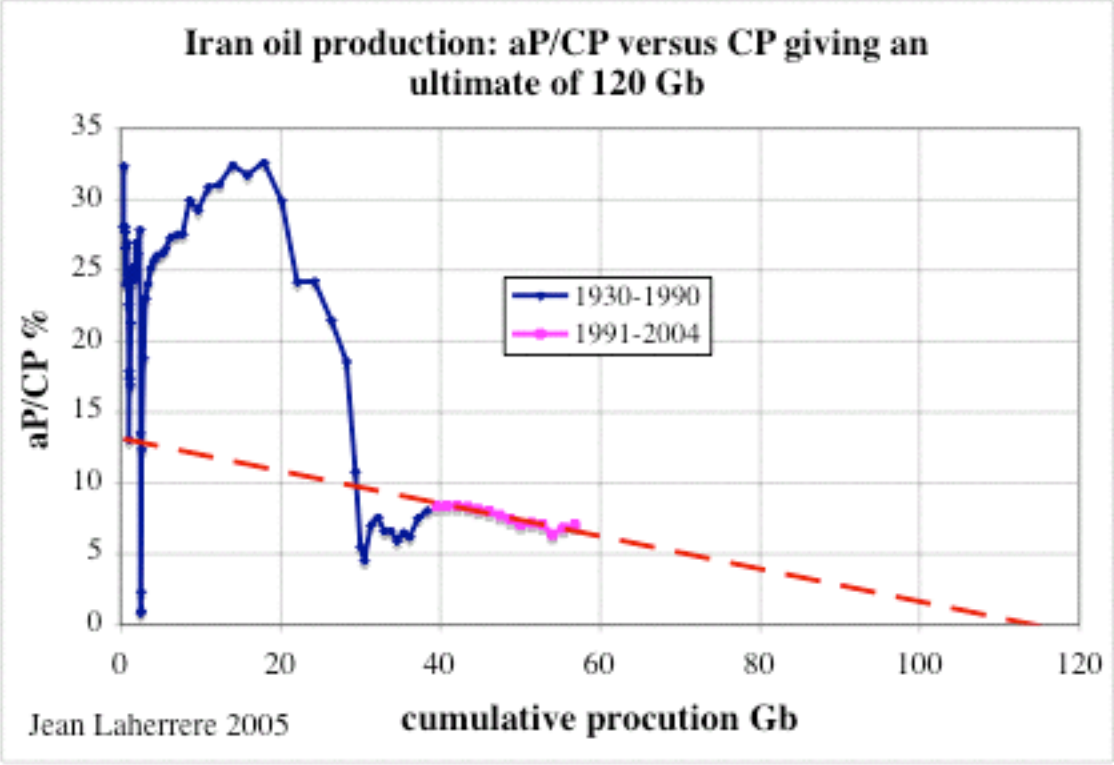


-Iran

Iran is the subject of political increase, which seems unjustified even by the recent discoveries as Azadegan. IHS and WM have increased cumulative oil discoveries from last year by more than 20 Gb.
Figure 33: Iran Arabia creaming curve

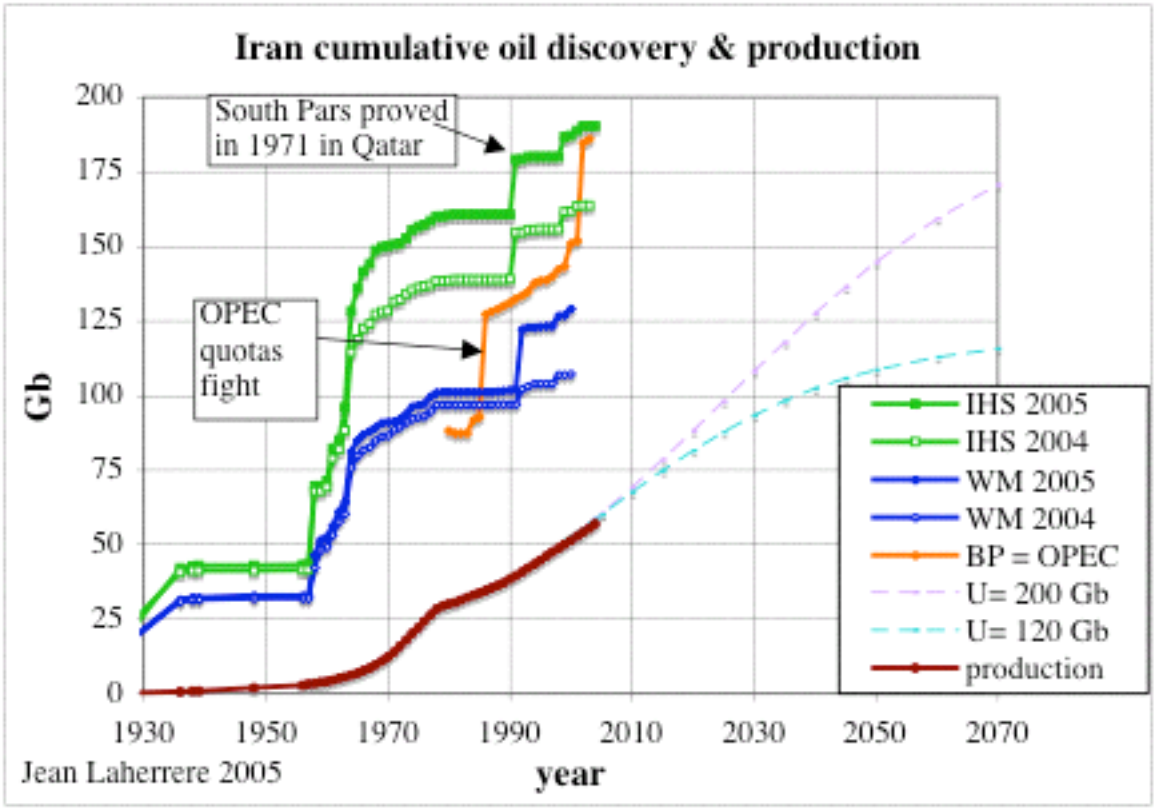


Check from oil production aP/CP versus CP gives an ultimate of 120 Gb in line with WM
Figure 34: Iran oil production aP/CP giving an ultimate of 120 Gb



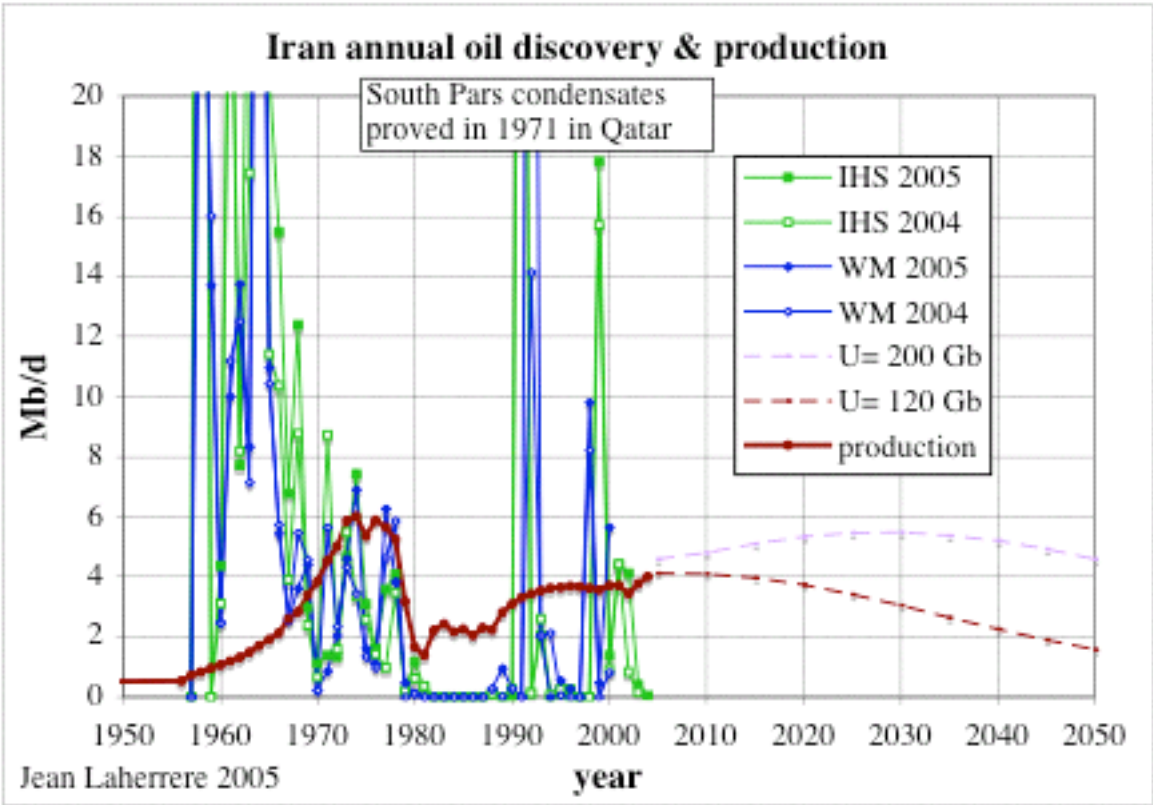
Cumulative production is modelled with ultimates of 120 (likely) & 200 maxi) Gb

Figure 35: Iran cumulative oil discovery and production as models U= 120 & 200 Gb



Annual oil production is modelled with ultimates of 120 & 200 Gb. The most likely 120 Gb shows that the oil peak is close, explaining why the Iranian government is so eager to get nuclear plants to satisfy growing population (and not mainly to get atomic weapons) in order to still exporting oil to keep their finance from collapse.

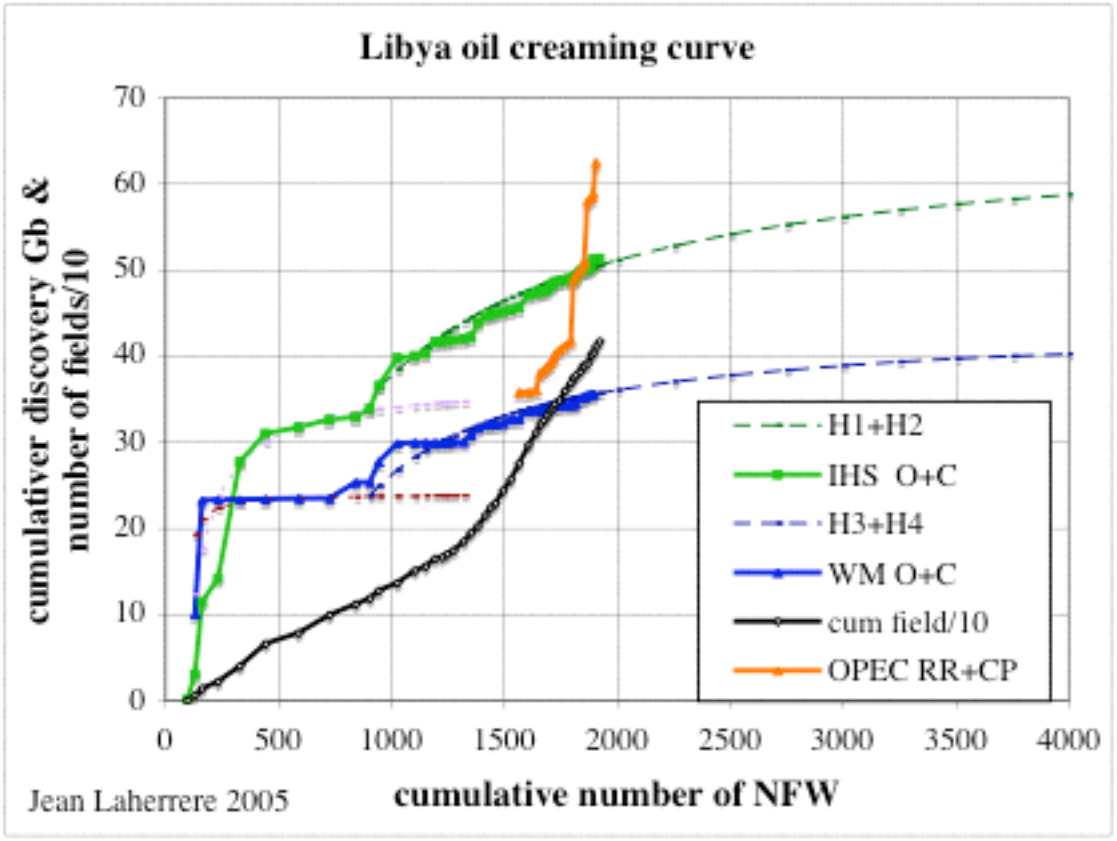
Figure 36: Iran annual oil discovery and production as models U= 120 & 200 Gb



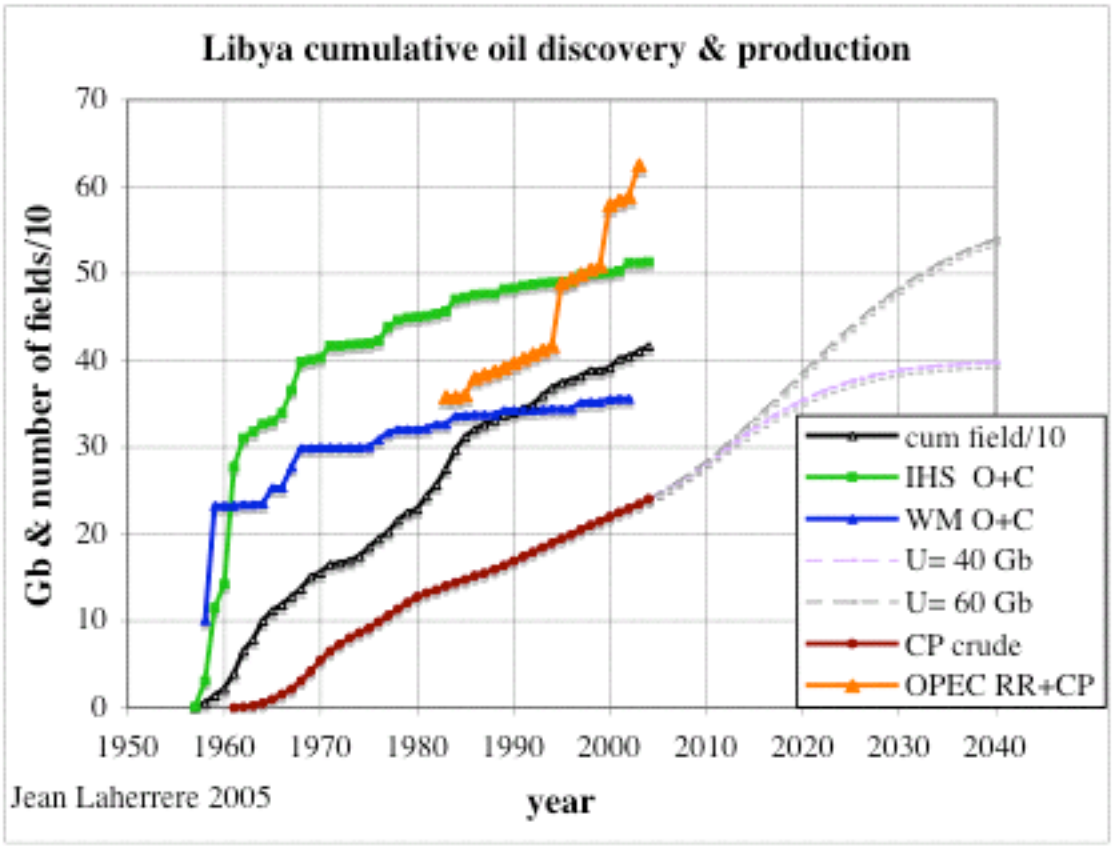
-Libya

Creaming curve shows that the oil ultimate is about 60 Gb from IHS, when it is 40 Gb from WM. Again OPEC data is useless.

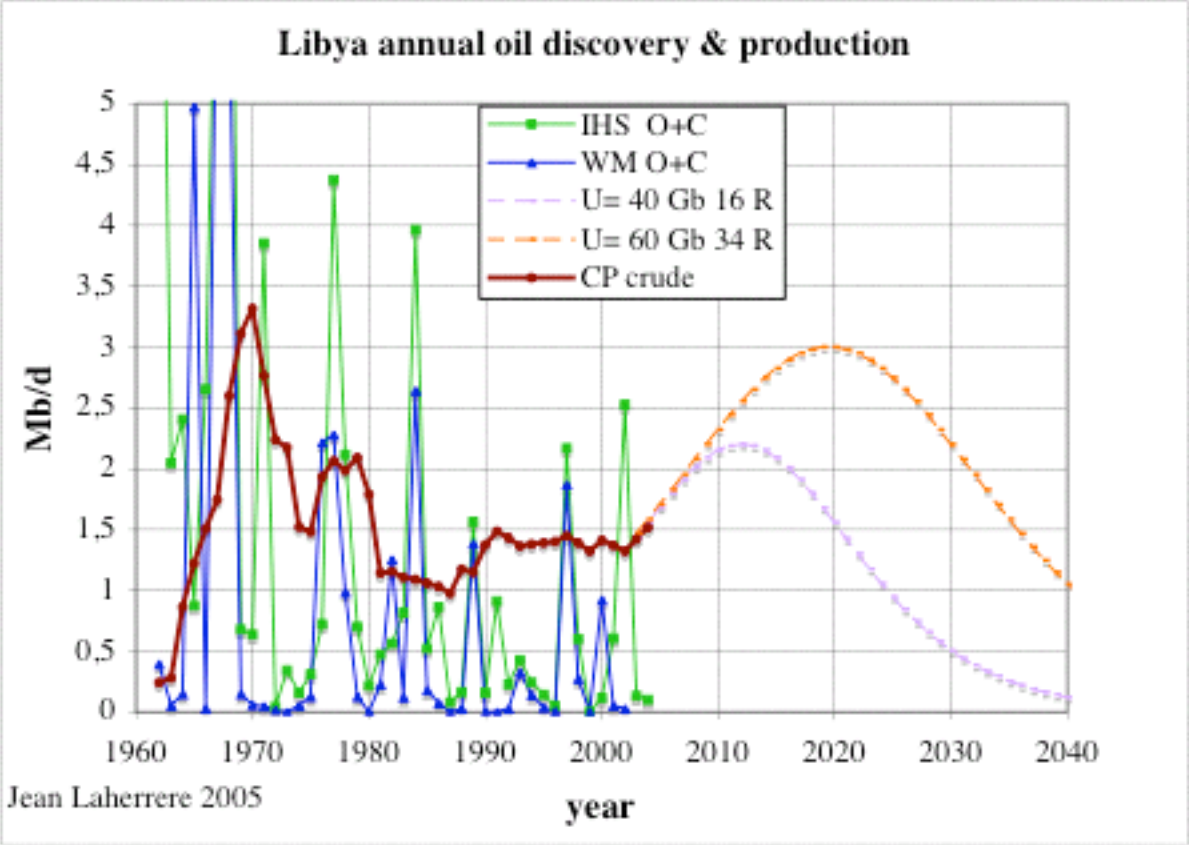
Figure 37: Libya creaming oil curve with U= 40 & 60 Gb



Cumulative oil production is modelled with ultimates of 40 & 60 Gb
Figure 38: Libya cumulative oil discovery and production with U= 40 & 60 Gb



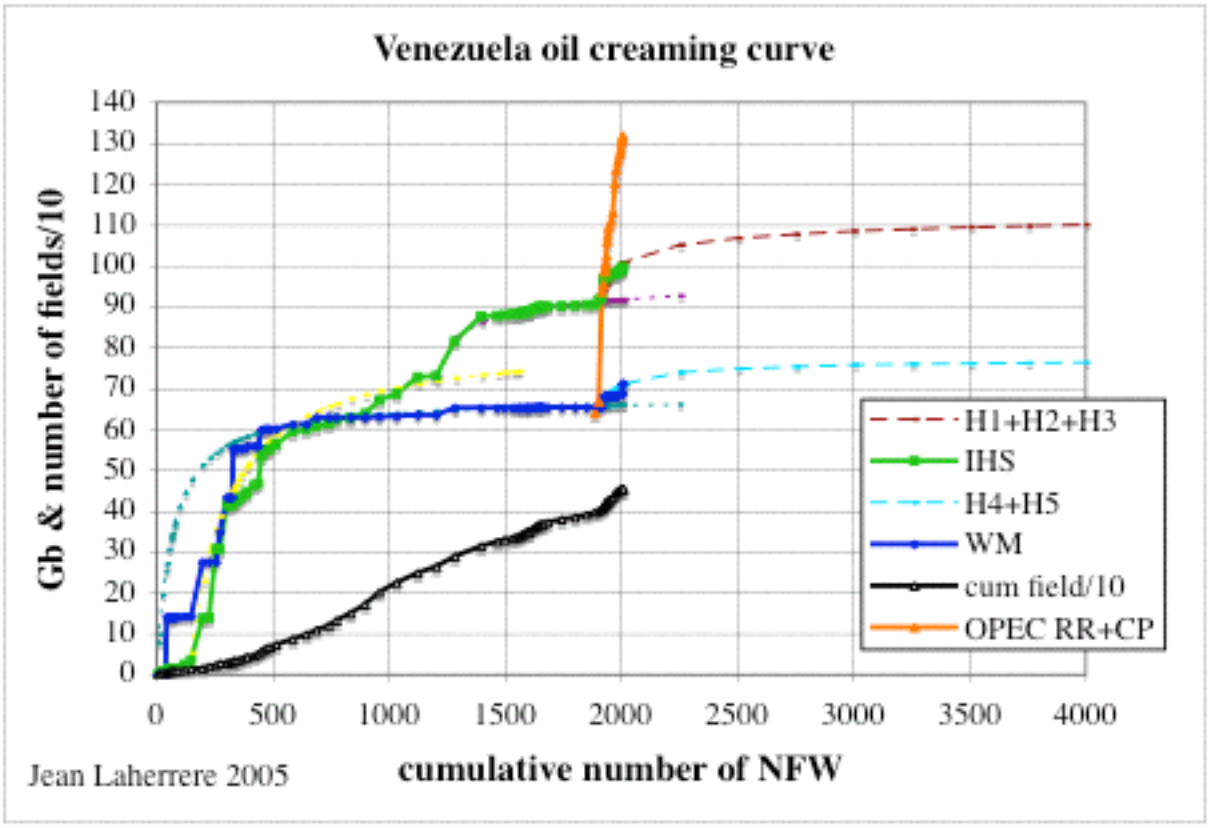
Annual oil production is estimated to have a new peak about 2 Mb/d around 2010 if U = 40 Gb = most likely, or 3 Mb/d around 2020 if U = 60 Gb.
Figure 39: Libya annual oil discovery and production with U= 40 & 60 Gb



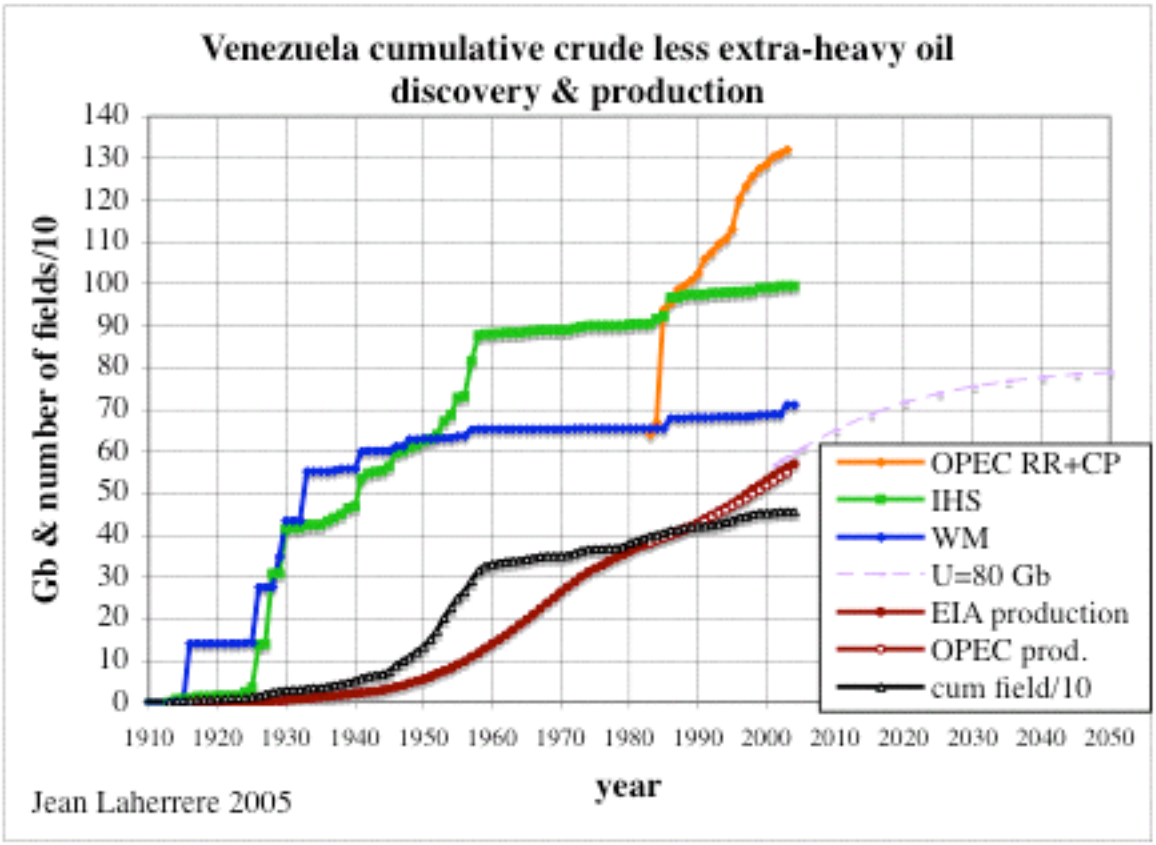
-Venezuela

Creaming curve for oil (excluding extra-heavy oils) can give either U=110 Gb from IHS or U=80 Gb from WM. OPEC data are as useless hopeless.

Figure 40: Venezuela creaming oil curve with U= 80 & 110 Gb

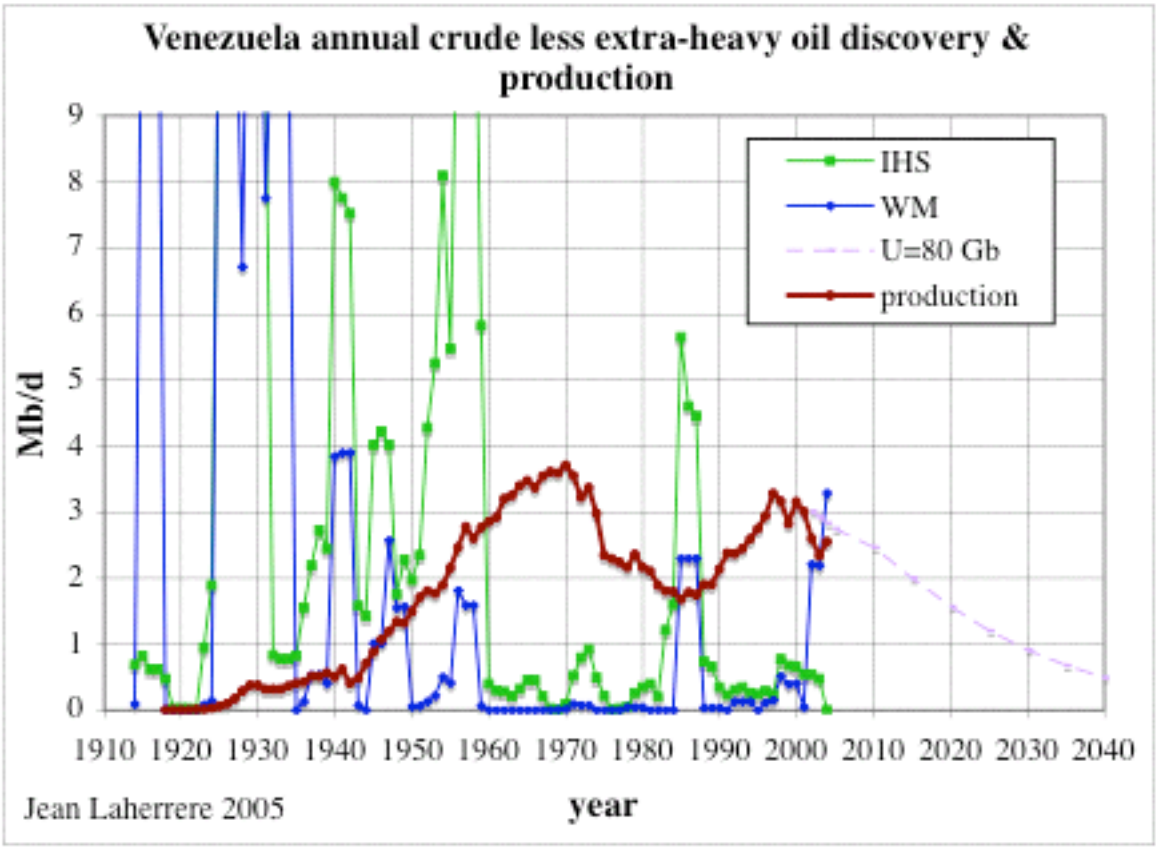


Cumulative oil production is modelled with 80 Gb ultimate.
Figure 41: Venezuela cumulative oil discovery and production with U= 80 Gb



Annual crude less extra-heavy oil which has peaked for the second time will continue to decline to 1 Mb/d in 2030

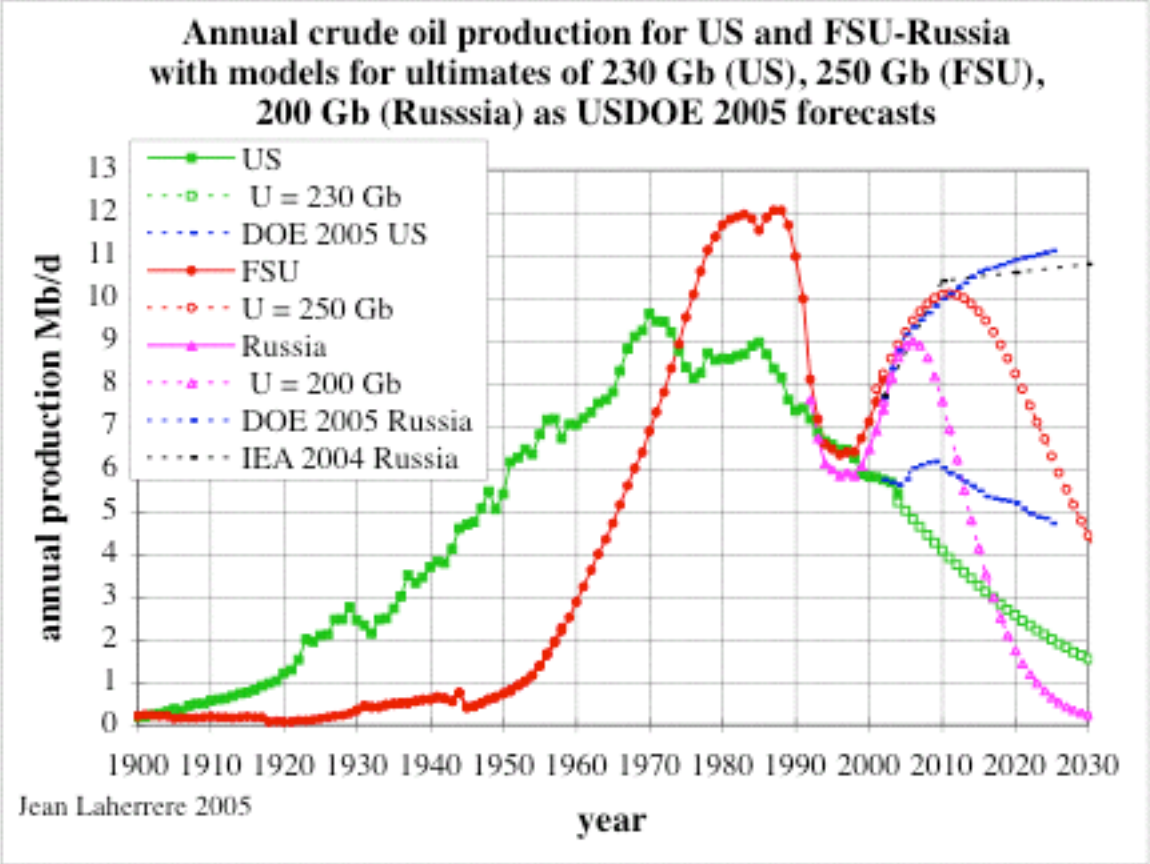
Figure 42: Venezuela annual oil discovery and production with U= 80 Gb



-US and FSU

In previous articles, oil ultimate was estimated at 250 Gb for FSU, 200 Gb for Russia and 230 Gb for US and the annual production is displayed below for the three, as USDOE and IEA forecasts. With these estimates Russia production will be at the same level as the US around 2020.

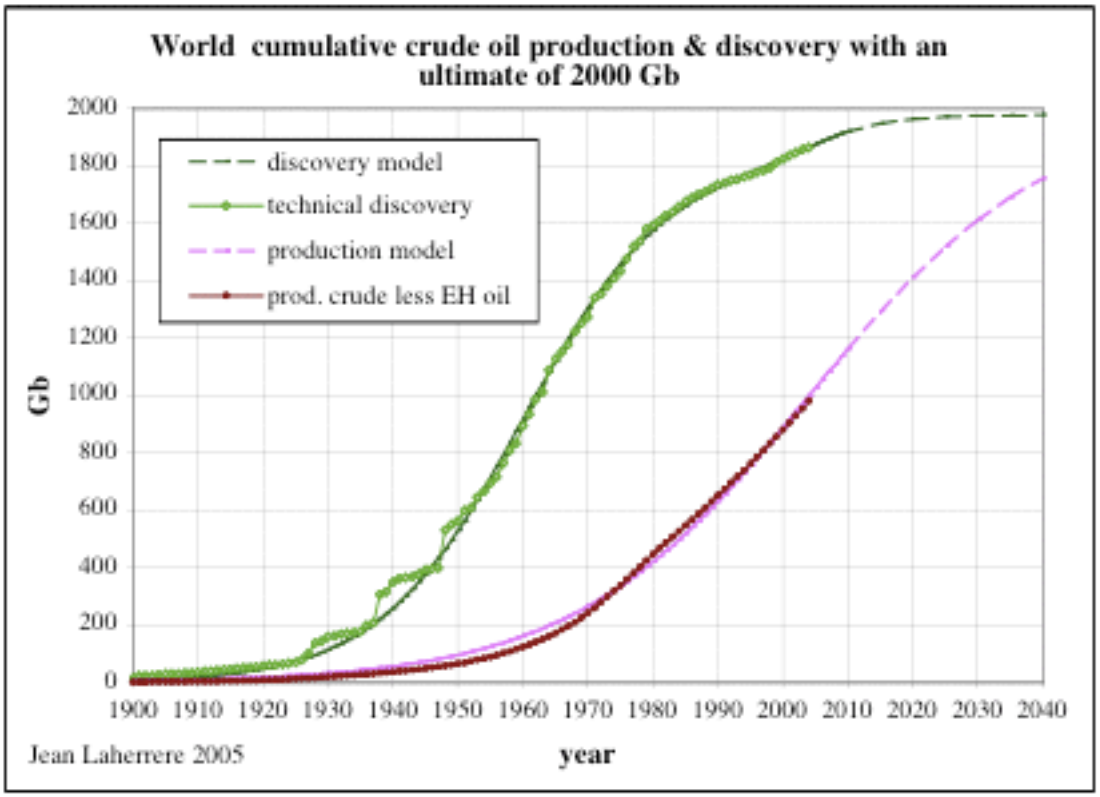
Figure 43: annual crude oil production for US and FSU-Russia with models for ultimates of 230 Gb (US), 250 Gb (FSU), 200 Gb (Russia) as USDOE 2005 forecasts



-World

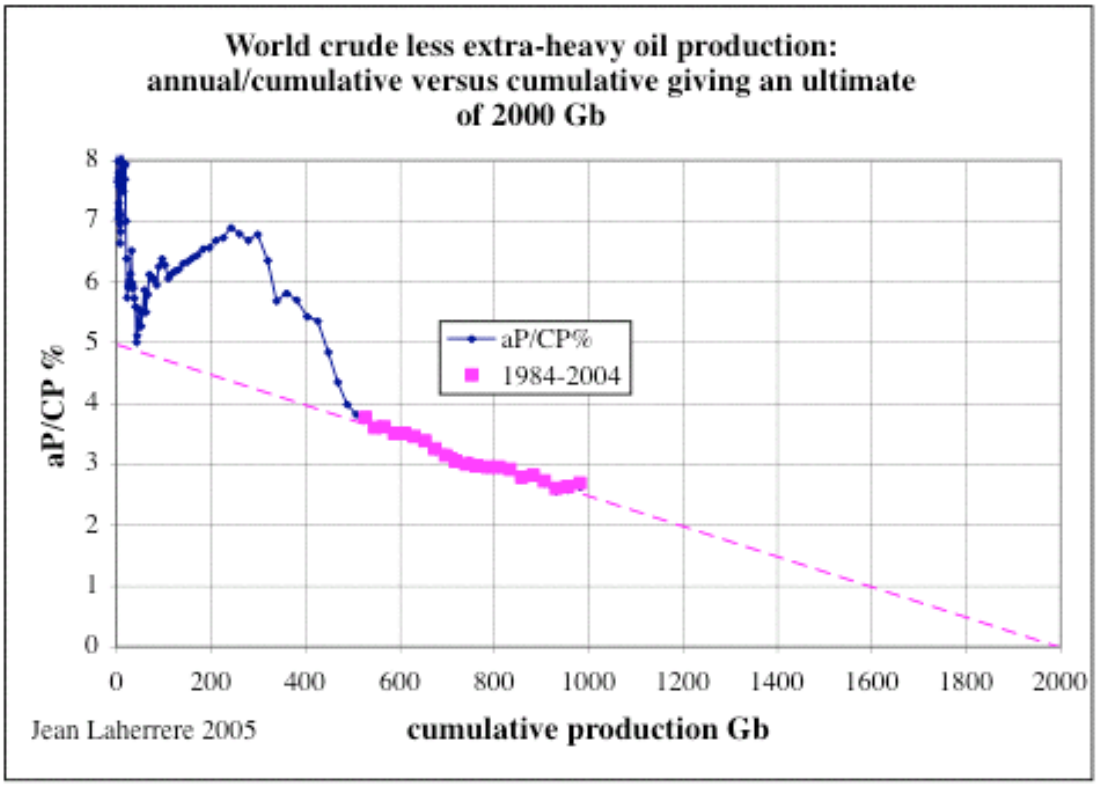
World cumulative crude less extra-heavy oil discovery is modelled with an ultimate of 2000 Gb. Such round value shows the uncertainty of such estimate. Production can be modelled with the same value.

Figure 44: World cumulative crude oil production & discovery U=2000 Gb



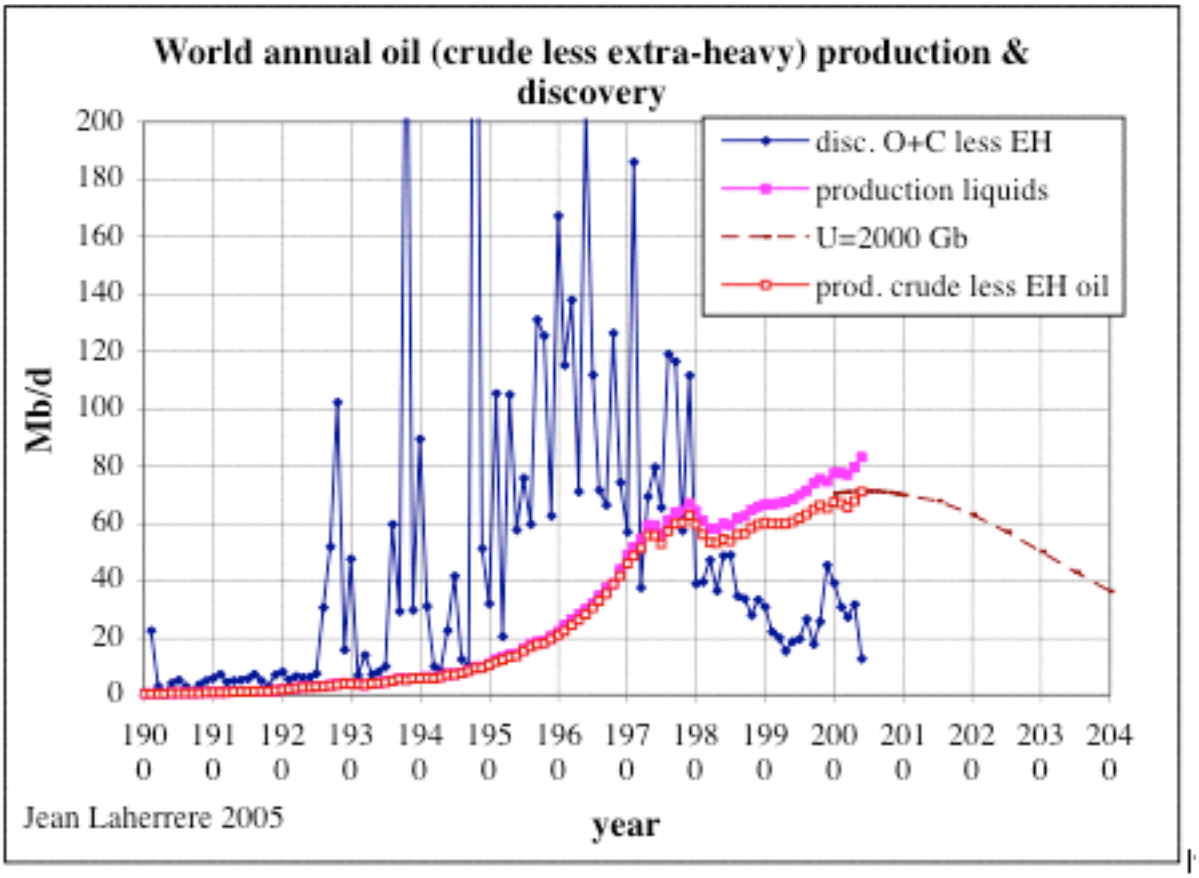
The aP/CP versus cumulative oil production gives such 2000 Gb as ultimate when extrapolating the last linear trend 1984-2004

Figure 45: World cumulative crude oil production: aP/CP giving an ultimate of 2000 Gb



Annual crude less extra-heavy oil is modelled with an ultimate of 2000 Gb showing that the peak is now

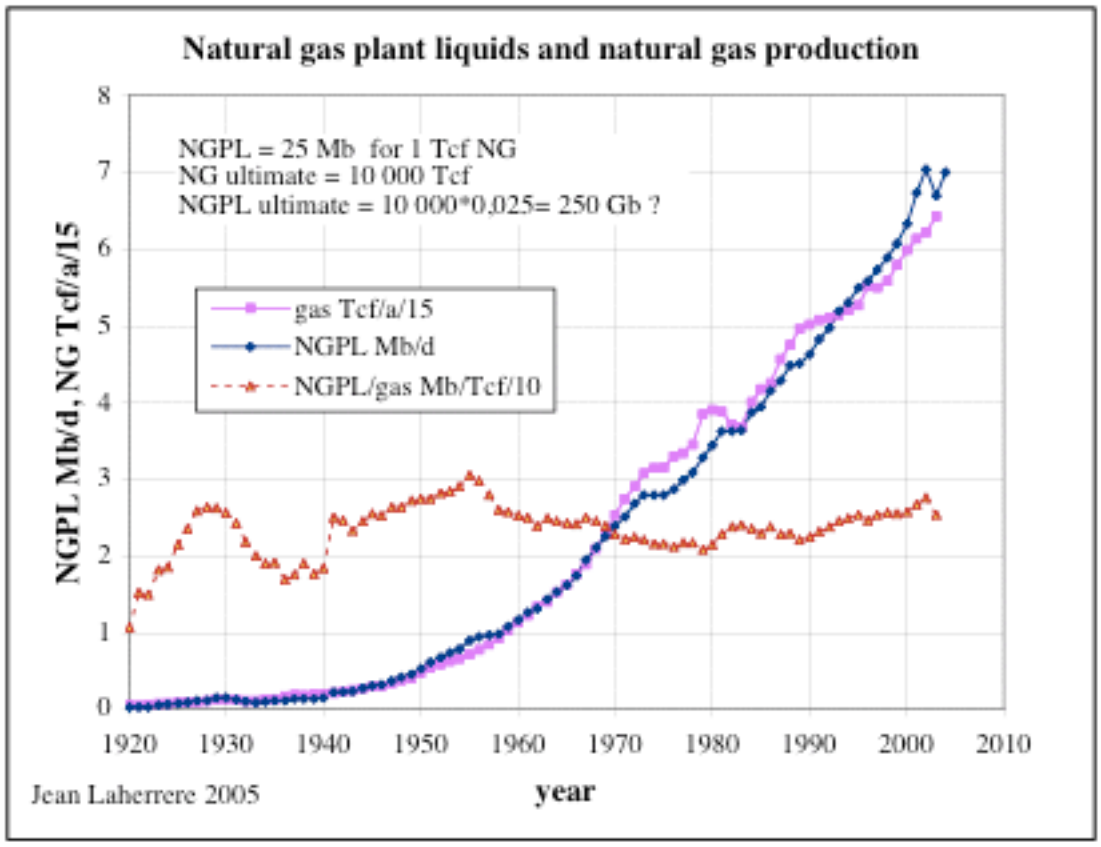
Figure 46: World annual crude less extra-heavy oil production & discovery



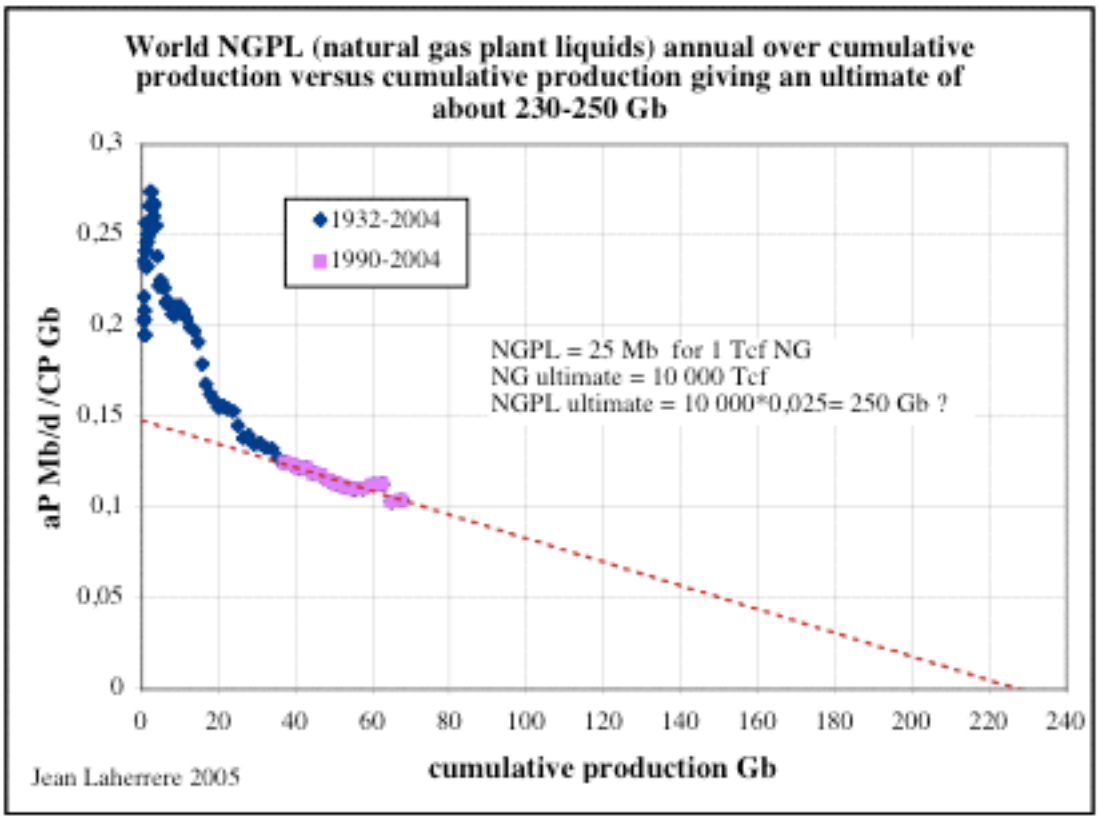
To obtain the liquids production forecast in volume, extra-heavy and natural gas liquids have to be added but also other liquids (synthetic oil from natural gas GTL or from coal CTL as 0.1 Mb/d in South Africa or from biomass as 0.2 Mb/d in Brazil) and finally refinery gain (heavy products converted into light products gaining volume by cracking and hydrogenation).

The world natural gas plant liquids production should a very good correlation with the natural gas production since 1920 with an average of 25 Mb per Tcf. As conventional gas ultimate is about 10 000 Tcf, NGL ultimate is about 250 Gb.

Figure 47: World annual natural gas plant liquids production

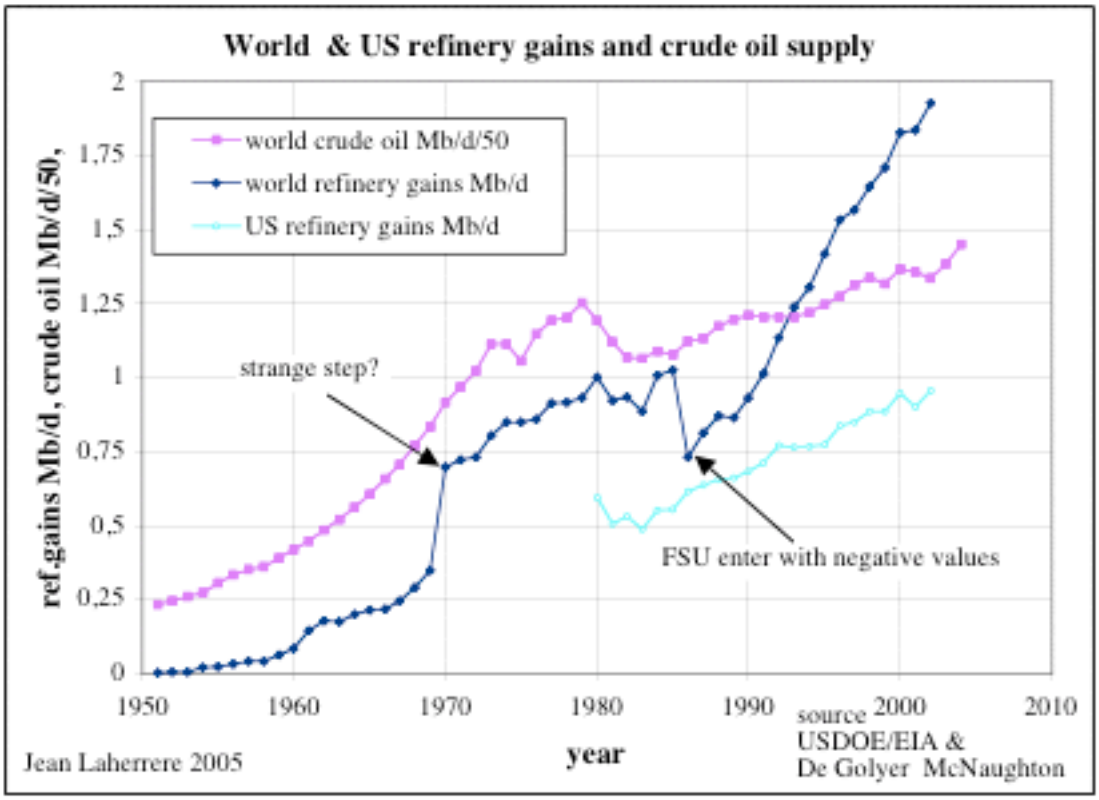


The aP/CP versus cumulative NGL production confirms this ultimate of 250 Gb.
Figure 48: World annual natural gas plant liquids production: aP/CP giving an ultimate of 230-250 Gb



Refinery gain with 2 Mb/d represents a larger volume than NGL or extra-heavy oils, but the value reported by the USDOE displays strange behaviour in 1970 and in 1986. Higher values are also reported.

Figure 49: World & US annual refinery gain as oil supply

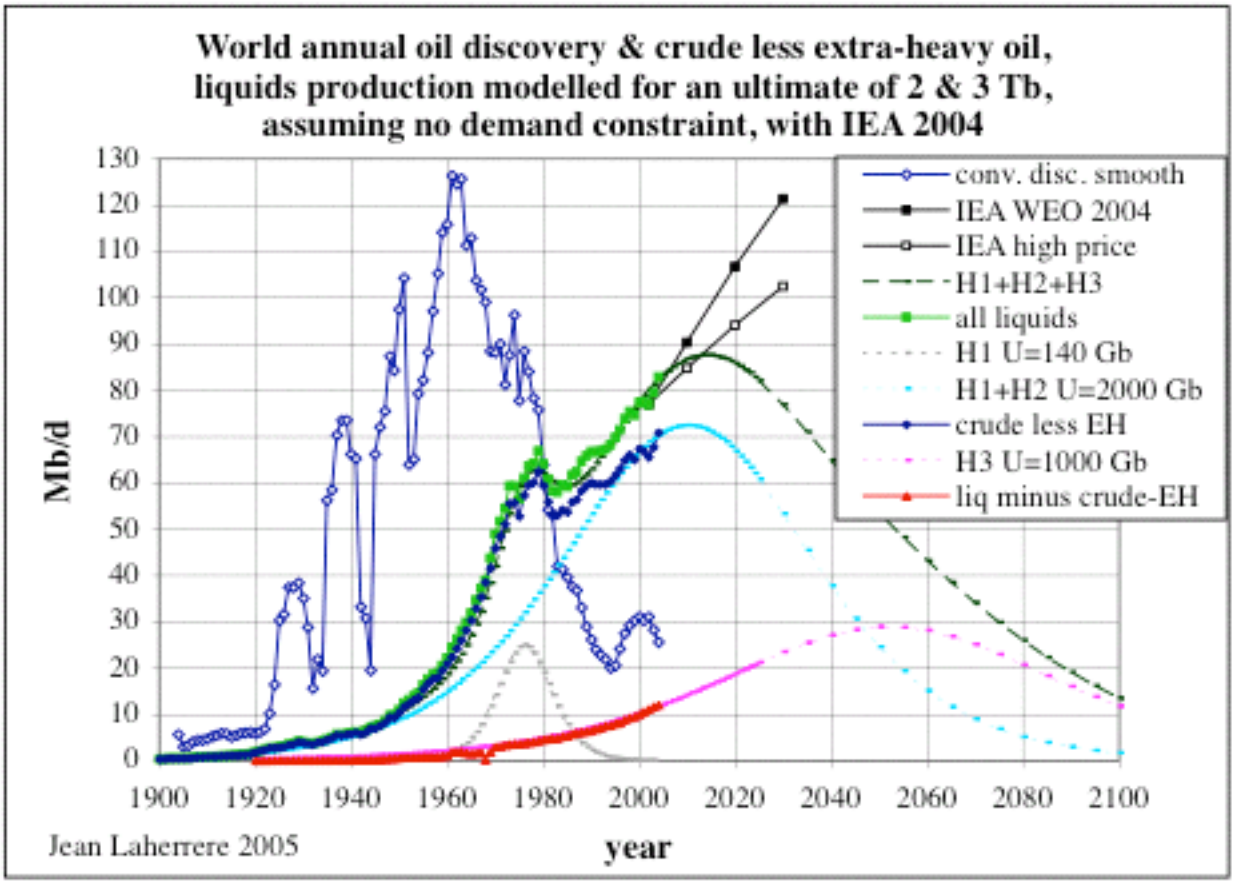


Liquids ultimate is estimated as follows:

Crude less extra-heavy oil	2000 Gb
Extra-heavy oil	500 Gb
Natural gas liquids	250 Gb
Synthetic oil & refinery gain	250 Gb
Total	3000 Gb

Annual liquids is modelled with such ultimate and will peak if there is no demand constraint (unlikely) around 2010, but if there is some constraint from the demand (likely depression) the peak will be a bumpy plateau and oil price will be chaotic. IEA 2004 forecast at 120 Mb/d in 2030 seems unrealistic as the price forecast at 25 $2004/b.

Figure 50: World crude & liquids production with model U=2 Tb & 3 Tb as IEA 2004 forecasts



-Conclusions

Reliable production forecasting needs reliable field discovery values.
Published proved values are completely unreliable, only mean (proven+probable) values have to be considered after correction (US, FSU being overestimated by 30%)
Technical field reserves are gathered by scout companies as IHS and WM but they differ widely, IHS seems moving towards political data, considering Middle East national companies as the future.
Forecasting needs to estimate first the ultimate using creaming curve.
Cumulative production is compared to cumulative discovery and ultimate is selected.
Finally the annual production is modelled with the selected ultimate.
Demand constraint and exploration cycles lead to several peaks or bumpy plateau.
Forecasts of how supply may meet demand need to cover all liquids demand including crude oil, extra-heavy oils, natural liquids as well as refinery gains as synthetic oil as GTL, CTL and BTL. ASPO graphs should cover all. It explains why it is difficult to be too precise on the ultimate values.

Reference:

Hubbert M.K.1956 “Nuclear energy and the fossil fuels” American Petroleum Institute Drilling & Production Practice, Proceedings Spring Meeting San Antonio Texas p7-25