Jean Laherrere 23 December 2023

Extrapolation of past oil production to forecast future production

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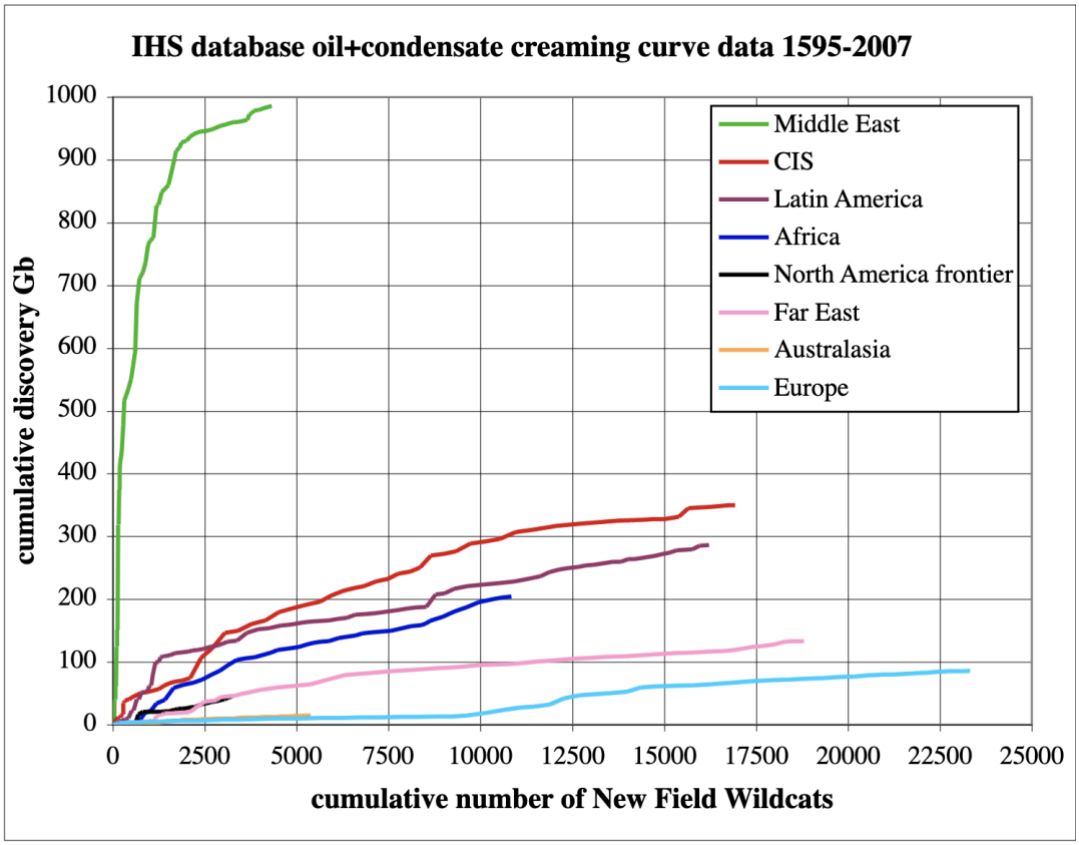
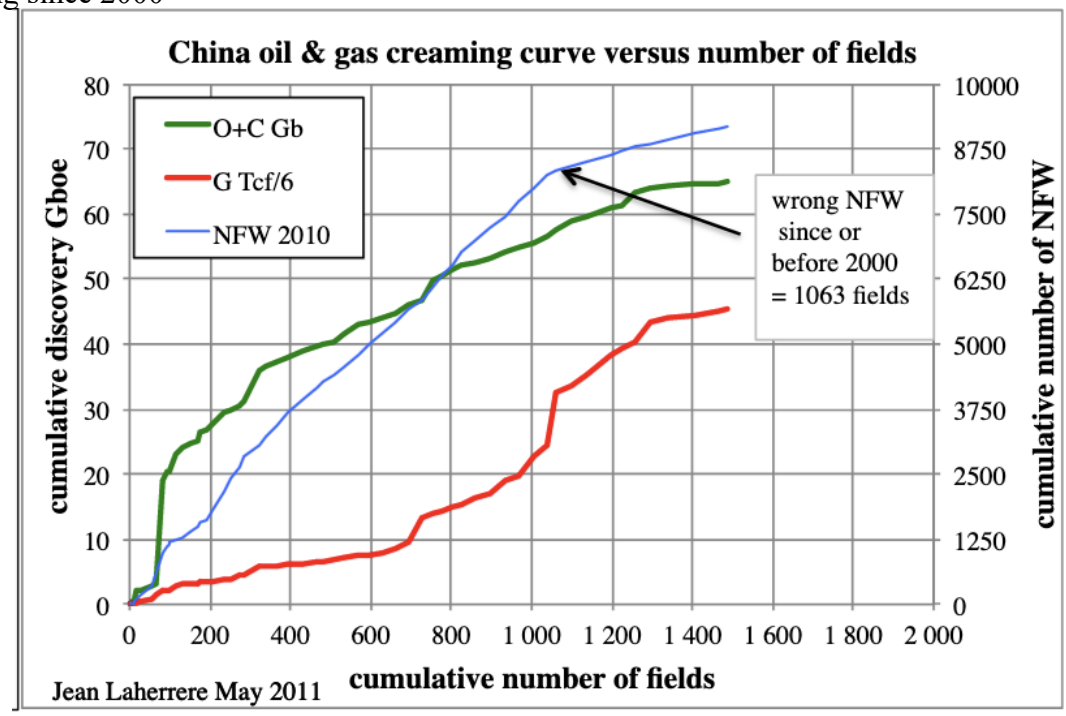
-Introduction

My old oil production forecasts were based on backdated 2P (proven + probable) reserves data from Petroconsultants base
I was Petroconsultants associate consultant and wrote several reports
-Laherrère J.H., A.Perrodon, G.Demaison 1994 “Undiscovered Petroleum Potential” Petroconsultants report, 383p
-C.J.Campbell, Laherrère J.H. 1995 “The world’s oil supply -1930-2050” Petroconsultants report, Oct ., 650p, CD-ROM
-Laherrère J.H., A.Perrodon, C.J.Campbell 1996 “The world’s gas potential” Petroconsultants report July, 200p, CD-ROM
The ultimate was estimated as the cumulative production + 2P remaining known discoveries + yet to find from extrapolation of the creaming curve
The extrapolation of cumulative 2P backdated discoveries versus new field wildcats towards the value for a doubling of NFW allows to estimate the yet to find
https://aspofrance.org/2016/06/07/document-les-creaming-curves/



But Petroconsultants data is missing for US & Canada non frontier and China NFW data is wrong since 2000

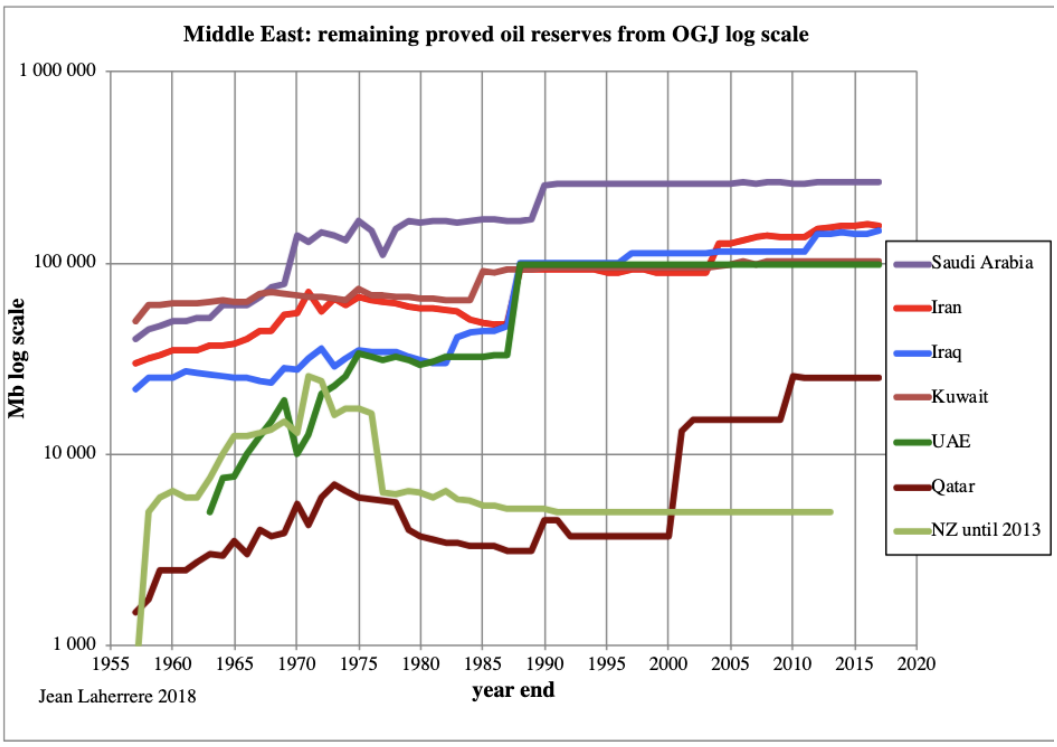


//aspofrance.files.wordpress.com/2018/08/35cooilforecast.pdf

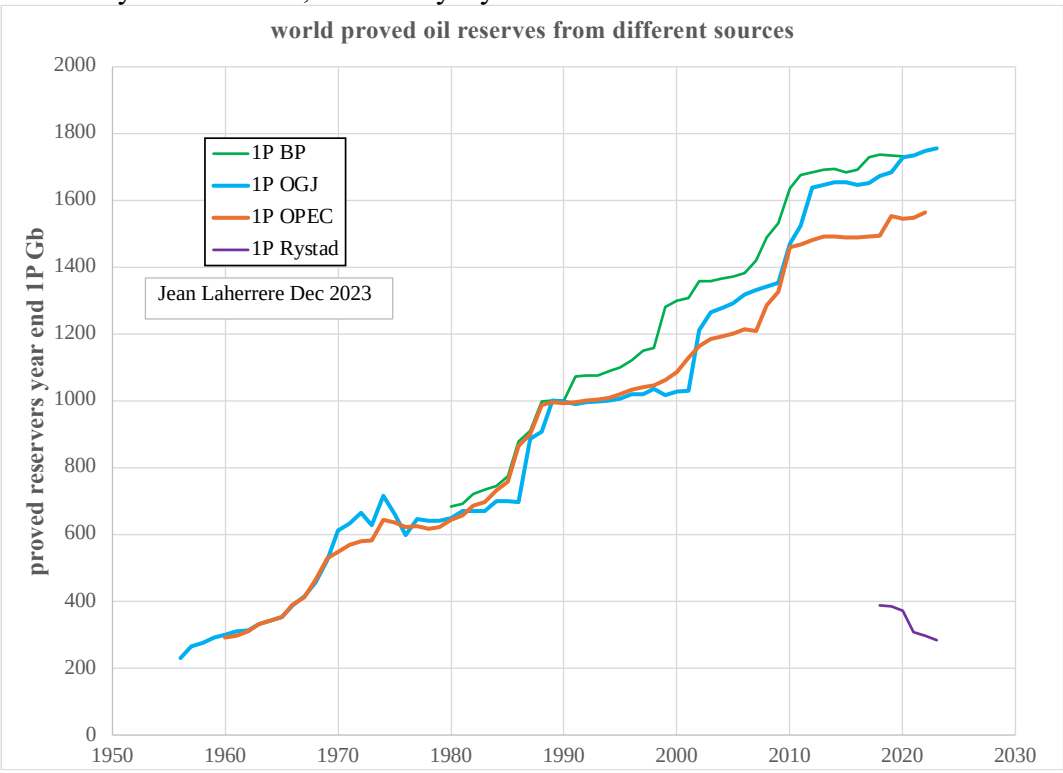
the IHS employee a Chinese born American was in jailed for 8 years for spying

After this failure on NFW data, the creaming curves were the extrapolation of cumulative discoveries versus cumulative number of fields

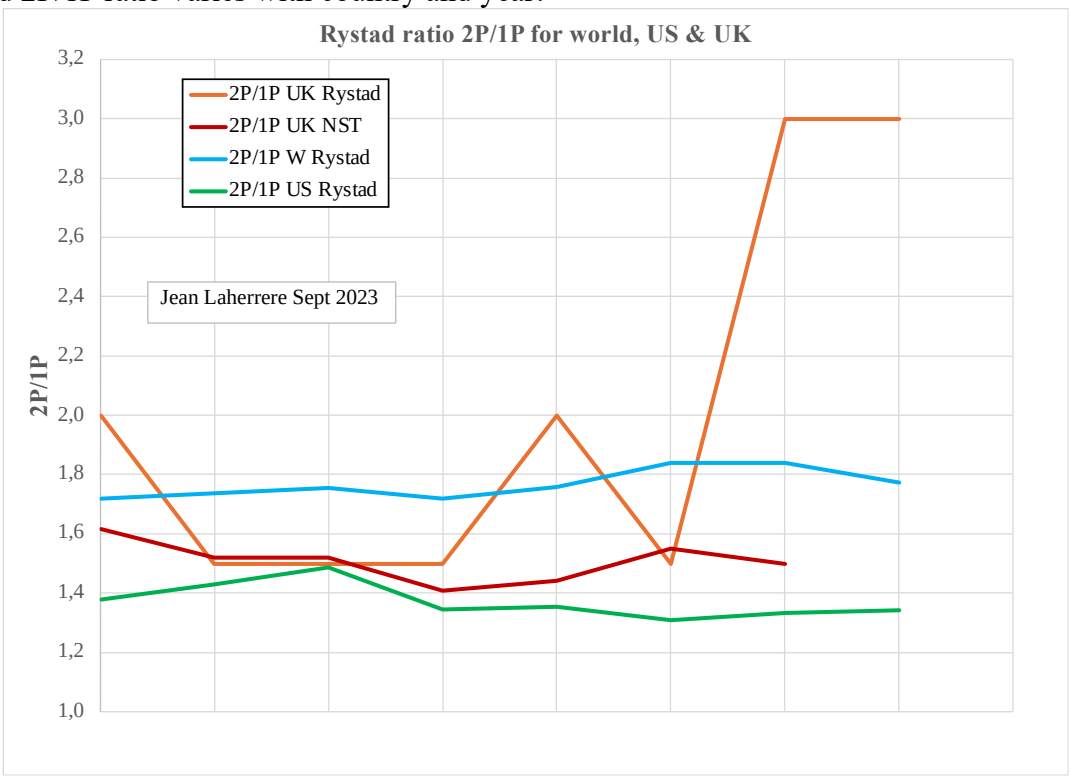
But after the OPEC members oil quotas fight 1985-1989 where proven reserves were increased by about 50 % without any new equivalent discoveries (Sadad al Husseini London 2007 = OPEC overstated 300 Gb) OPEC 2P were also increased and became unrealistic.
The next graph on log scale displays the burst of OPEC oil reserves from 1985 to 1989 except for the Neutral Zone (50/50 Saudi Arabia, Kuwait) and Qatar (not involved as their reserves are mainly in NG)



1P reserves vary with sources, with crazy Rystad estimates

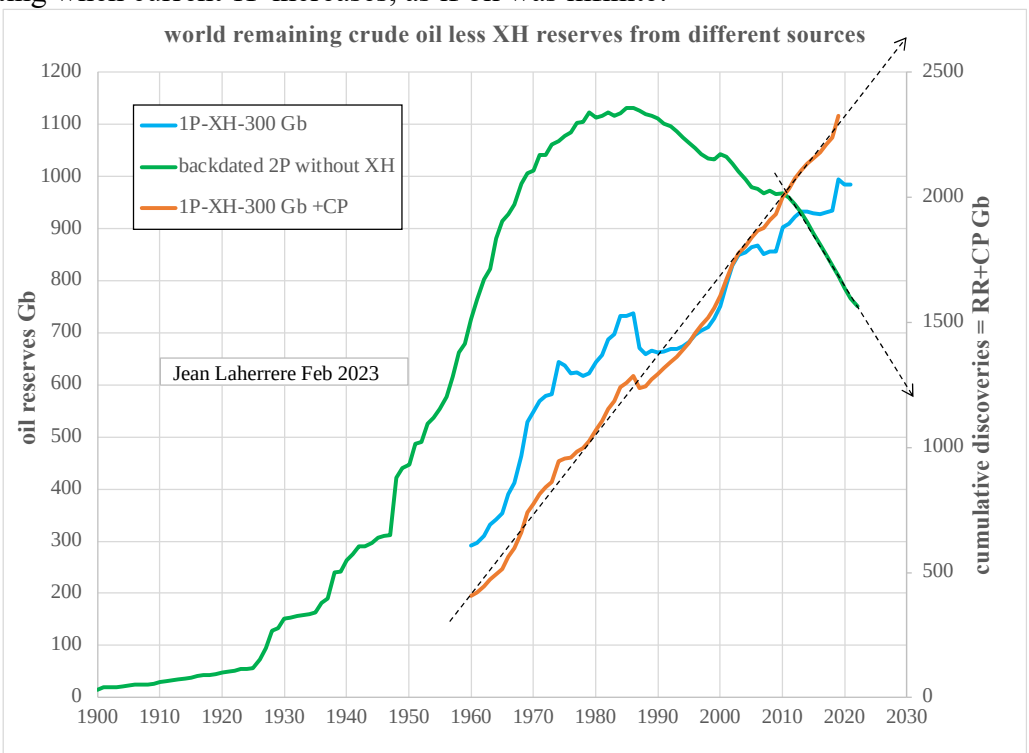


Rystad 2P/1P ratio varies with country and year!



Extra-heavy (XH) trap and production are different from conventional crude and reserves should be excluded from world data

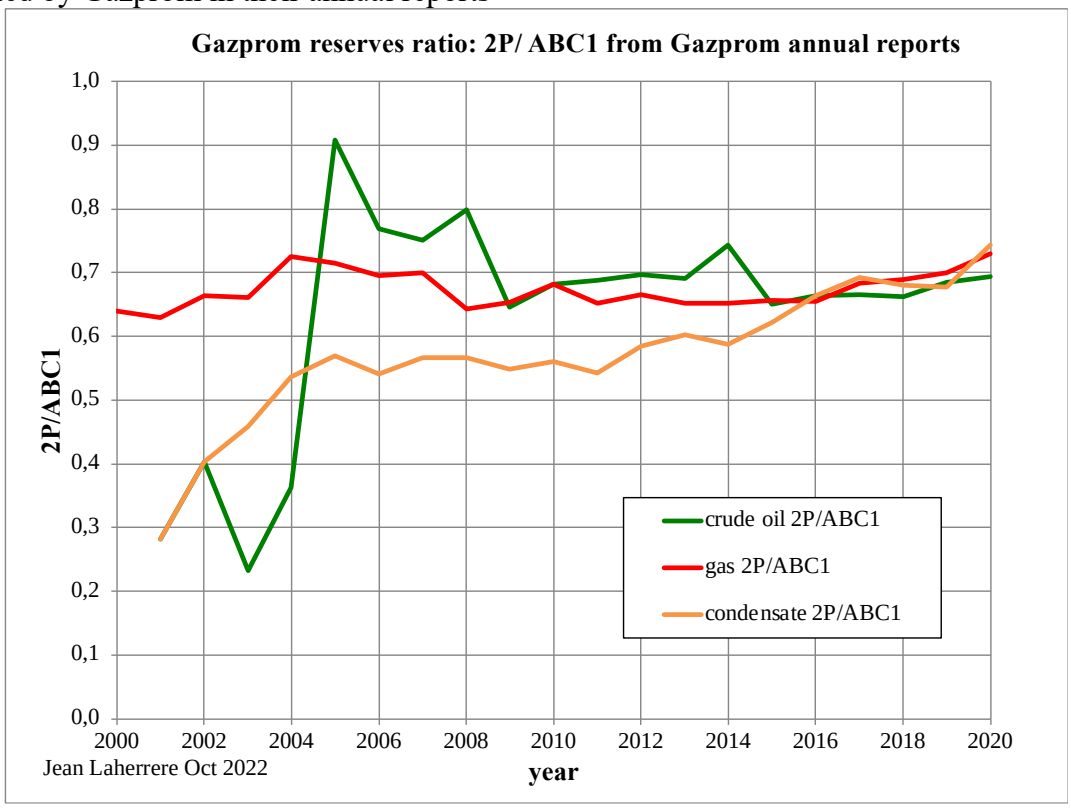
World remaining crude oil less XH reserves from different sources: 2P declines because the backdating when current 1P increases, as if oil was infinite!



1P reserves are current estimated each year under the SEC rules with the data and the oil price of the year when 2P reserves are using the present estimate backdated to the year of discovery.

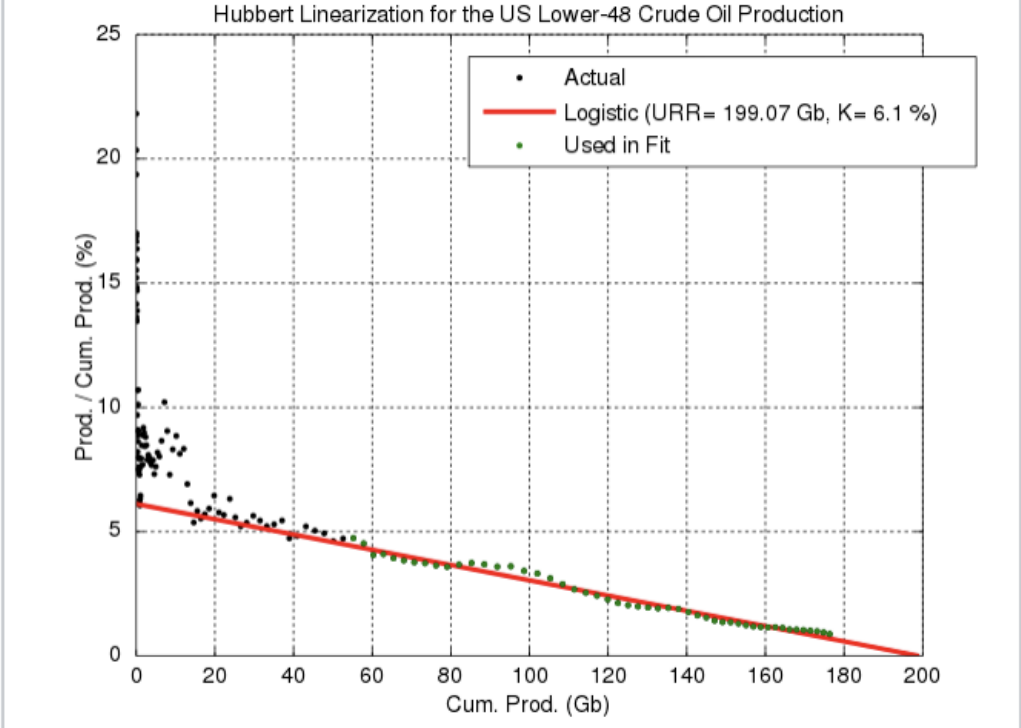
Another problem is that there are several very different reserves classifications:
https://aspofrance.files.wordpress.com/2018/08/35cooilforecast.pdf
There are several reserves classifications:
-OPEC unaudited proved reserves = fight for quotas 1985-1989 giving 300 Gb speculative resources (S. al-Husseini London 2007) = it is a political value
-SEC audited proved reserves (defined with a reasonable certainty to exist, but no definition of reasonable), forbidding to report probable reserves = it is a financial value to please the bankers, every international oil company listed on the oil market is obliged to follow the SEC rules. Reserves at year end were in the past estimated with the oil price at the 31sttDecember, now with the annual average.
-SPE/WPC/AAPG PRMS: 1P = proved = P90, 2P = proved +probable = P50, 3P = proved + probable + possible = P10, arithmetic addition is only correct for 2P. Every international oil company uses SPE rules internally to decide the development of a field but keeps the data confidential.
-Russian ABC1 grossly exaggerated (Khalimov 1959 & 1993) = 3P using the maximum theoretical recovery
-Norwegian classification = mean value
There is also a reserves classification by the United Nations, but no one uses it, because too complex (3D)!
It is incorrect to add arithmetically the proved field reserves to get the world proved reserves, giving an underestimation, leading to artificial reserves growth (= bad practice of reserves reporting), but everybody adds proved reserves, without knowing that it is wrong, believing that it should be right because everyone does it

Scout companies (IHS, Rystad) confuse 2P with ABC1 (in fact 3P), when 2P = 0,7 ABC1 as reported by Gazprom in their annual reports



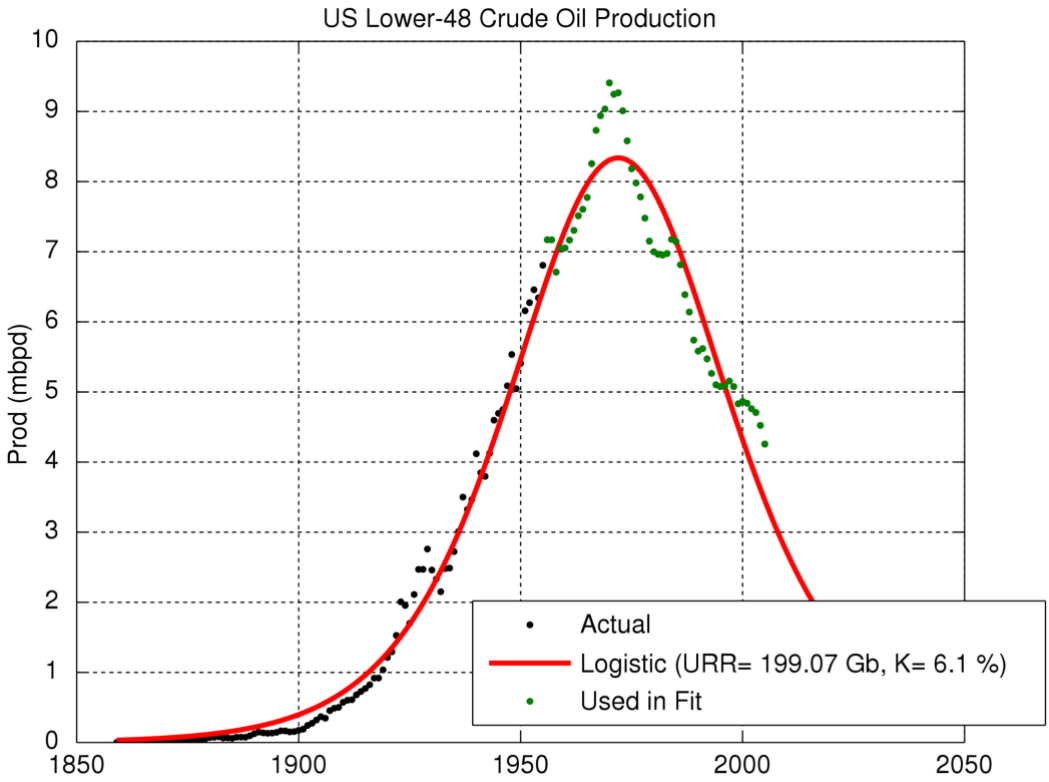
The scout cumulative discoveries must be corrected by several hundreds Mb for the overestimation of OPEC and the confusion of ABC1 in 2P: see Laherrere et al https://doi.org/10.1016/j.crsust.2022.100174,

Now, as 2P reserves are unreliable, my oil production forecasts are based on ultimates estimated from the extrapolation of the HL = Hubbert linearization technique
aP = annual production, CP = cumulative production
HL is the plot of aP/CP% versus CP.
The extrapolation of aP/CP% towards the zero = end of aP = end of the production where the cumulative production represents the ultimate reserves
King Hubbert proposed this linear extrapolation in 1982 and K. Deffeyes applied HL in 2005 "Beyond Oil – The view from Hubbert's peak"
Hubbert defines the extrapolation to the US oil, which is produced with present techniques, meaning that in 1956 he excludes deepwater (starting in 1979) and LTO.
Wikipedia reports on Hubbert linearization with
https://en.wikipedia.org/wiki/Hubbert_linearization with a poor example on past USL48
The charts below give an example of the application of the Hubbert Linearization technique in the case of the US Lower-48 oil production. The fit of a line using the data points from 1956 to 2005 (in green) gives a URR of 199 Gb and a logistic growth rate of 6%.



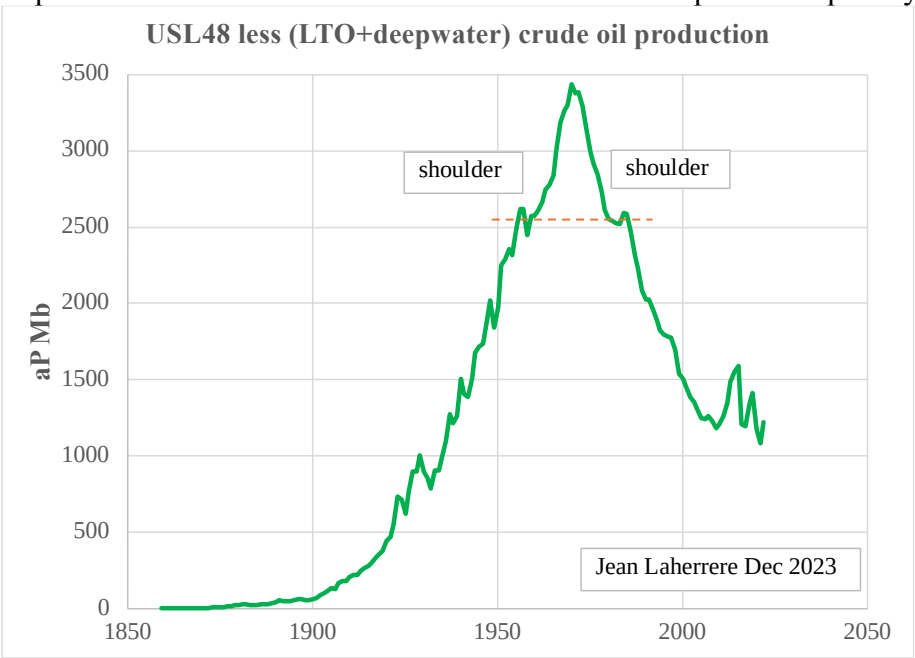
Example of a Hubbert Linearization on the US Lower-48 crude oil production.

Wiki comparing USL48 crude oil prodiction data (stopping in 2005 because LTO) with Hubbert model with a bell shape peak when real peak is angular, but symmetrical with both shoulders at 7 Mb/d:

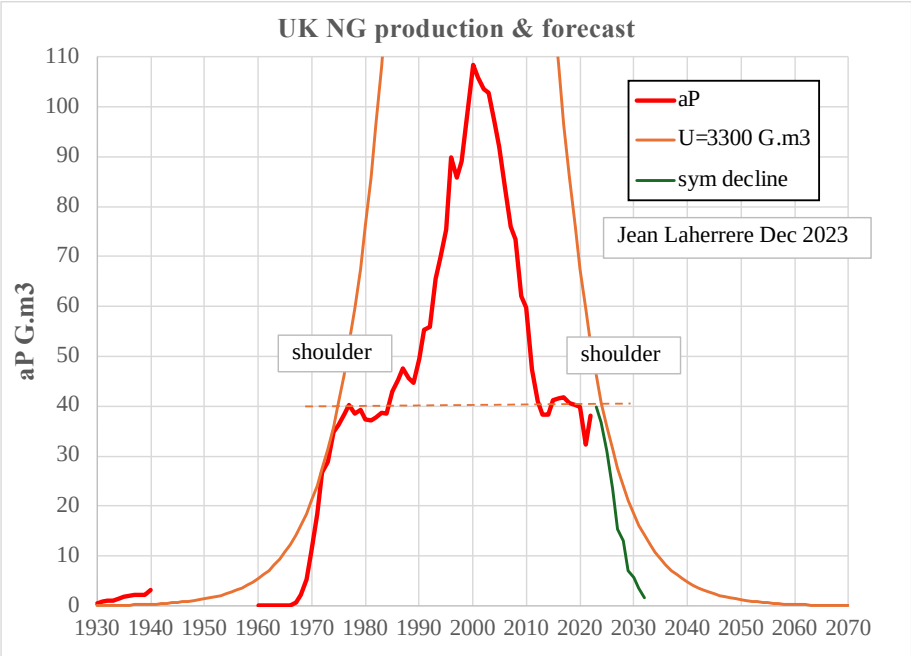


But the data stop at 2005. The 2005 HL trends towards 200 Gb (giving an URR with 5 significant digits as 199.07 is ridiculous!), which is the highest value chosen by Hubbert in 1956 Gb coming from Platt's geological estimate giving a peak in 1970, the lowest value of 150 Gb giving a peak in 1965). But Hubbert 1986 estimate what for the oil produced with 1956 techniques excluding the deepwater which is included in 2005 data

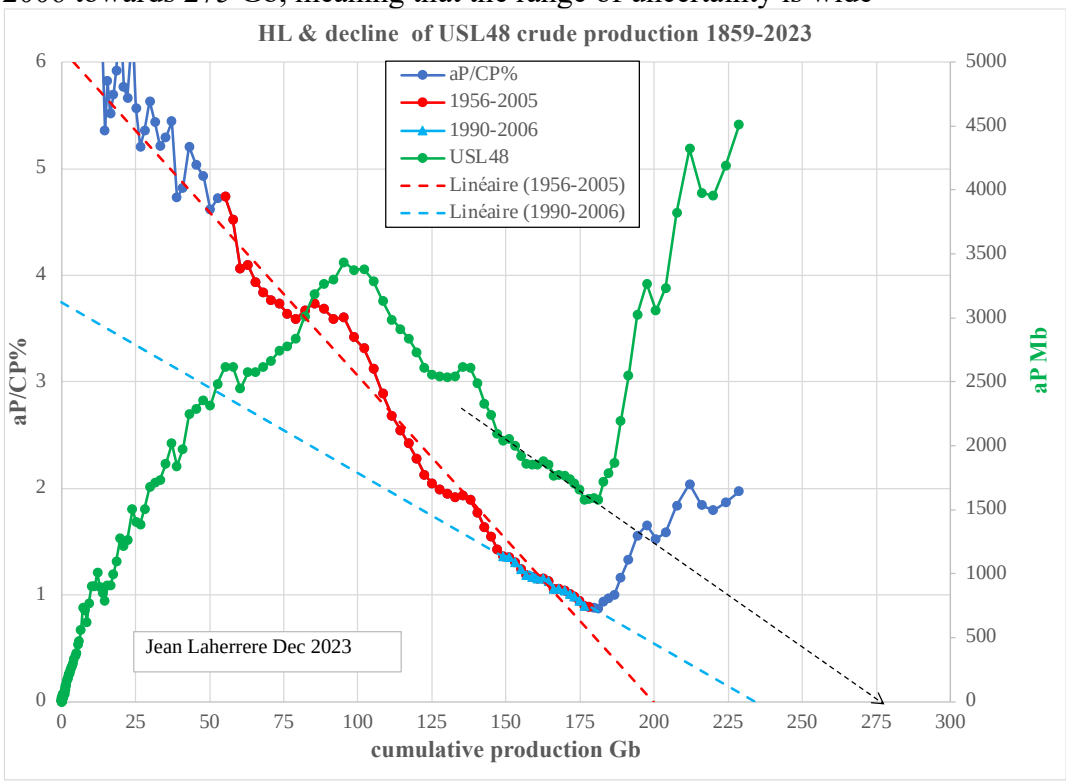
It is interesting to notice that USL48 peak was angulous, far from a bell shape curve with also shoulder for a production of 2550 Mb/a: USL48 less LTO and deepwater is quite symmetrical



It is fascinating to find the same symmetry and shoulder for UK NG production

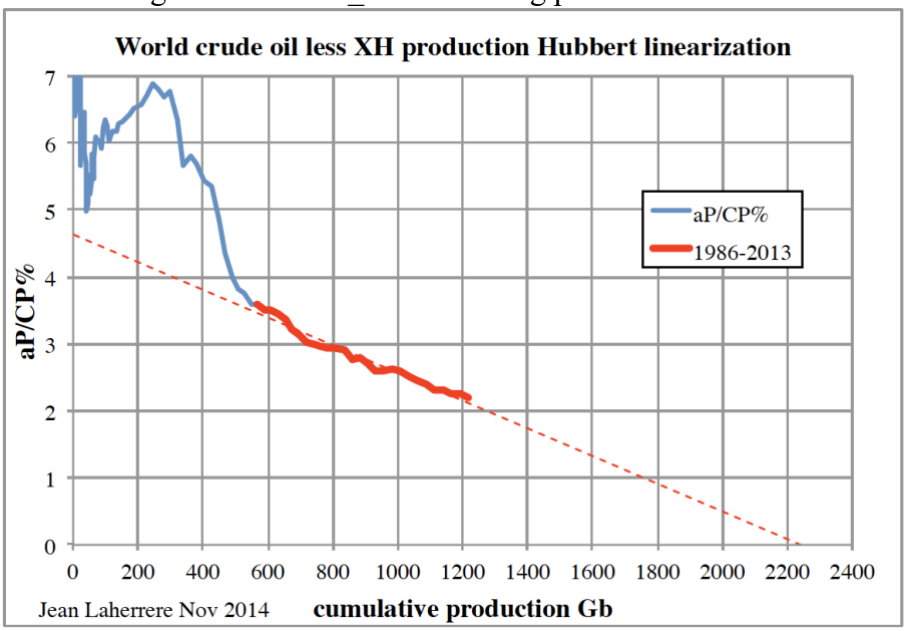


The present USL48 data 1857-2023 is quite different with the burst of LTO = light tight oil or the so-called shale oil, thanks to the new fracking with very long horizontal extents and very large volume of water and proppants.
HL extrapolation is difficult: the period 1956-2005 (red) trends towards 200 Gb; the period 1990-2006 (light blue) trends towards 230 Gb, but the decline (green) trends for the period 1990-2006 towards 275 Gb, meaning that the range of uncertainty is wide



The 2008 paper "Hubbert math" https://sepwww.stanford.edu/sep/jon/hubbert.pdfh speaks about HL.

The extrapolation should be the best way (or the least bad) to obtain the ultimate before peak (but usually there are several peaks), if the recent plot is linear, by a linear extrapolation, but if the plot is hyperbolic a hyperbolic extrapolation (very uncertain) will give an unreliable ultimate.
I used HL in 2014 a linear extrapolation on a long period: 1986-2013
http://aspofrance.viabloga.com/files/JL_2014Nicelong.pdf

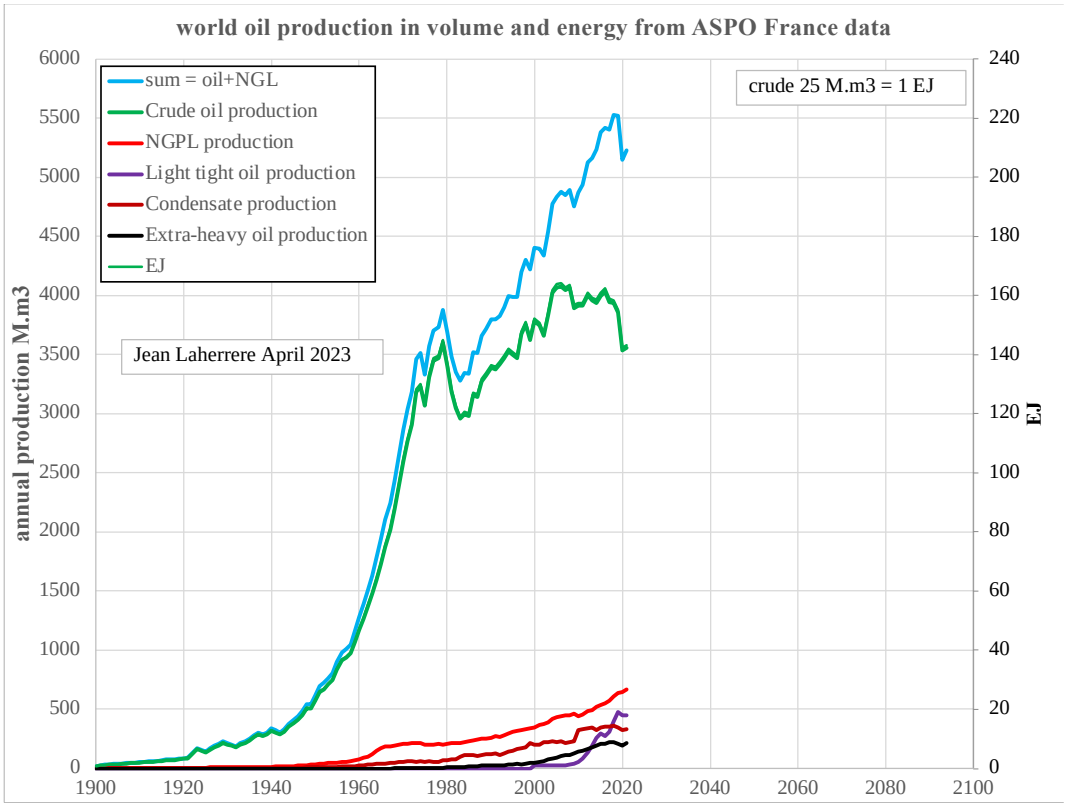


I used HL in 2020 to forecast covid19 deaths "Using Hubbert linearization to forecast covid19 deaths "https://aspofrance.files.wordpress.com/2020/03/hlcovid19-16mars.pdf
In my May 2023 paper "Peaks from past data with HL: energy, fossil fuel, CO2, population & gold" https://aspofrance.org/2023/05/30/peaks-from-past-data-with-hl-energy-fossil-fuel-co2-population-gold/
In my August 2023 paper: « Updated metal peaks"
https://aspofrance.files.wordpress.com/2023/08/metalpeaks2023.pdf

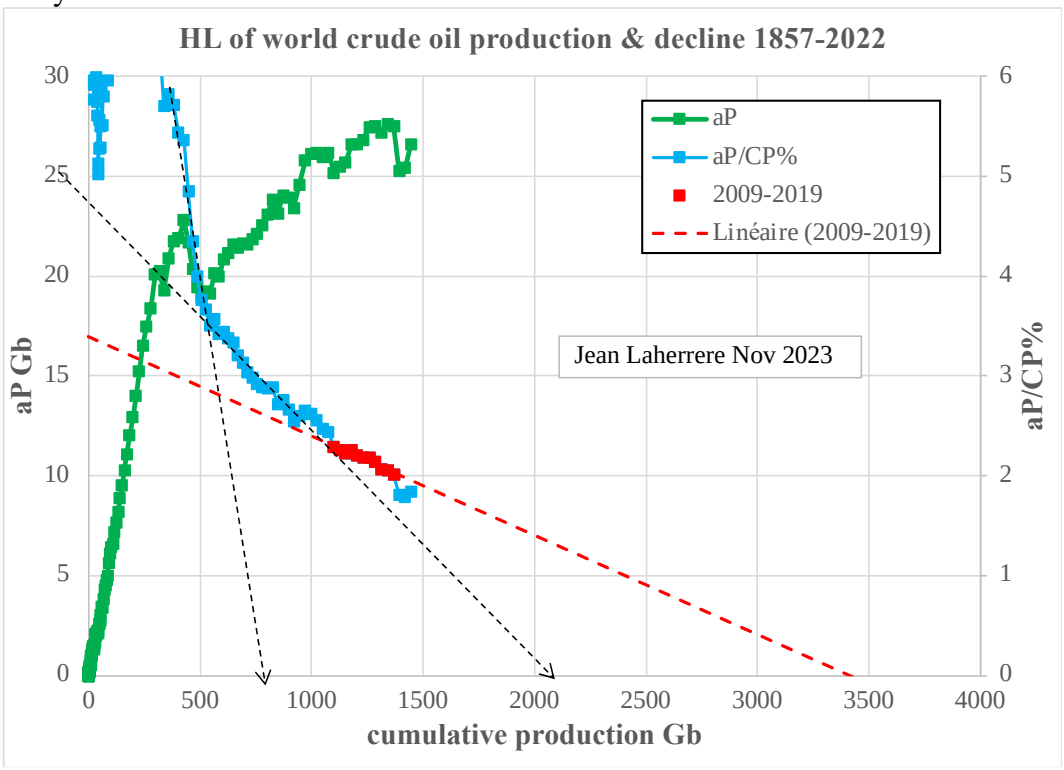
Before peak, HL is the only way outside the right backdated 2P reserves to estimate ultimate.
After peak the plot of aP decline versus CP could also estimate ultimate.
Unfortunately, most of HL cases are not linear, but hyperbolic, making the extrapolation difficult!

Paul Alba has suggested to use for the CP axis a log scale instead of the normal data: this plot is called LL = linear log.
Patrick Brocorens has written in 2023 "when is the peak?" with many examples of HL https://aspofrance.files.wordpress.com/2023/10/peak_oil_aspofrance_17oct2023.pdf , as "Asymmetry and duration of production"
https://aspofrance.files.wordpress.com/2023/03/presentation_aspofrance_brocorens_14mars2023.pdf

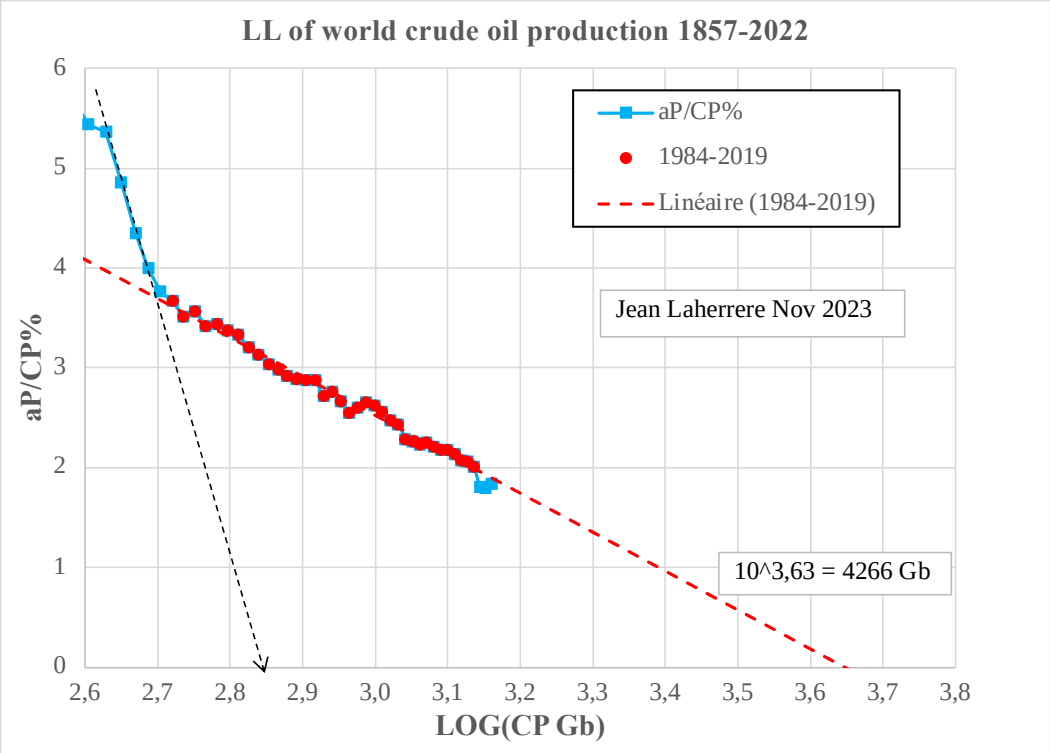
-world crude oil
The plot of world oil production uses ASPO France (M.m3) data starting in 1900:



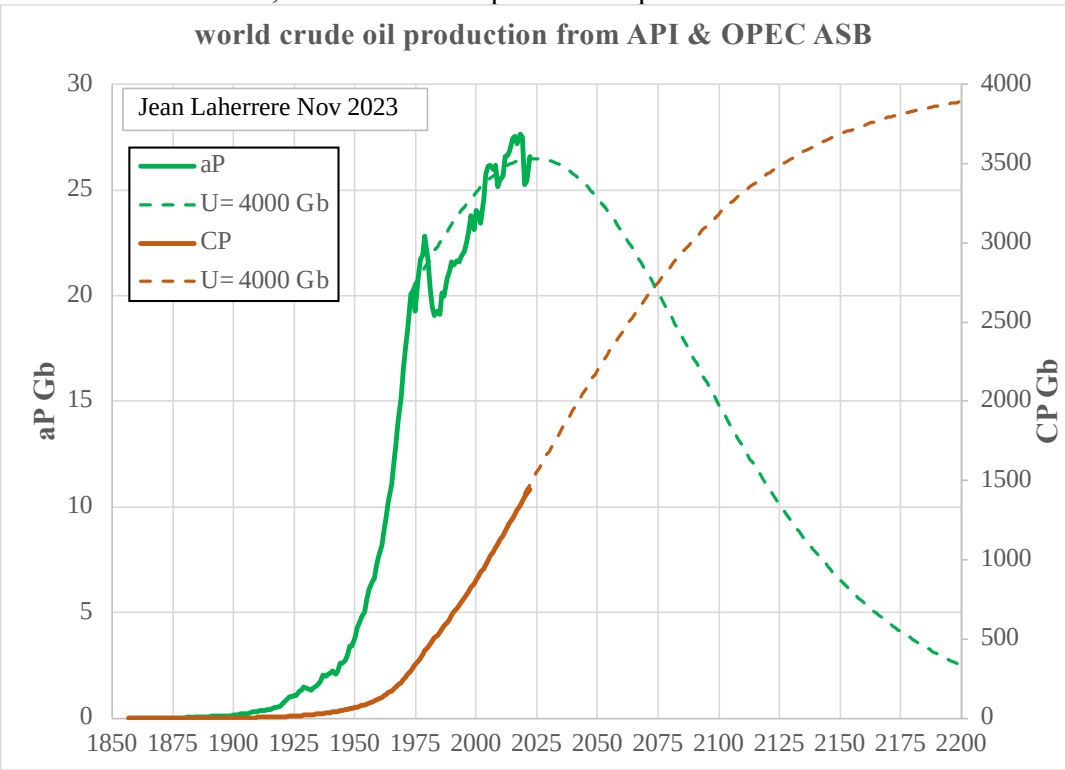
HL of world crude oil production trends for 2009-2019 = 11 years towards about 3500 Gb.
My ultimates are always rounded up with only 2 significant digits, but I try often to use only one significant digit.
Anyone using more than 2 significant digits for estimate shows that he does not understand uncertainty on oil data.



LL trends for the period 1984-2019 = 36 years towards 4200 Gb



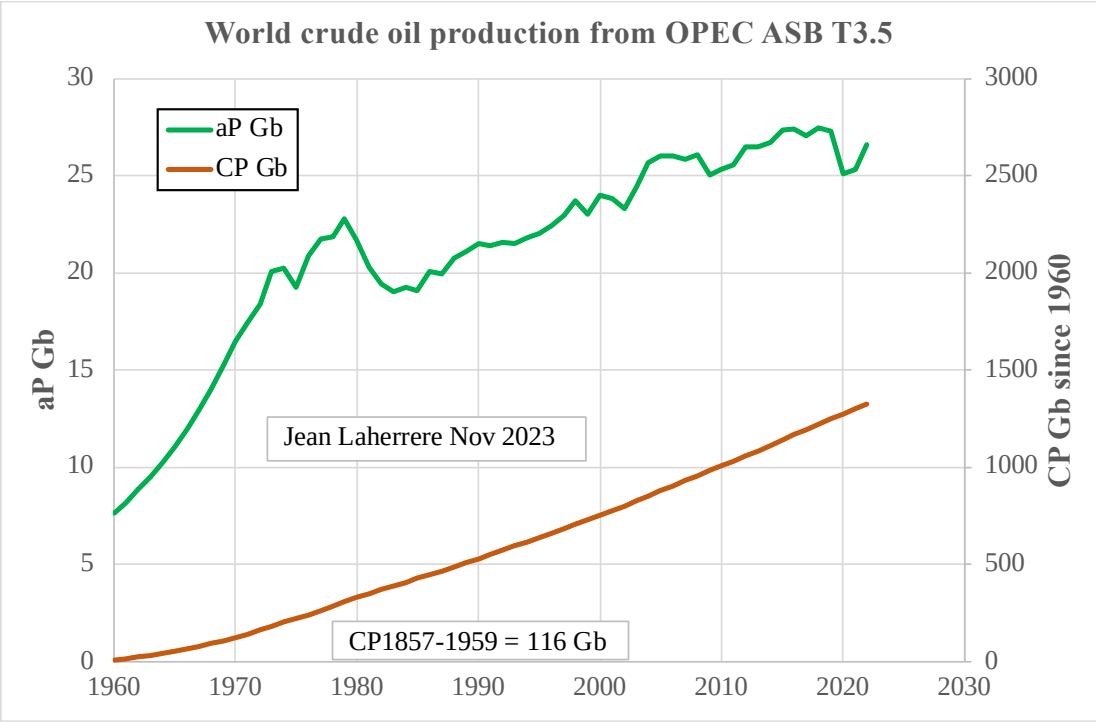
HL and LL give a range of 3500-4200 Gb in line with the uncertainty of the estimate and a 4000 Gb word crude oil ultimate is chosen.
For an ultimate of 4000 Gb, world crude oil production peak will be in 2024.



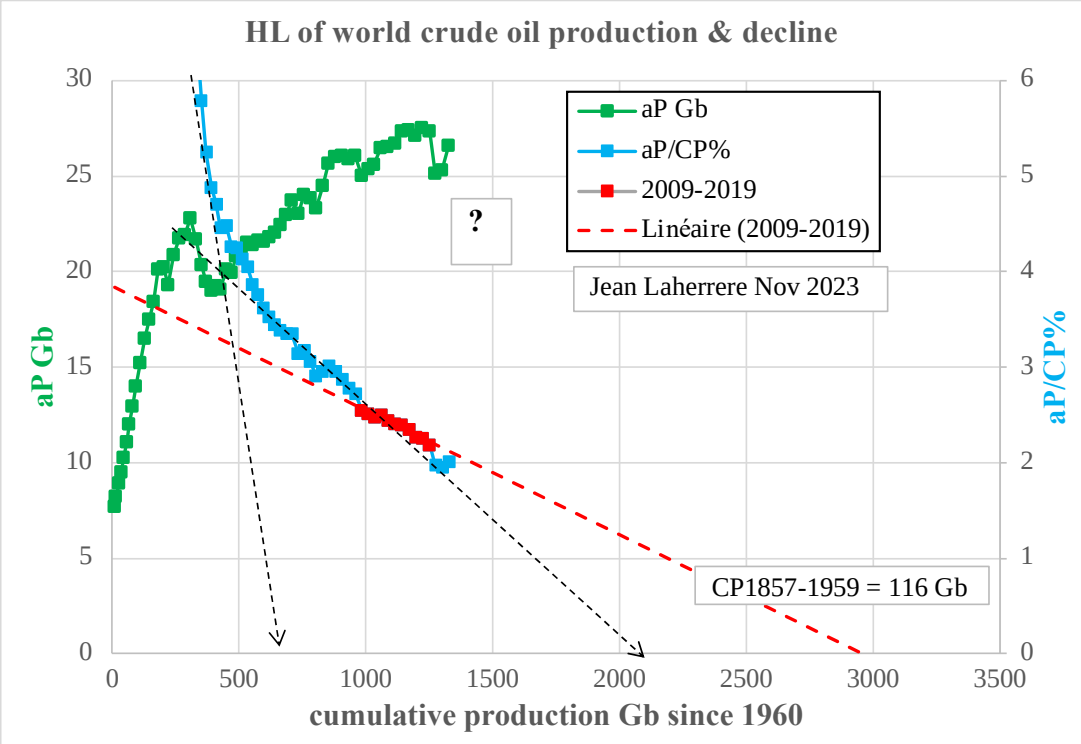
In 2050 crude oil production will be 67 Mb/d, in 2100 40 Mb/d and in 2200 7 Mb/d.

-World crude oil production with OPEC data since 1960

OPEC ASB reports crude oil production since 1960



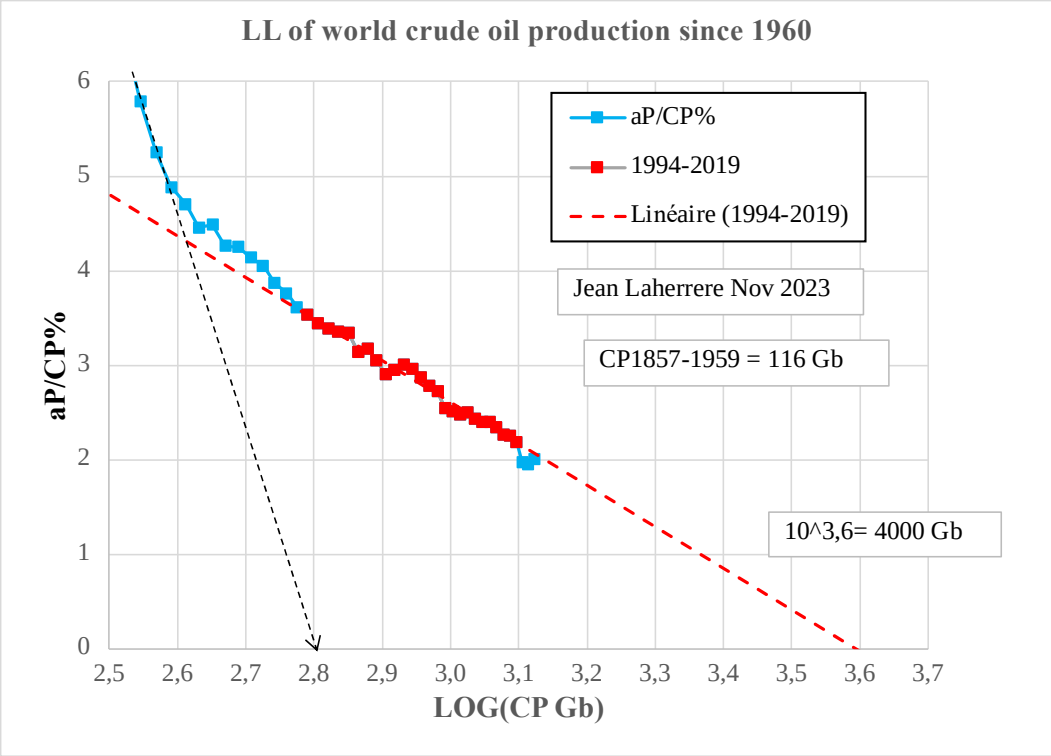
HL of world crude oil production from OPECASB data



World crude oil production since 1960 gives an ultimate of 3000 Gb and adding the CP 1857-1959 = 116 Gb gives a total far from the ultimate estimated of the crude oil production since 1857.

It means that it is incorrect to estimate real oil ultimate with data not starting from the beginning.

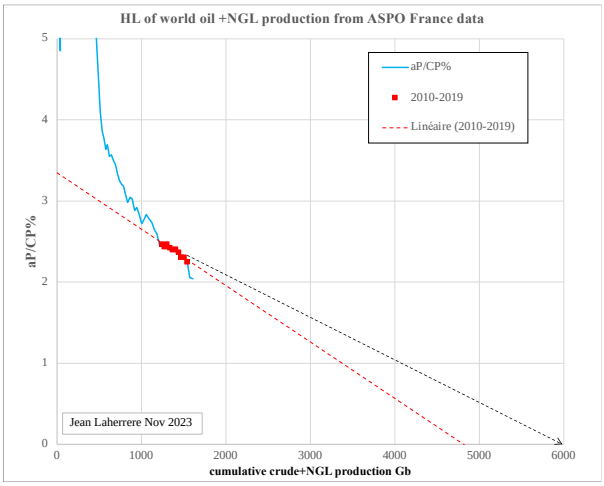
LL using x-axis with LOG(CP)

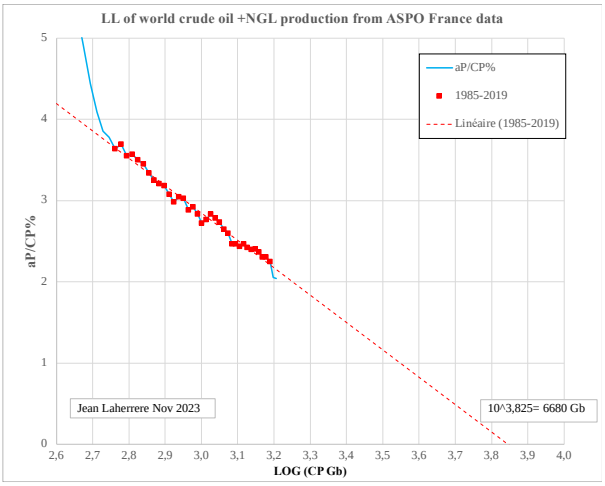


LL (x-axis in log scale) of world crude production is similar as HL, being two completely different trends of same periods, what it is different is the ultimate 4000 Gb for LL and 2800 Gb for HL: which is right? Or are they just estimates in a wild range of uncertainty!

-world crude oil + NGL

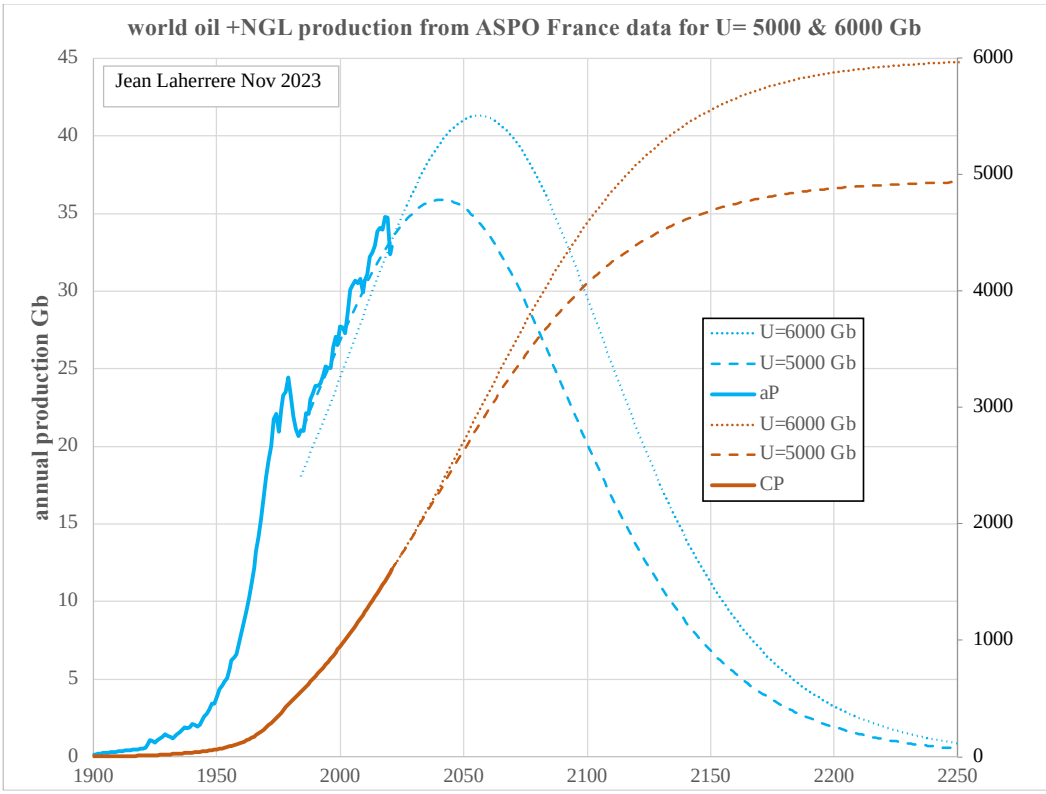
HL of world oil + NGL production in Gb is linear at the end for the period 2010-2019 = 10 years (forgetting 2020 and 2021 disturbed with covid) trending towards 4800 Gb, round up to 5000 Gb.





LL is linear from 1983 to 2019 or 27 years, much more than HL, trending towards 6700 Gb

The future production for the two ultimates 5000 and 6000 Gb

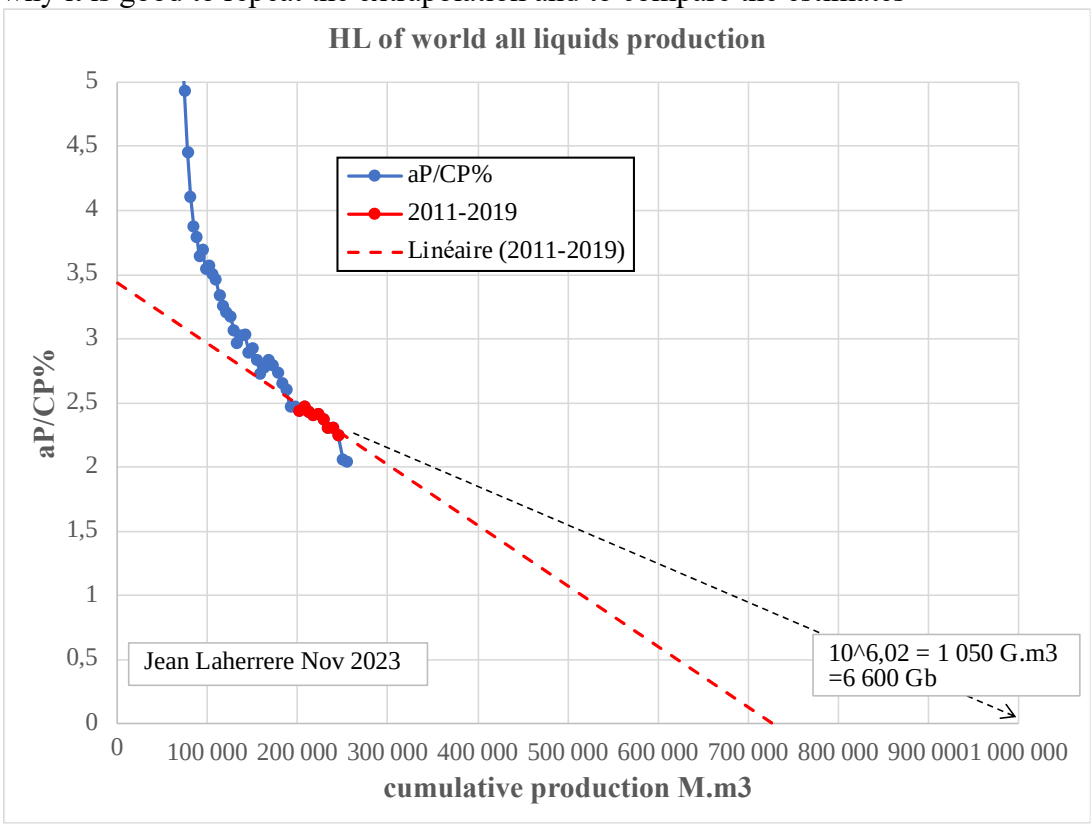


Both modelling looks realistic, meaning that LL forecast has to be considered

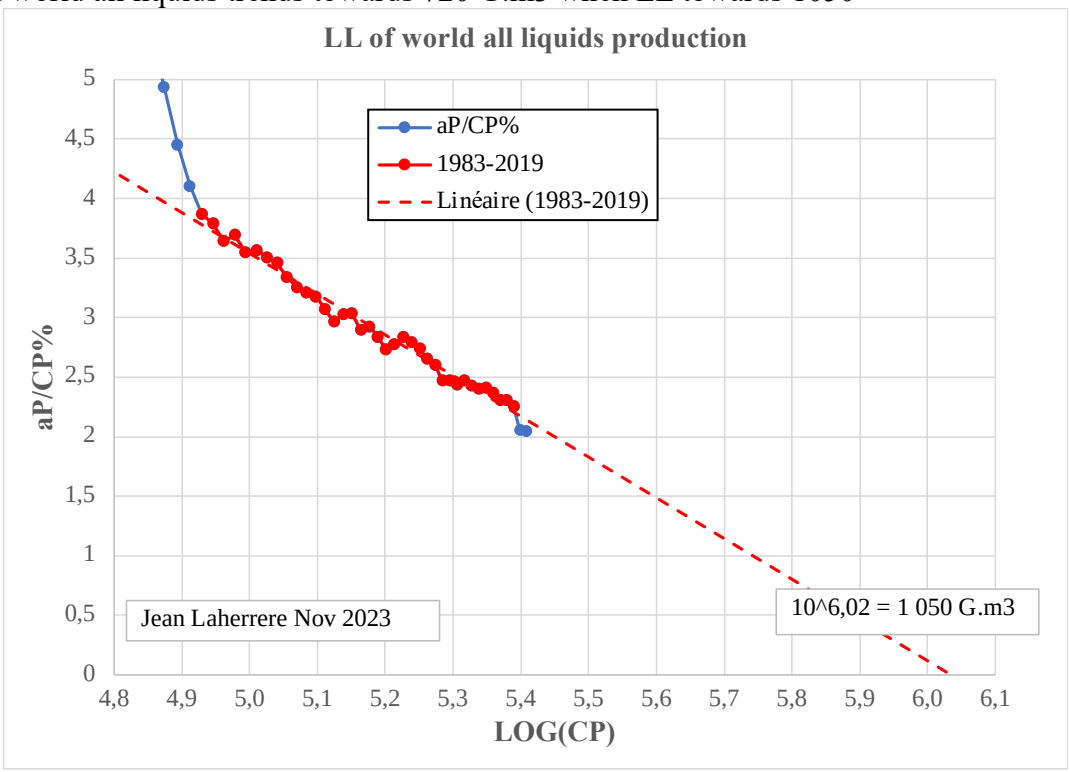
-world all HC liquids production from ASPO France data in M.m3

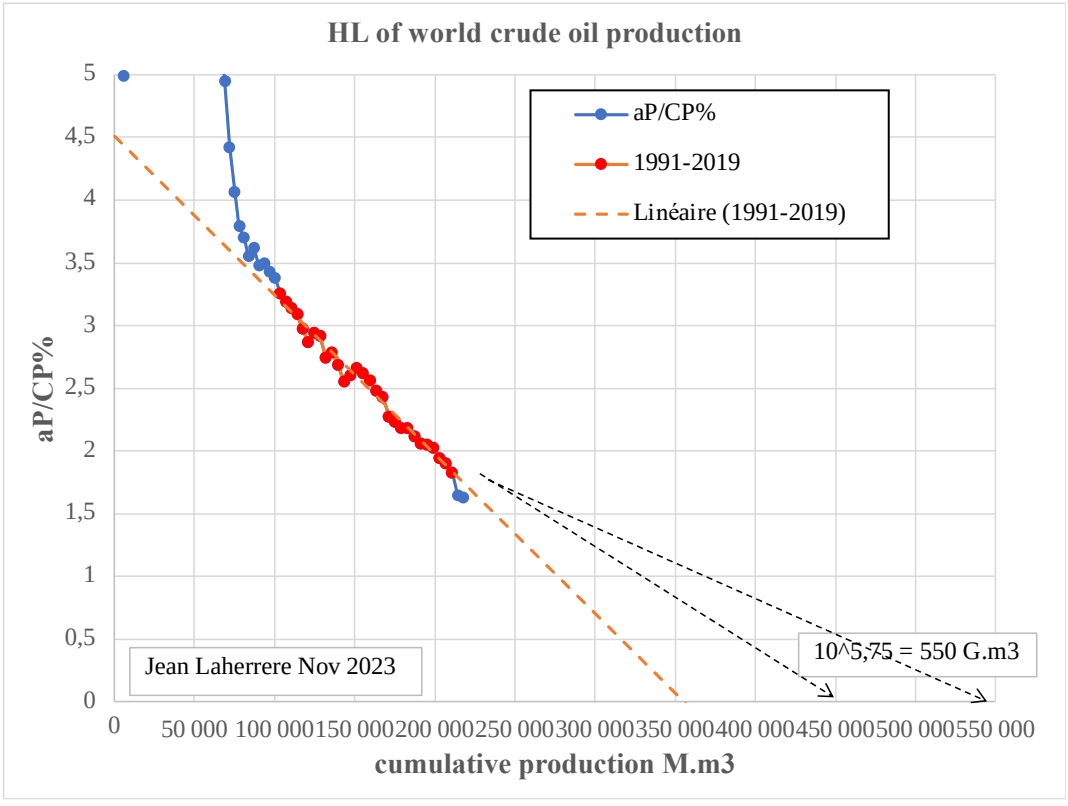
It is obvious that the extrapolation depends upon the chosen period and this choice varies with time and mood.

It is why it is good to repeat the extrapolation and to compare the estimates

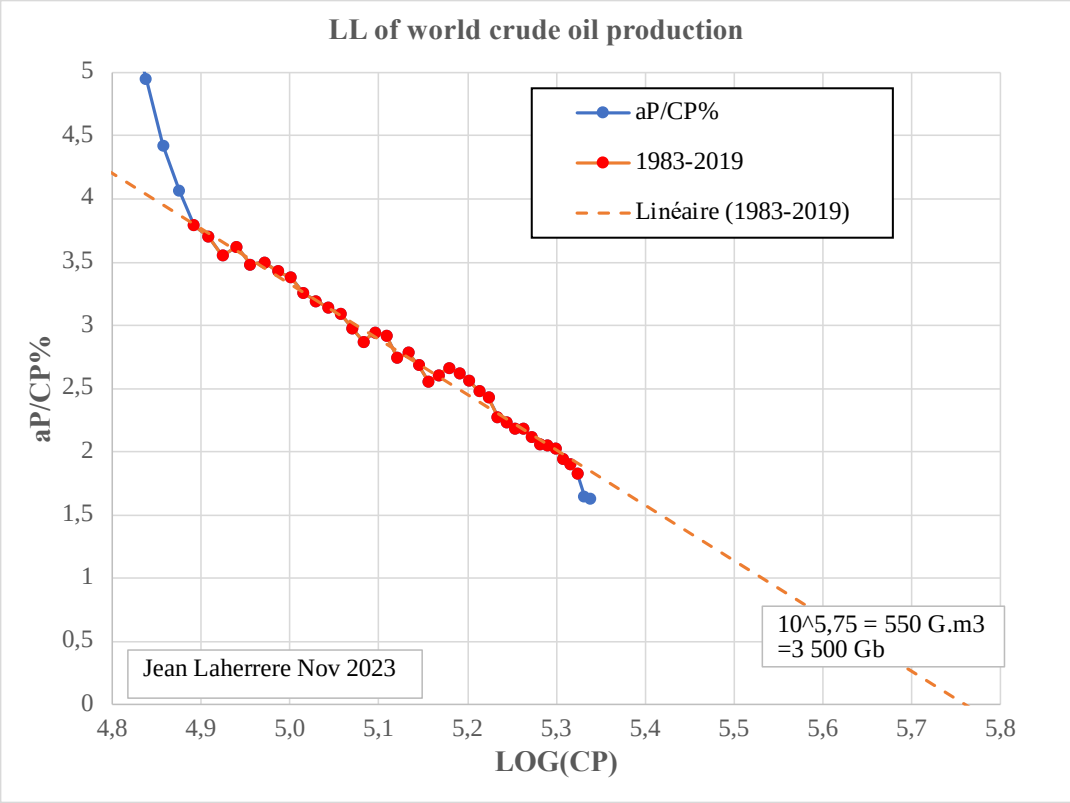


HL of world all liquids trends towards 720 G.m3 when LL towards 1050

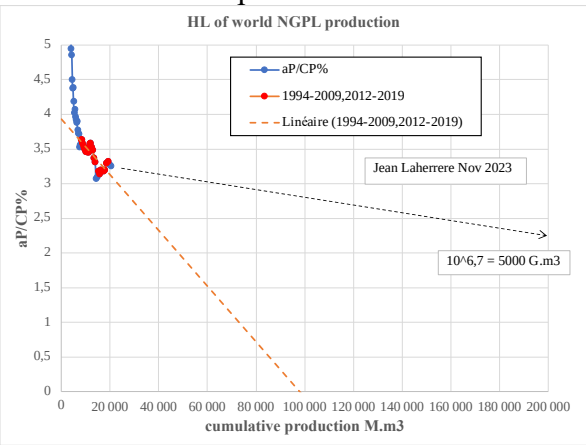


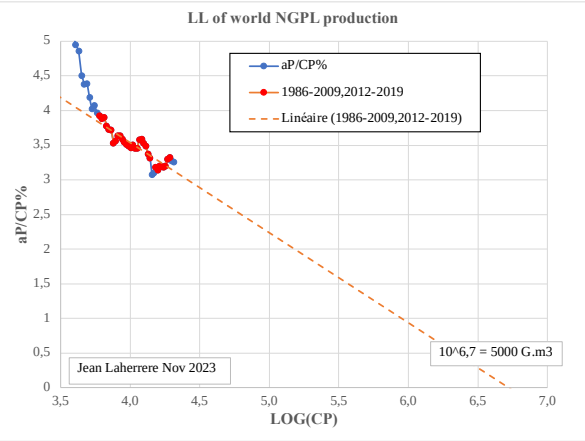


LL of world crude oi production trends towards 550 G.m3 when HL towards 350



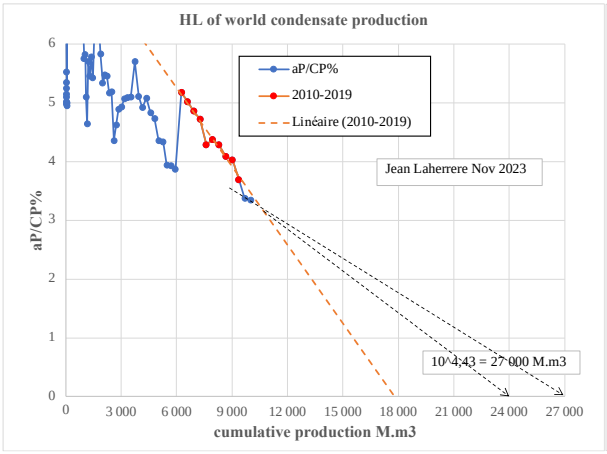
HL of world NGPL production trends towards 100 G.m3:

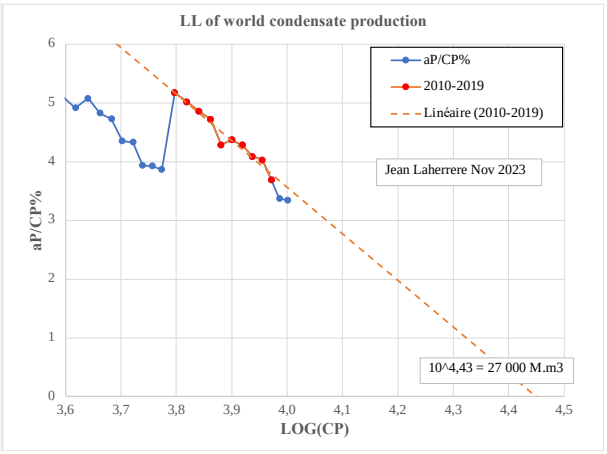




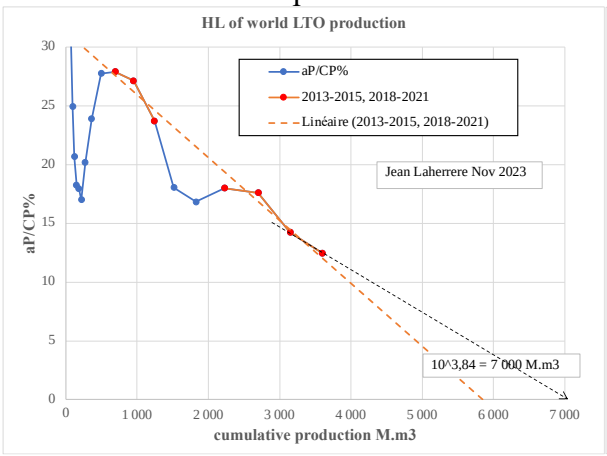
The NGPL ultimate from LL is 5000 G.m3 against 100 for HL = 50 times more: it is too much

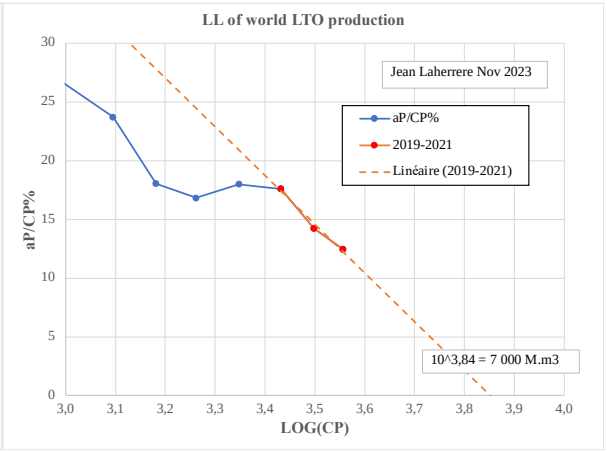
HL of world condensate production trends towards 18 G.m3 when LL trends towards 27 G.m3:



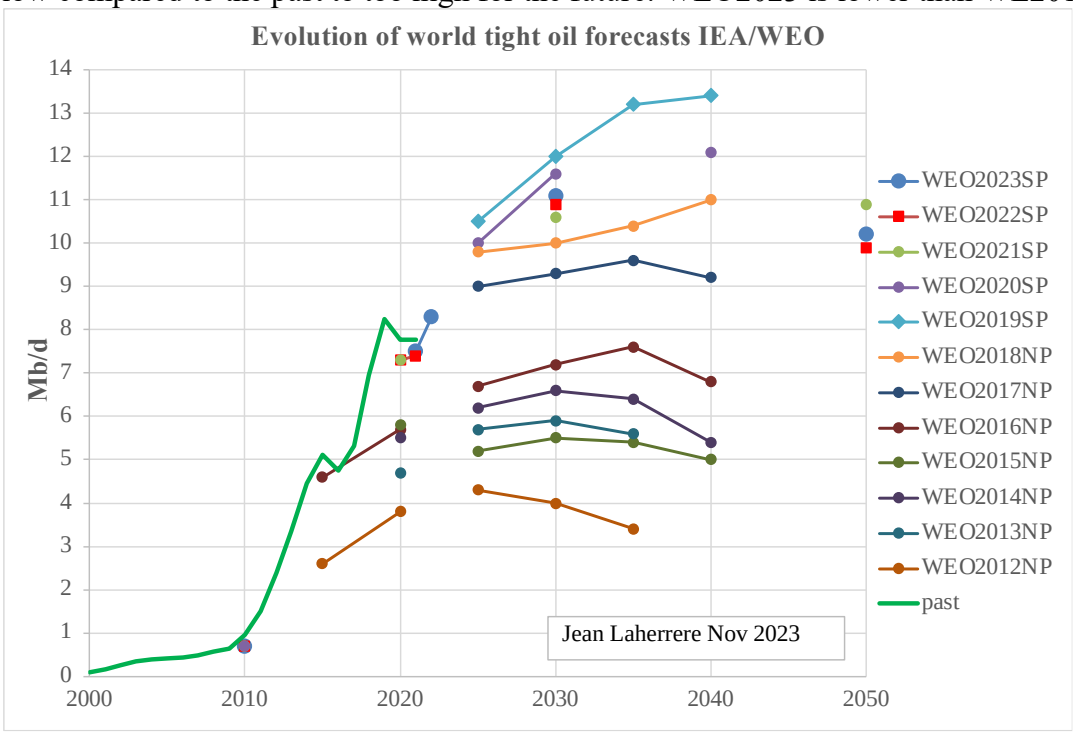


HL for the world LTO production trends towards 6 G.m3 when LL towards 7 G.m3, close

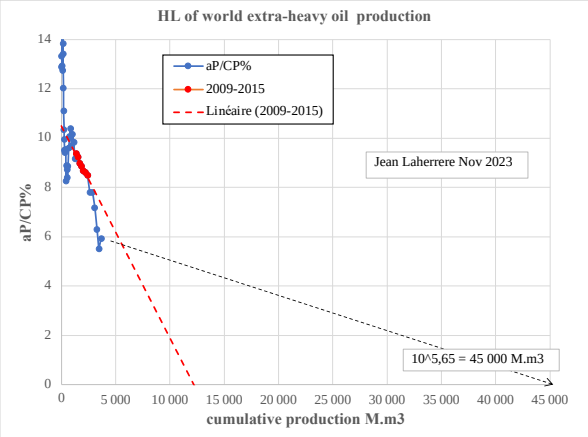


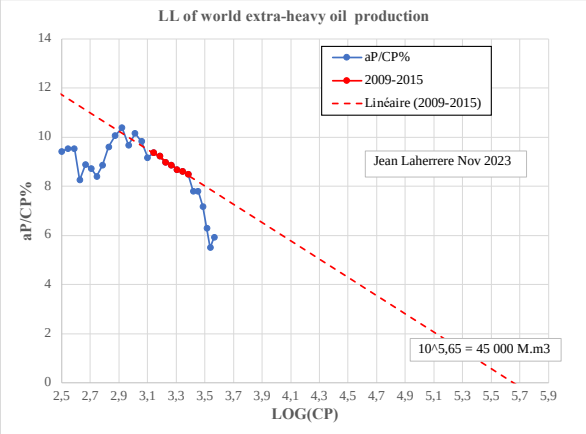


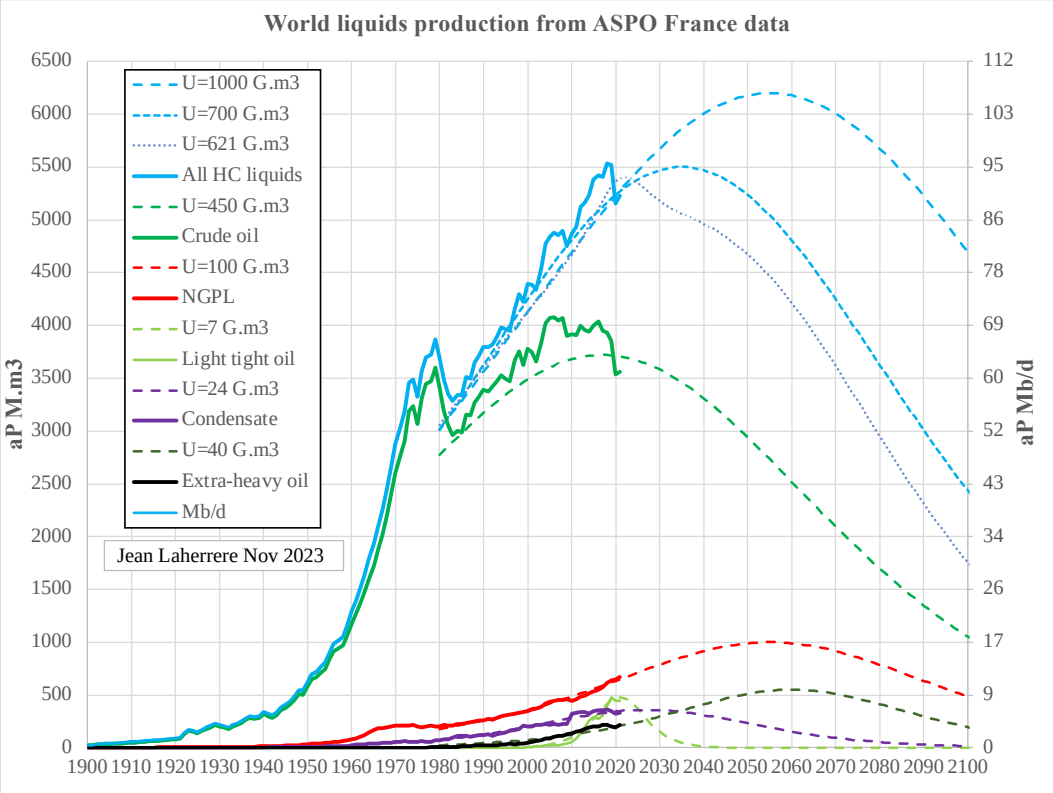
The IEA SP world tight oil forecast evolution from 2012 to 2023 has varied widely, from too low compared to the past to too high for the future: WEO2023 is lower than WE2019



HL for the world XH production trends towards 12 G.m3 when LL towards 45 G.m3
Orinoco production in Venezuela was disturbed since 2016 for political reasons and only the data 2009-2015 represents the potential of the extra-heavy





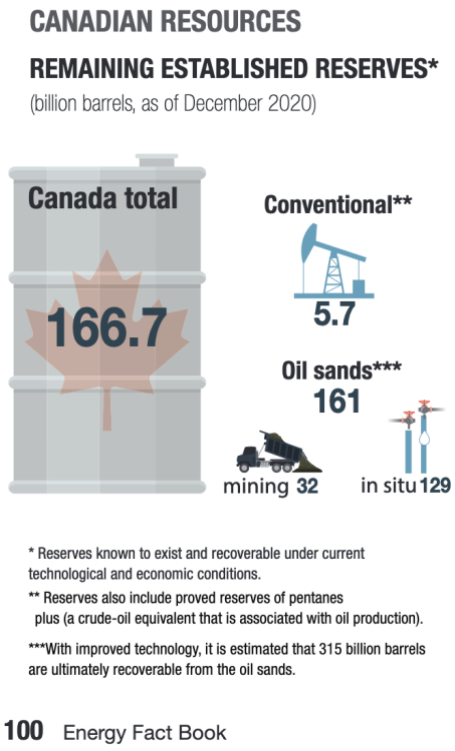


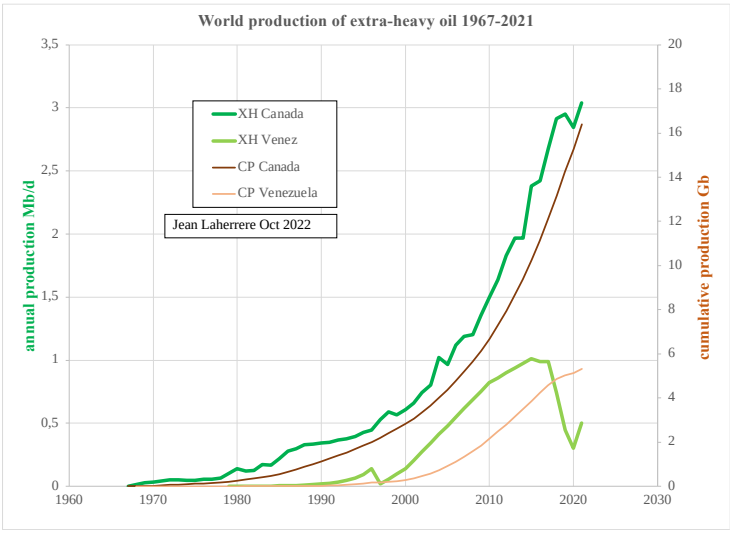
-comparison of ultimates

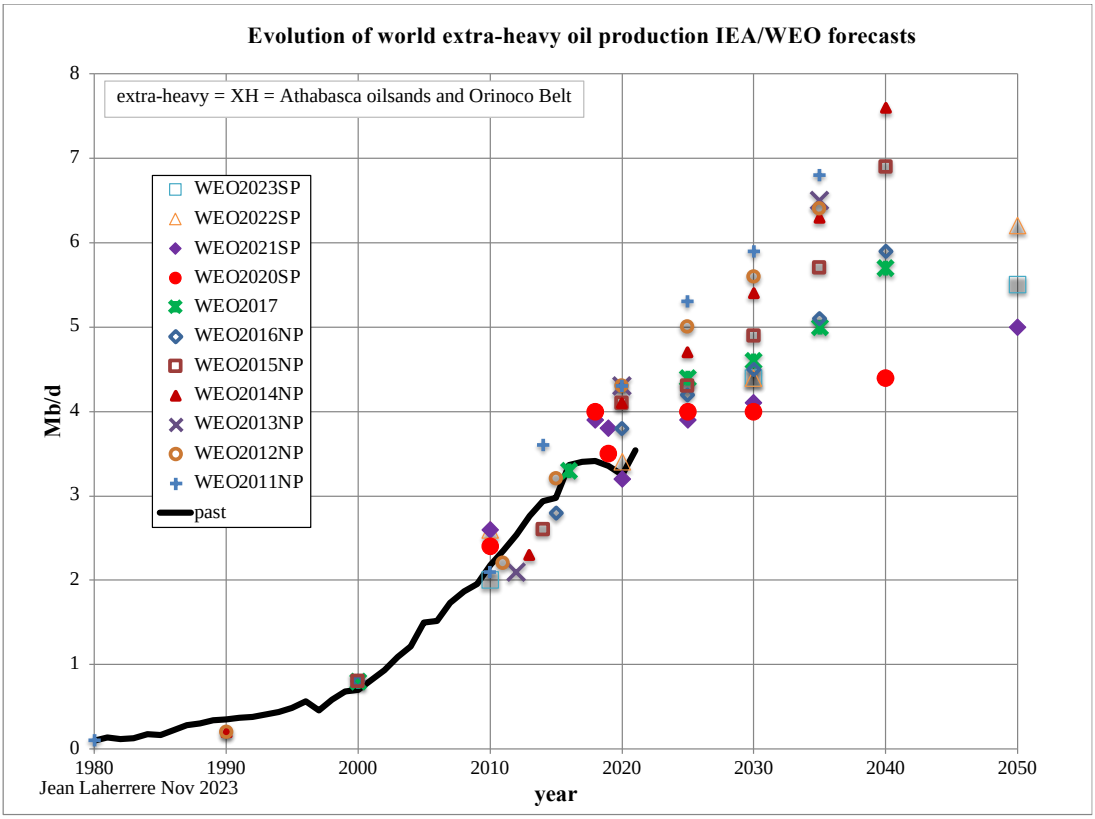
The comparison of ultimates from LL and from HL looks good, except for NGPL, with LL giving about 50 % more

Gb	world crude (	oil+NGL	NGPL	condensate	LTO	XH	all liq
data	1857-2022	1900-2021	1900-2021	1900-2021	1900-2021	1900-2021	1900-2022
period	2009-2019	2010-2019	1994-2019	2010-2019	2013-2021	2006-2021	2011-2019
HL	3400	4800	600	110	40	80	4500
period	1984-2019	1985-2019	1986-2019	2010-2019	2019-2021	2004-2015	1983-2019
LL	4200	6700	30000	170	45	280	6600
LL/HL	1,2	1,4	50,0	1,5	1,1	3,5	1,5

XH reserves (Athabasca and Orinoco) are well known (close to surface) and well estimated: CAPP reports at end 2020 167 Gb remaining oilsands reserves with a cumulative production of 15 Gb, giving a CP+RR of 182 Gb
In Venezuela Orinoco production were disturbed since 2010 by politics: nationalization and US sanctions.





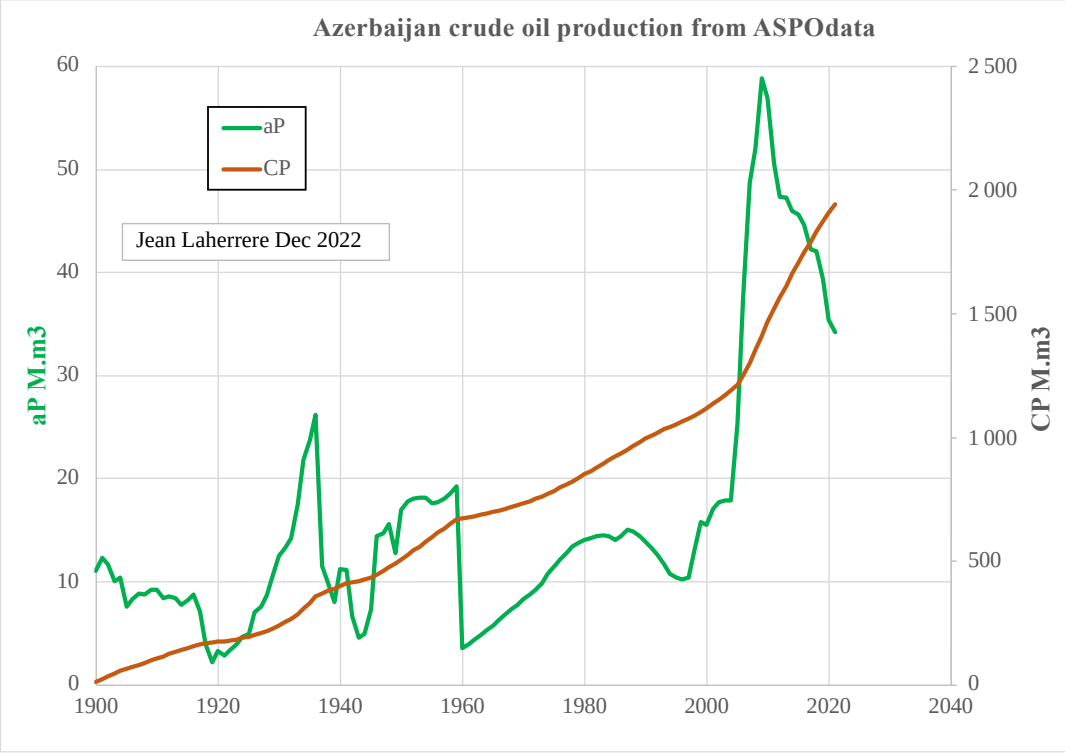


It appears on this case that LL technique widens the range of ultimates, but more examples are needed to appreciate the value of LL technique.
The best is to start with countries after peak, close to production end to compare HL and LL, and the extrapolation of oil decline is another good check of the ultimate.
The crude oil production from ASPO France data starting since 1900 in volume M.m3 is the best data to work with.

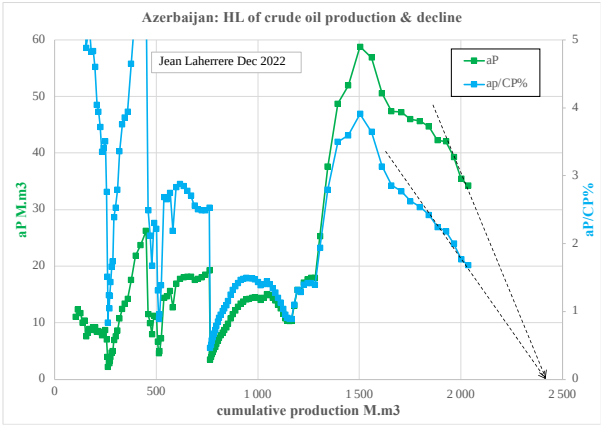
-After peak countries:

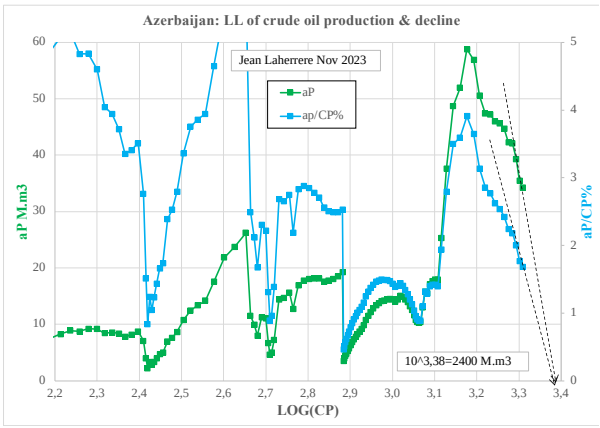
-Azerbaijan

Azerbaijan is the first oil producing area, already reported on the third century. According to Marco Polo, the Apsheron peninsula was dotted with oil wells and the oil extracted was used for lighting and for healing purpose, but no data is reported before 1857 by API.
Azerbaijan crude oil production is rather chaotic because wars and policies.



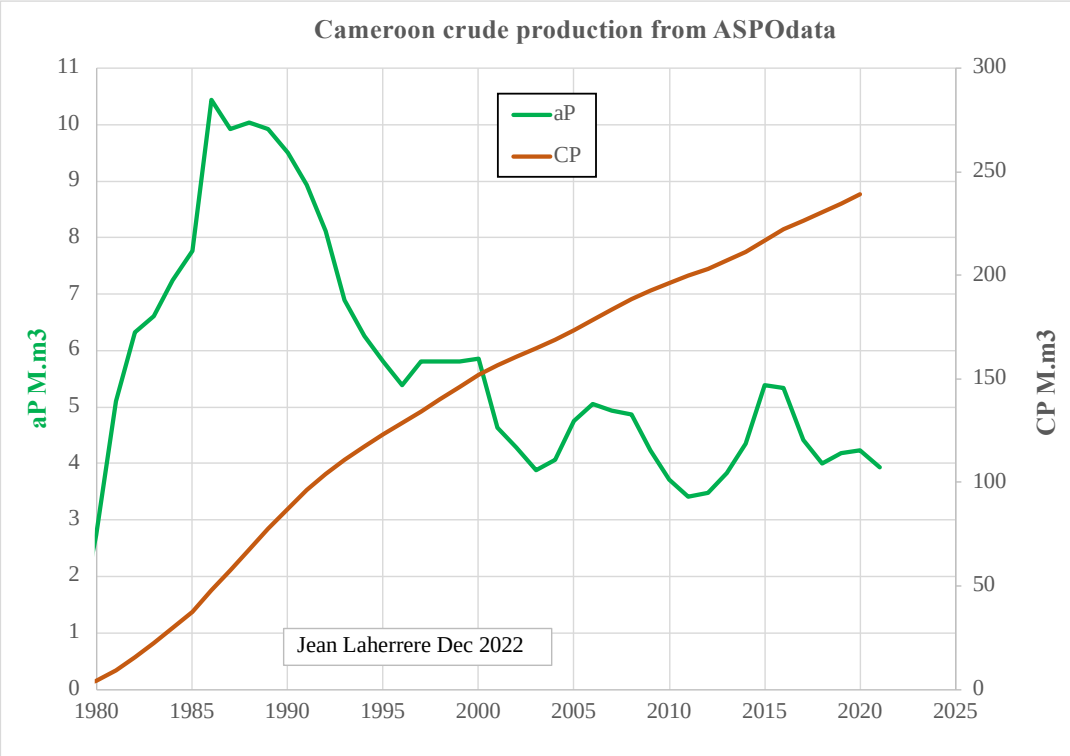
HL and decline trends for the last years towards the same ultimate of 2.4 G.m3 = 15 Gb, as also LL



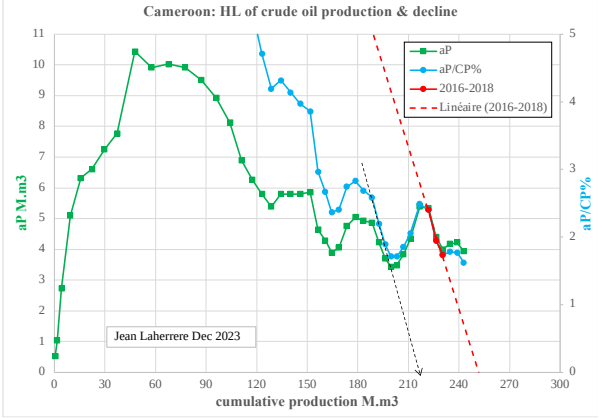


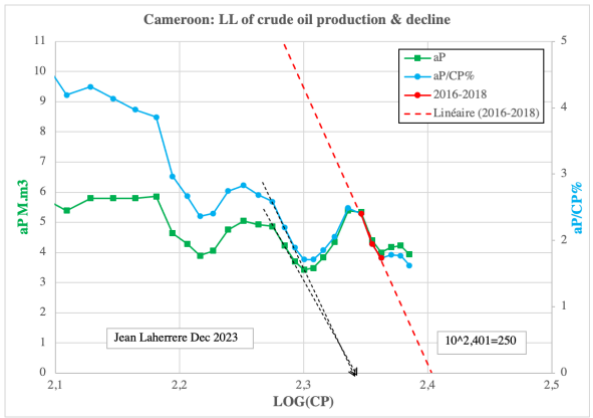
-Cameroon

Cameroon crude oil production peak is 1984 and its decline is rather chaotic



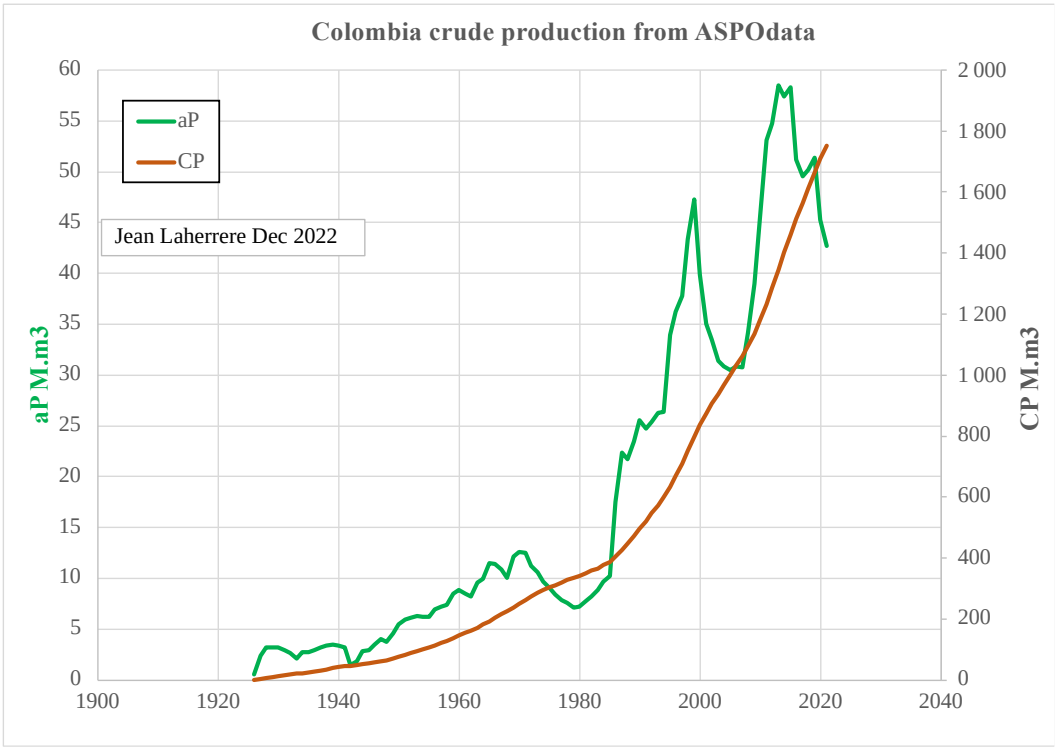
HL and LL for the period 2016-2019 trends towards 250 M.m3



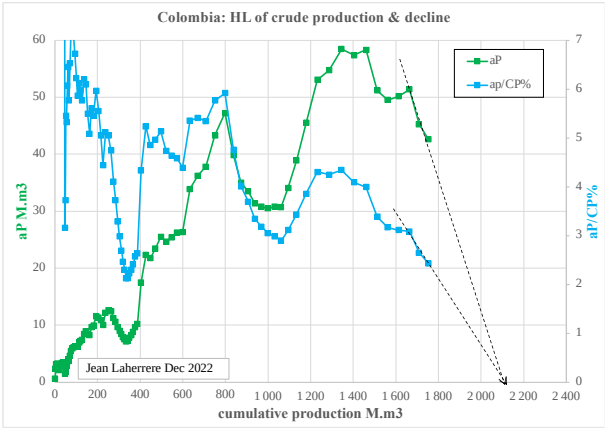


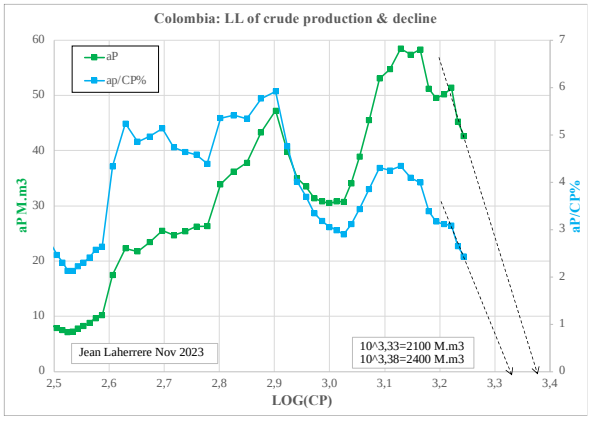
-Colombia

Colombia crude oil production displays 2 peaks and a strong decline

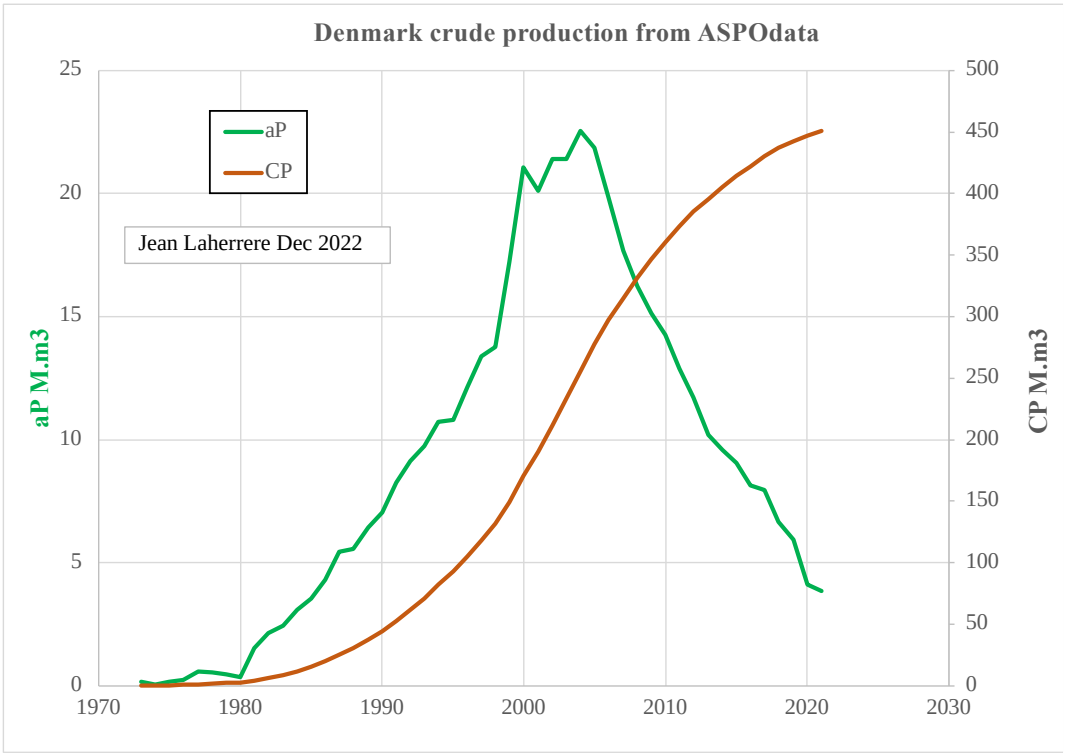


HL and LL trends towards 3200 M.m3, as decline (green) in normal scale but not in log scale

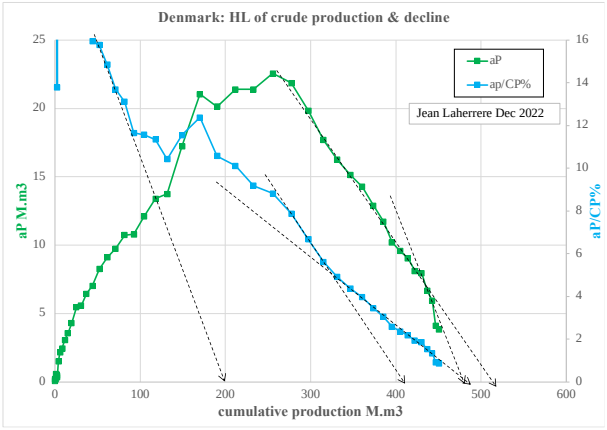


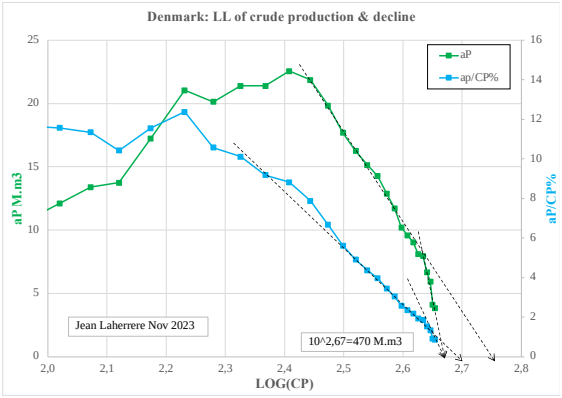


-Denmark



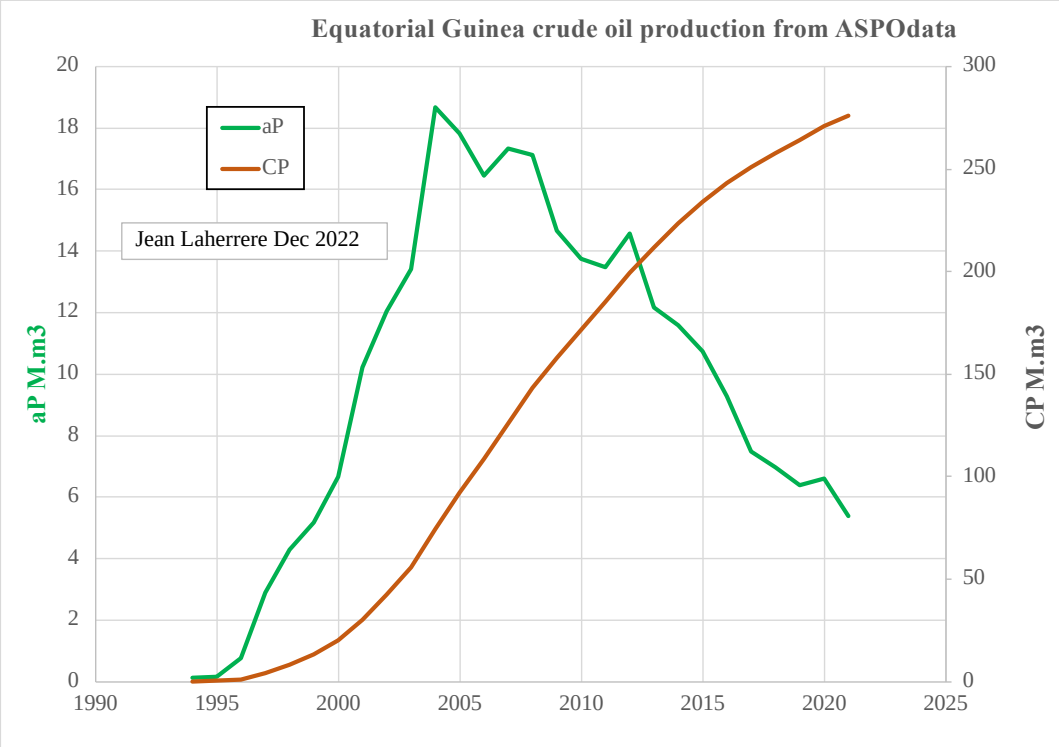
HL and LL trends towards the same ultimate



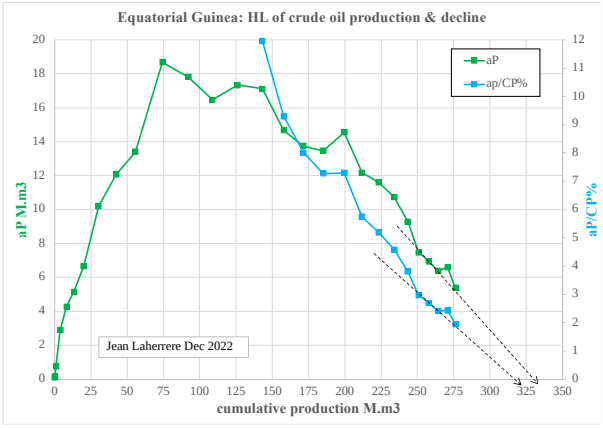


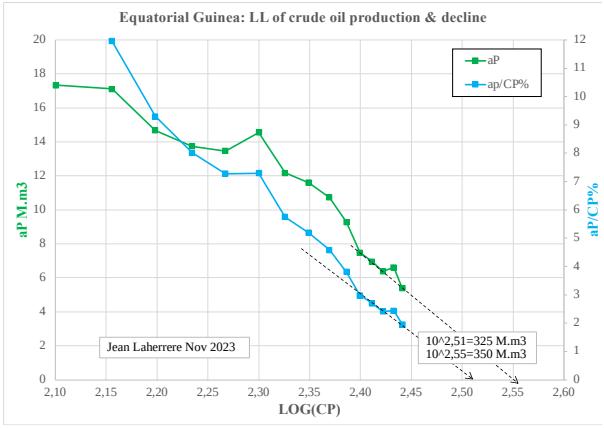
-Equatorial Guinea

Equatorial Guinea crude oil production peaked in 2004 and declines rather with the same rate



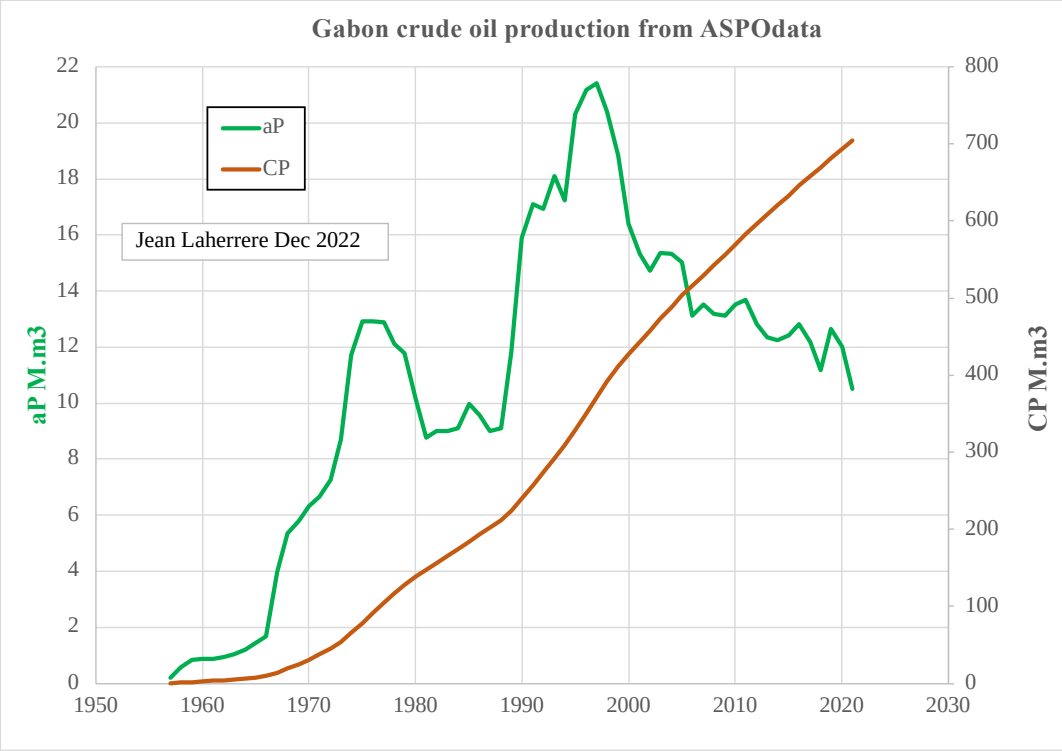
HL and LL trends towards 325 M.m3



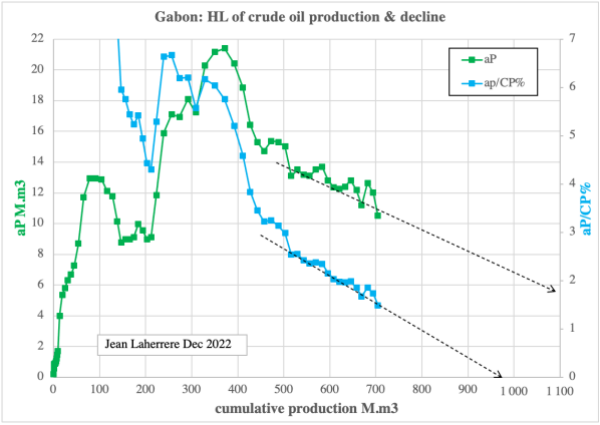


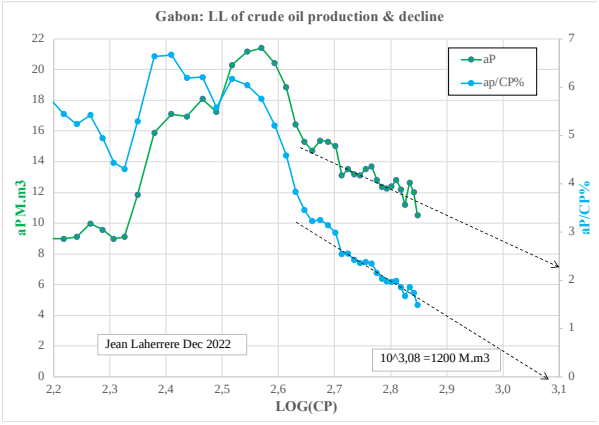
-Gabon

Gabon crude oil production peaked in 1998 and since 2000 declines with the same trend

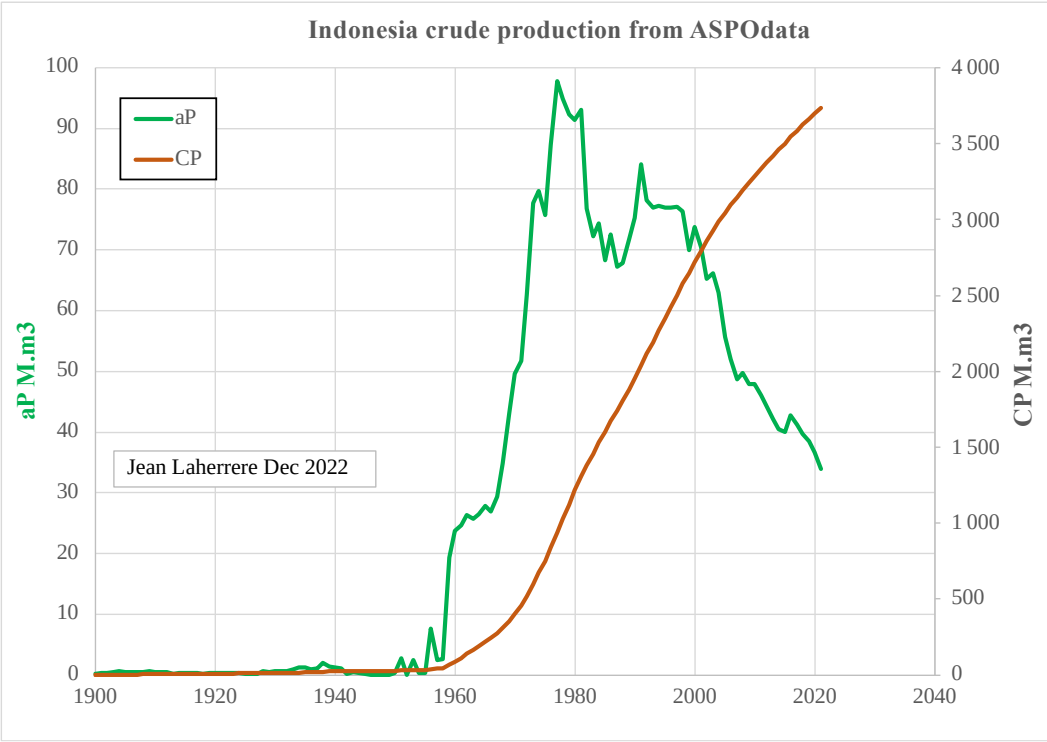


HL trends towards 1 G.m3 when LL towards 1.3

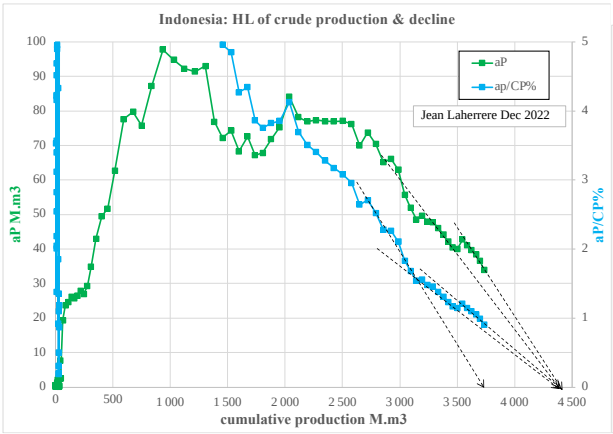


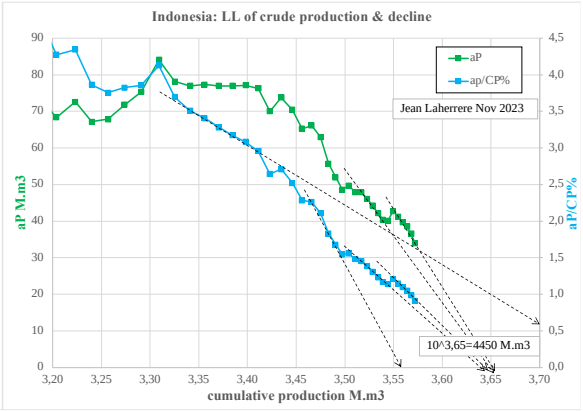


-Indonesia



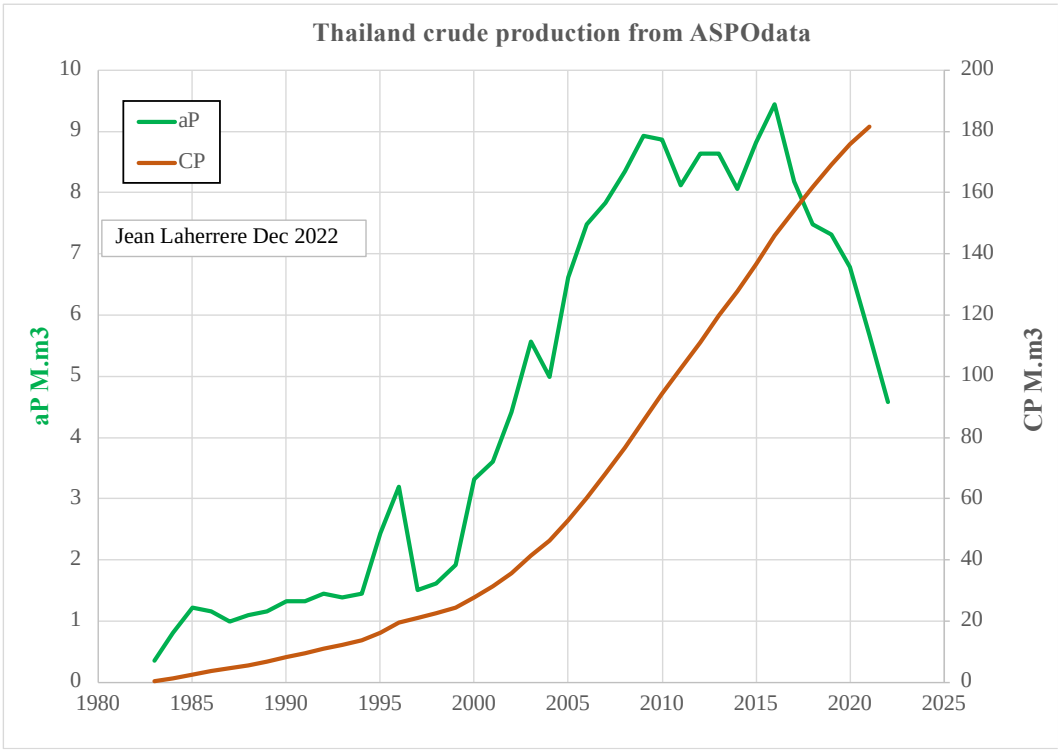
HL and LL trend towards 4.4 G.m3



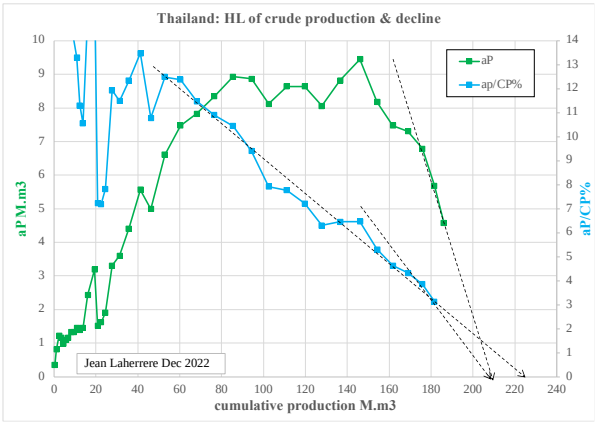


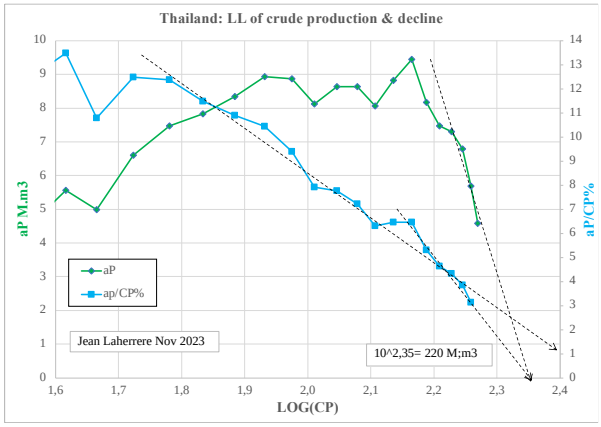
-Thailand

Thailand crude oil production peaked in 2016 and declines sharply



HL and LL trends towards 220 M.m3

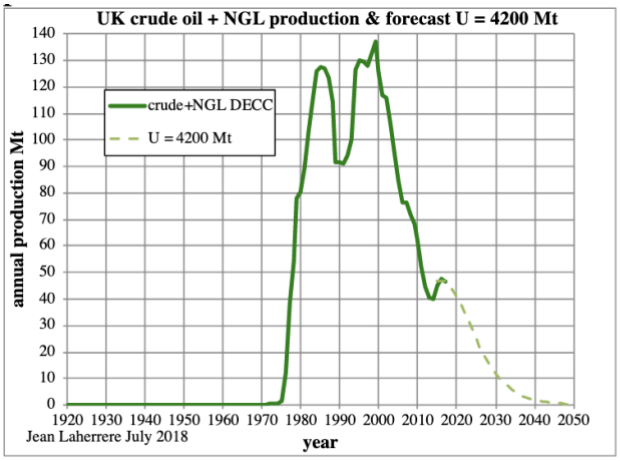


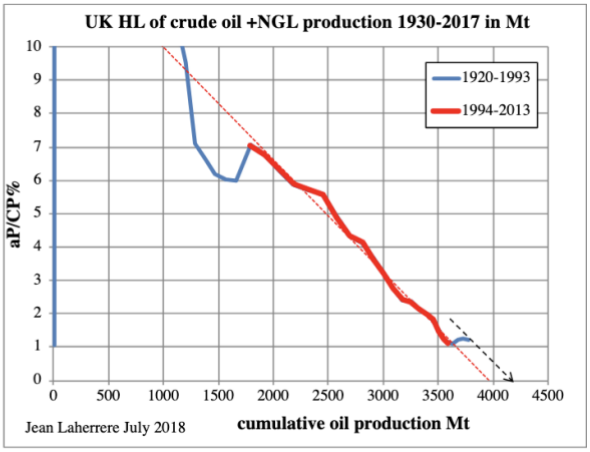


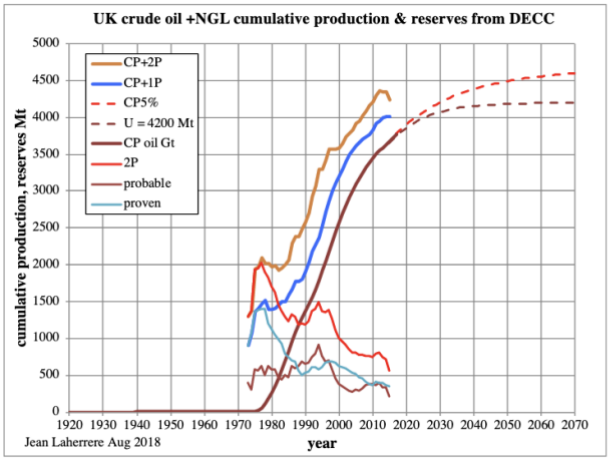
-UK

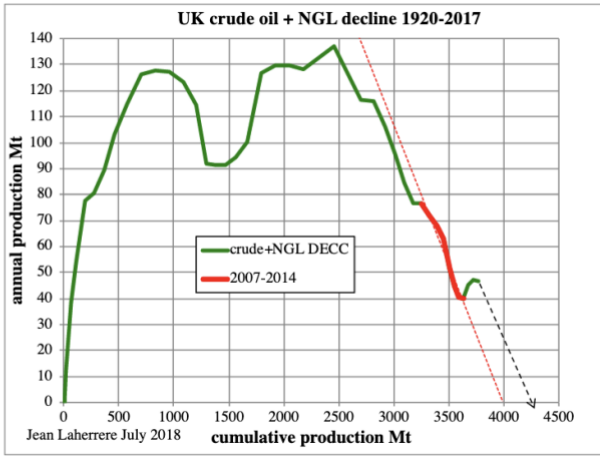
In 2018 UK crude oil + NGL was forecasted for an ultimate of 4200 Mt, both from creaming curves and HL

https://aspofrance.files.wordpress.com/2018/08/35cooilforecast.pdf



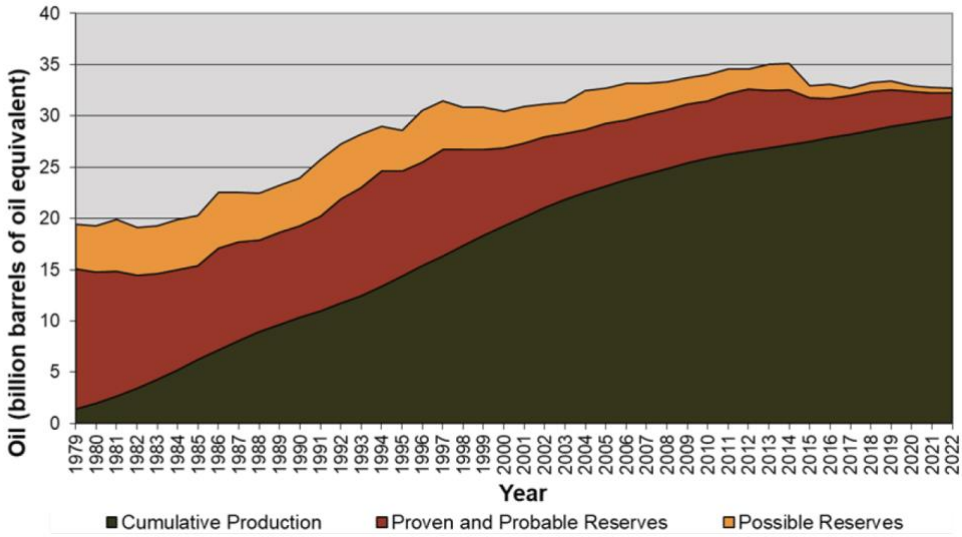




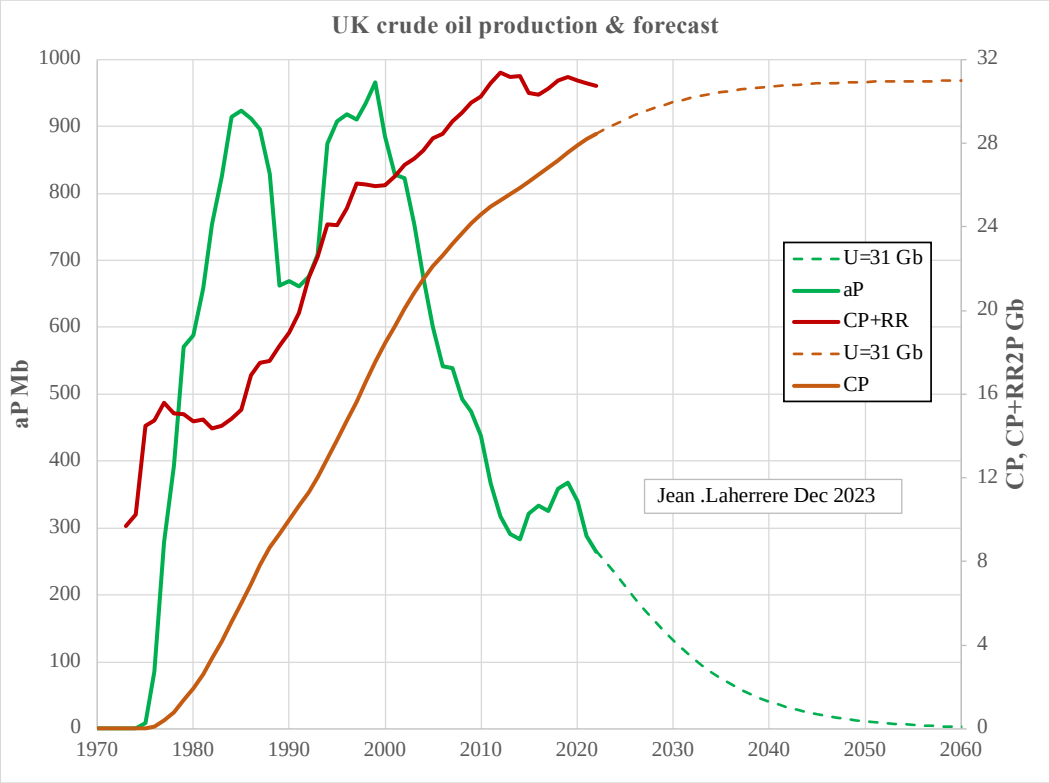


From the present data oil cumulative production trends towards 32 Gb for the UK graph

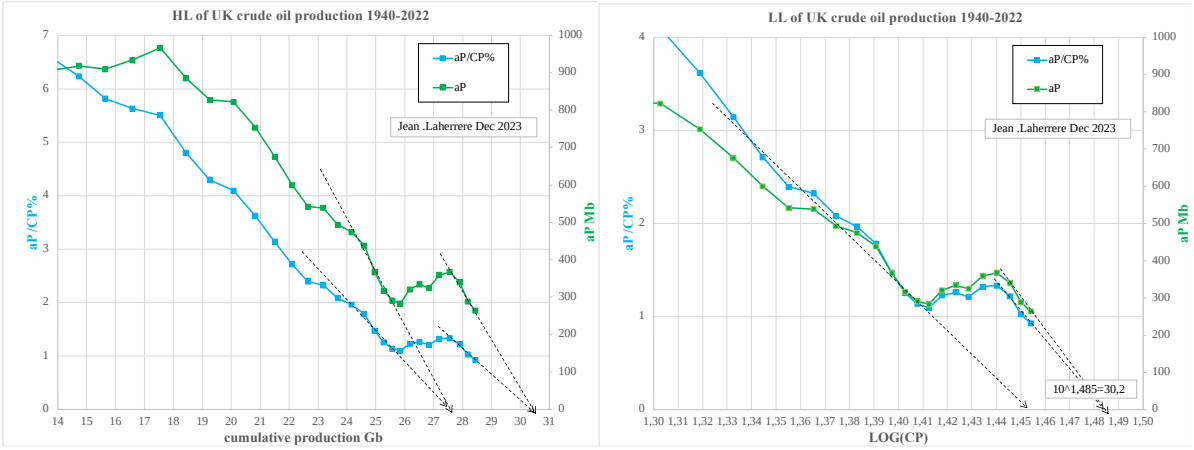
Figure 6: Oil Estimated Ultimate Recovery vs time (to end 2022)



But the UK data CP + remaining reserves trends towards 31 Gb



HL and decline as LL trends towards 30.5 Gb

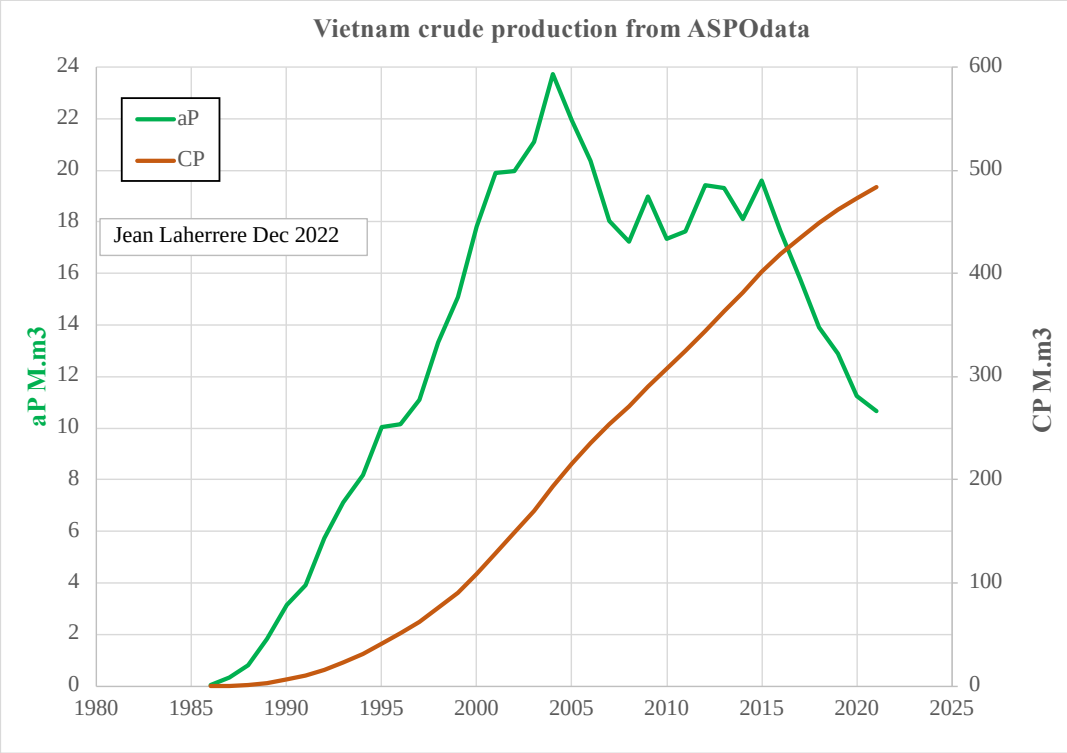


It appears in this case that it is useless to use more than 2 significant digits and that 31 Gb or 32 Gb is about the same

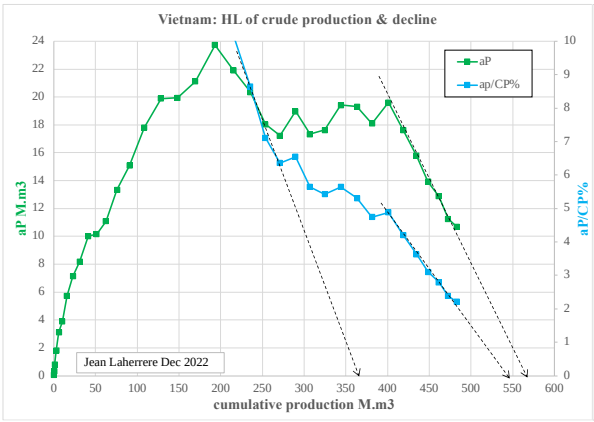
For a long time, oil production was measured in weight and the conversion in volume is tricky as density varies with field and with time

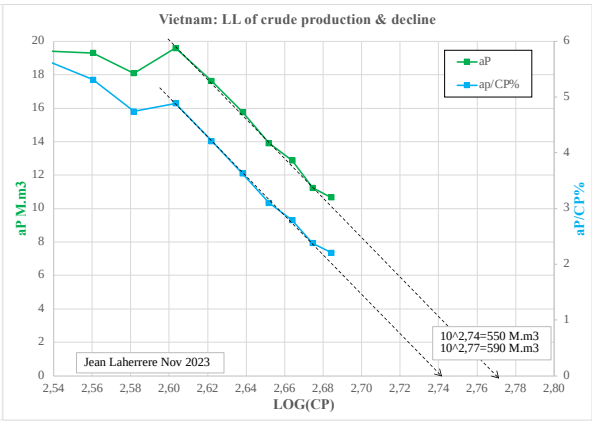
-Vietnam

Vietnam crude oil production peaked in 2004 and declines sharply since 2015



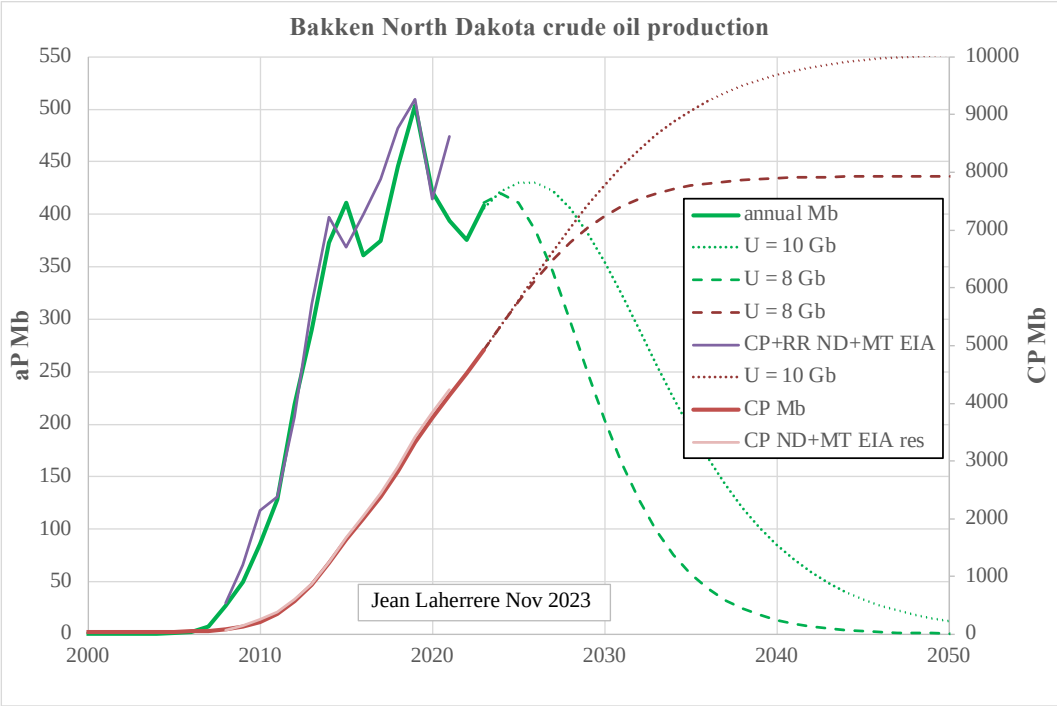
HL and LL trends towards 550 M.m3



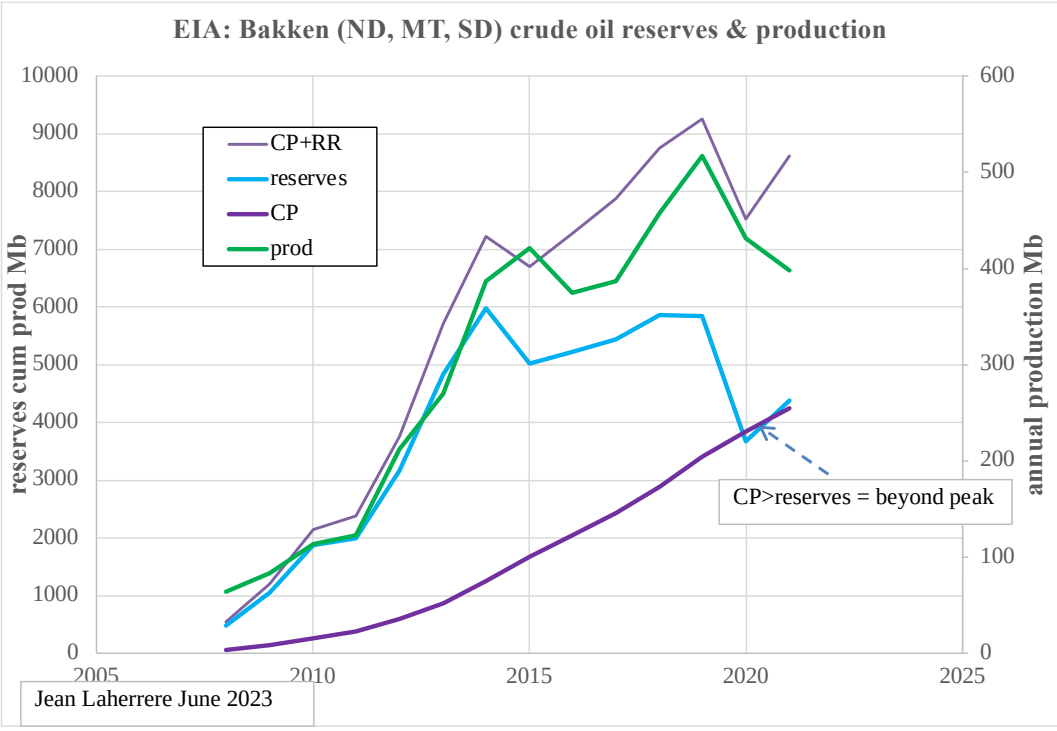


-Bakken North Dakota

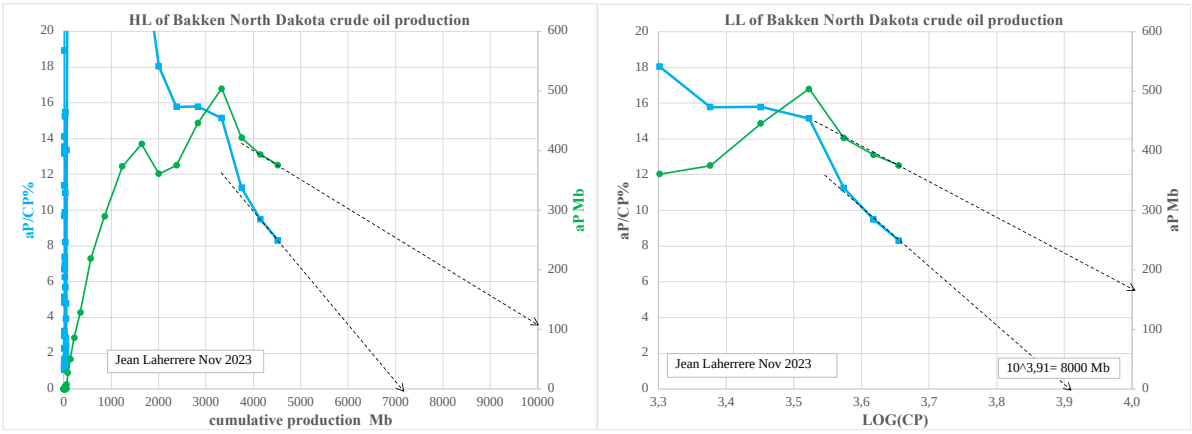
North Dakota Bakken crude oil annual production from www.dmr.nd.gov Is forecasted with 2 ultimates of 8 and 10 Gb in line as end 2021 with the EIA proven remaining reserves +cumulative production for North Dakota and Montana of 8621 Mb



U= 8 Gb peak will be 2024

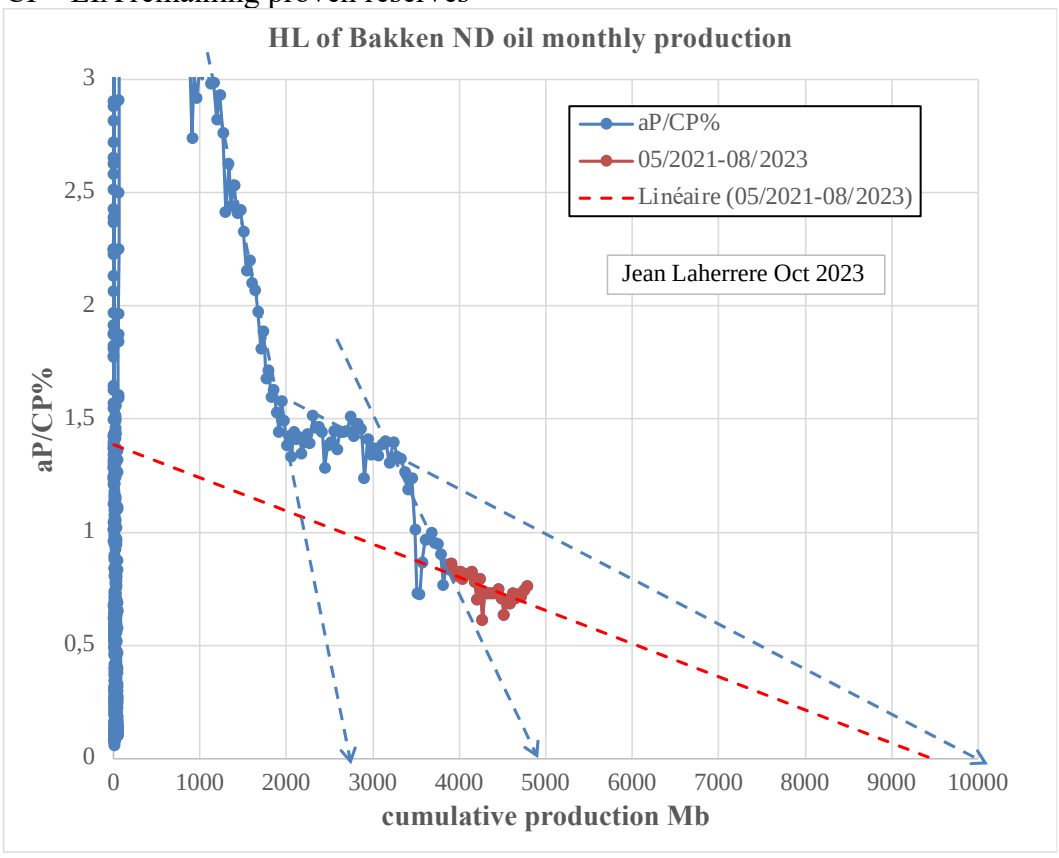


HL of ND Bakken annual crude oil production (blue curve) is not really linear and the last three values (2020-2022) trends towards 7 Gb when the annual decline trends well over 10 Gb, meaning very poor estimates.
But the three last points of LL trend towards 8 Gb

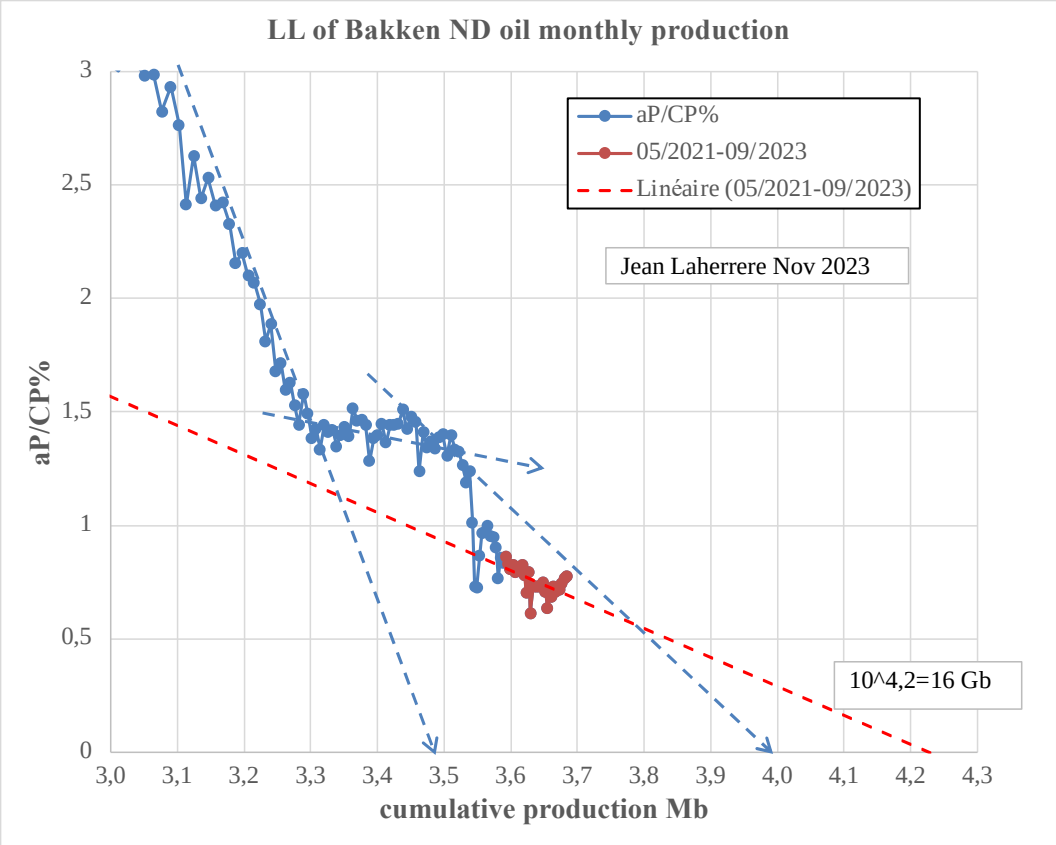


Most of the potential area is drilled but the producers continue to increase the monthly production as the last report

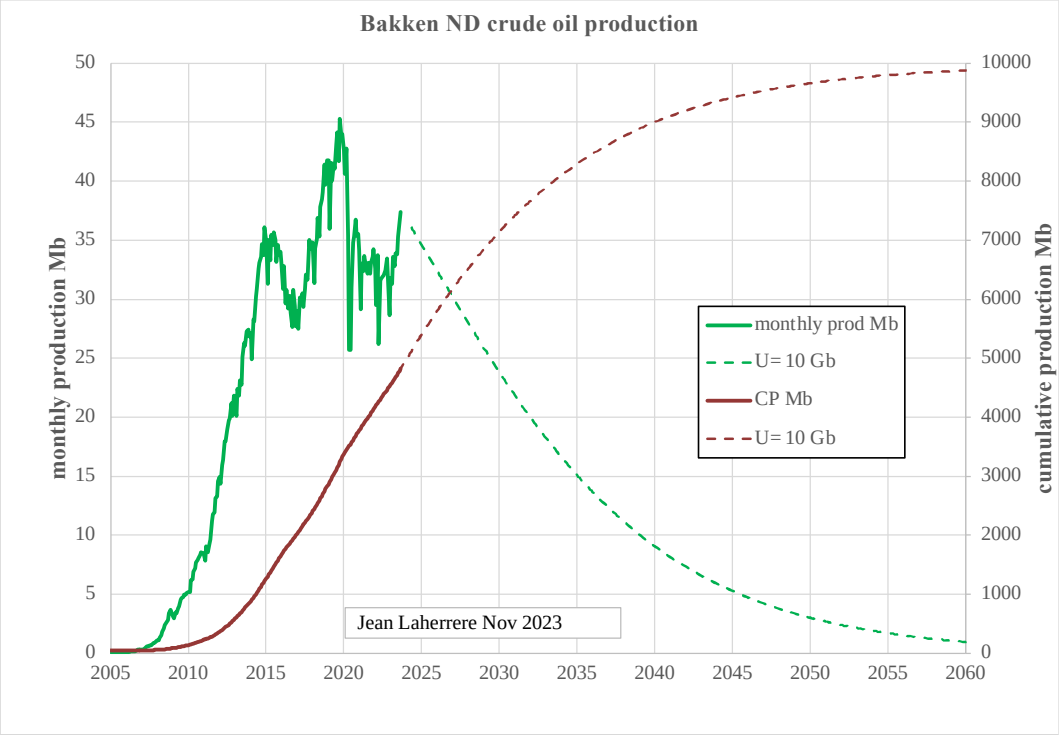
HL of ND Bakken monthly data trends for the last 29 months towards 10 Gb, which is not far to the CP+ EIA remaining proven reserves



LL of Bakken monthly production trends towards 16 Gb, quite too high

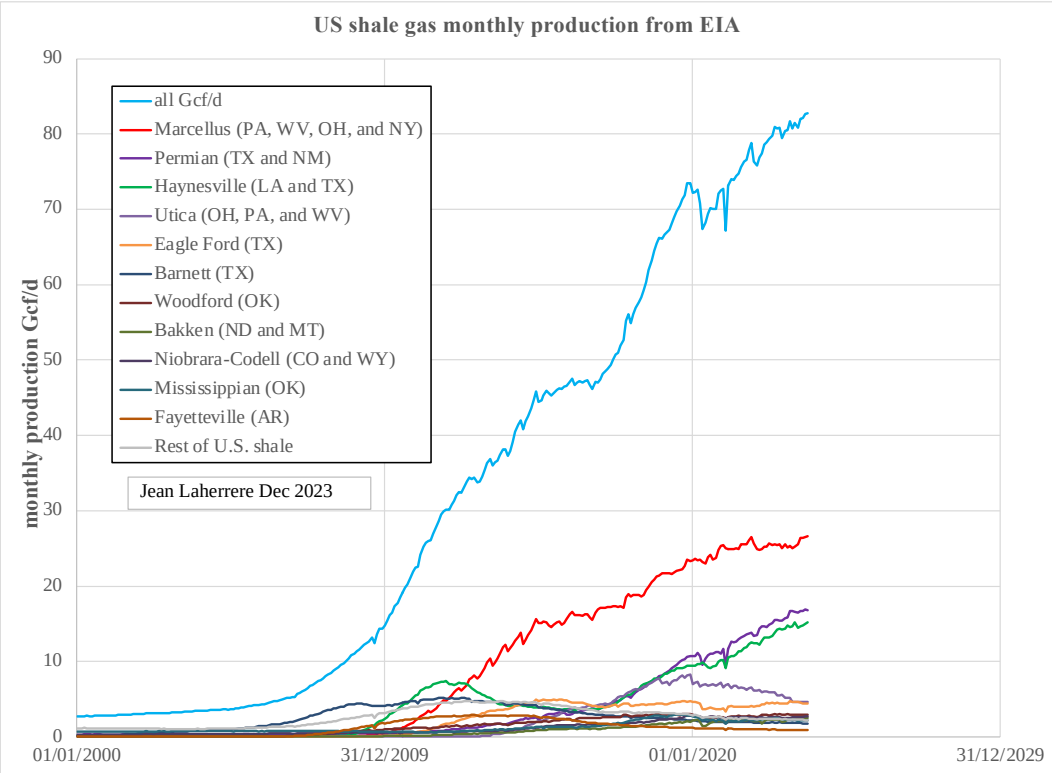


Future Bakken production is forecasted to decline soon, but the decline will be slow with still production in 2050, much than the rapid increase

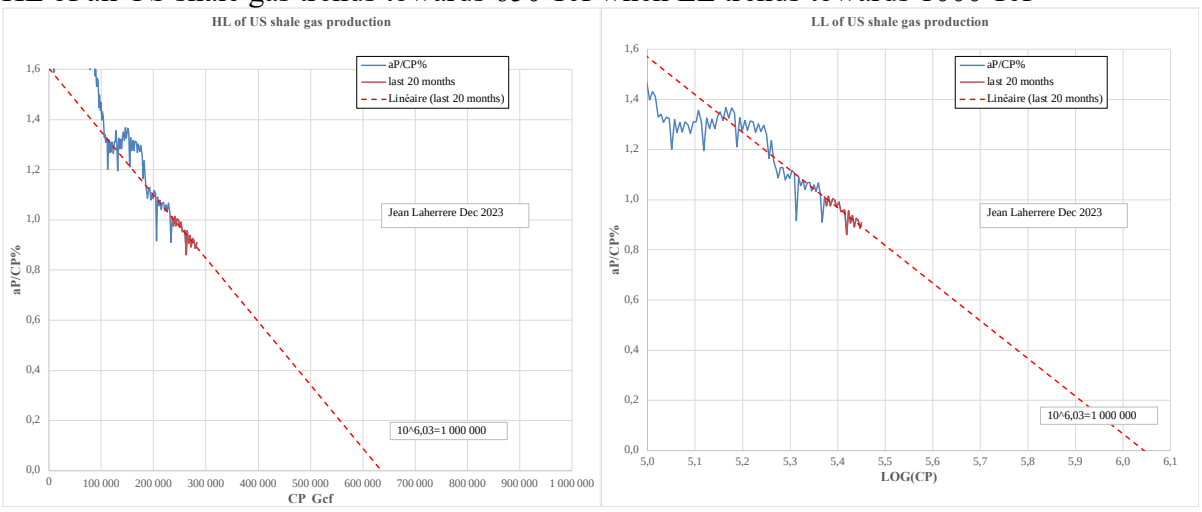


-US shale gas

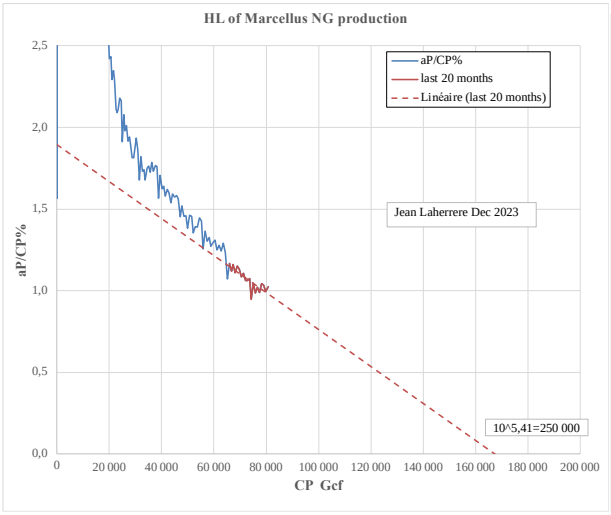
EIA reports US shale das monthly production in Gcf/d

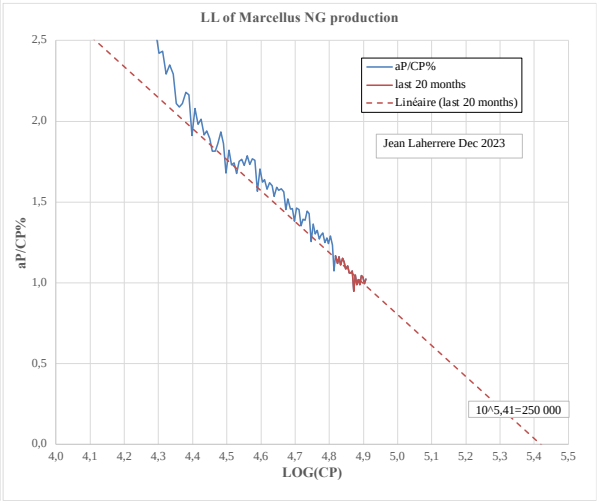


HL of all US shale gas trends towards 650 Tcf when LL trends towards 1000 Tcf

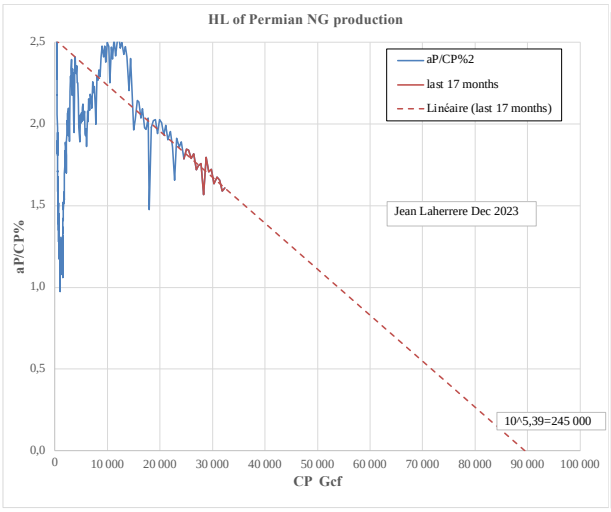


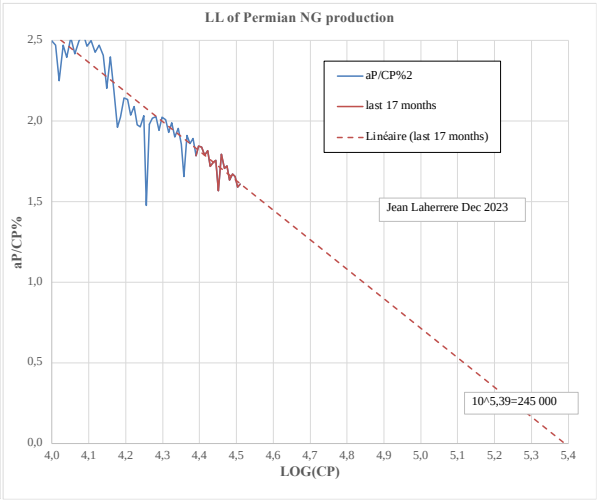
HL of Marcellus trends towards 170 Tcf when LL towards 250 Tcf



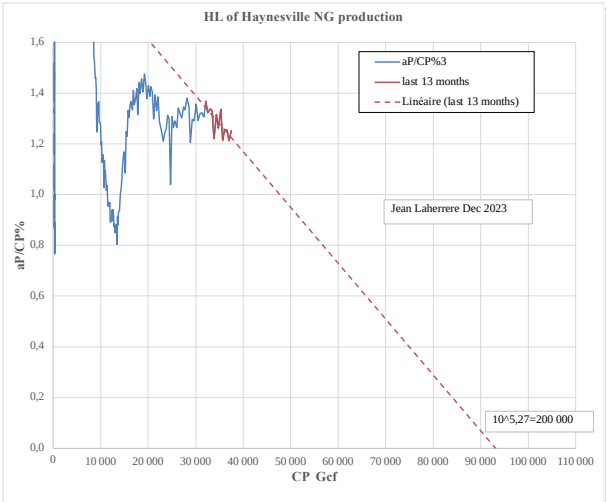


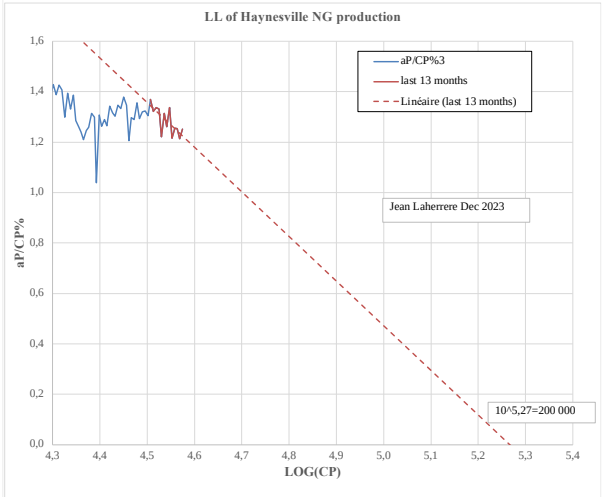
HL of Permian trends towards 90 Tcf when LL towards 200 Tcf



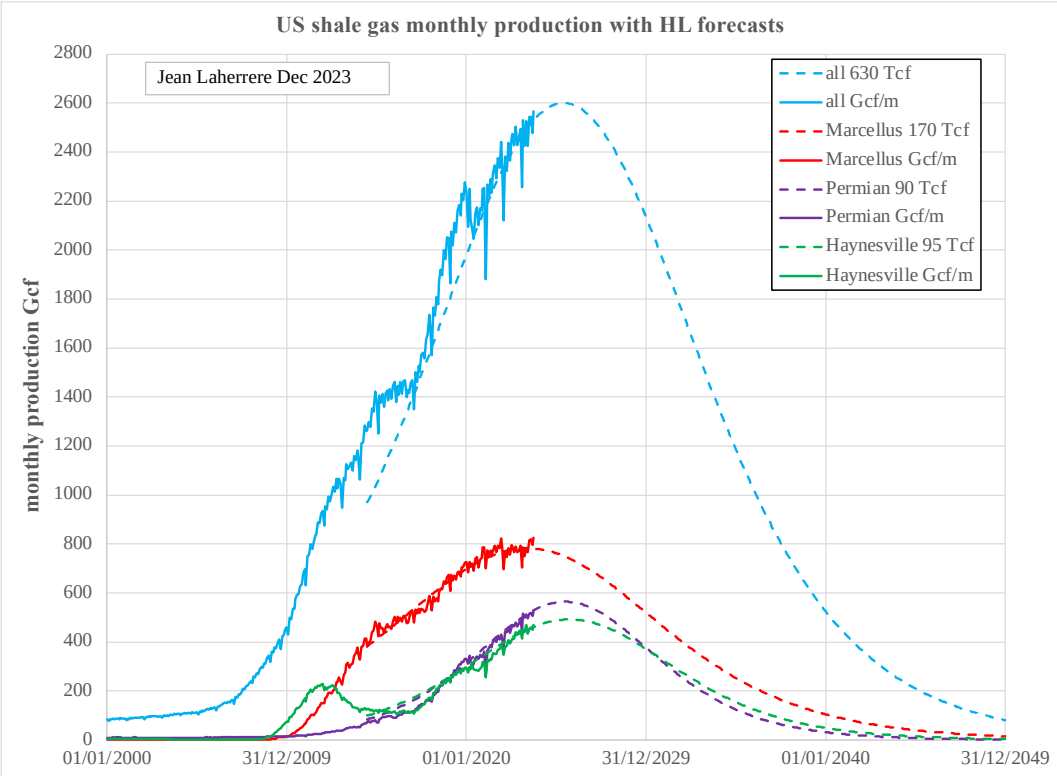


HL of Haynesville trends towards 95 Tcf when LL towards 200 Tcf

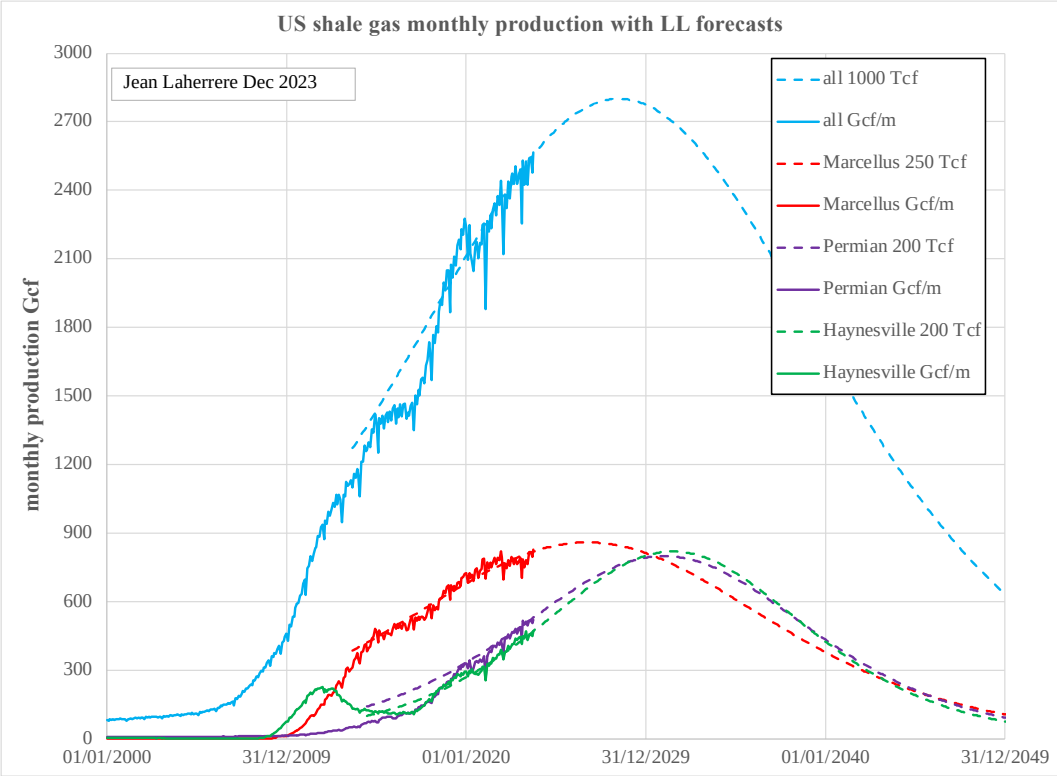




Each HL and LL ultimates are modelled easily
HL forecasts



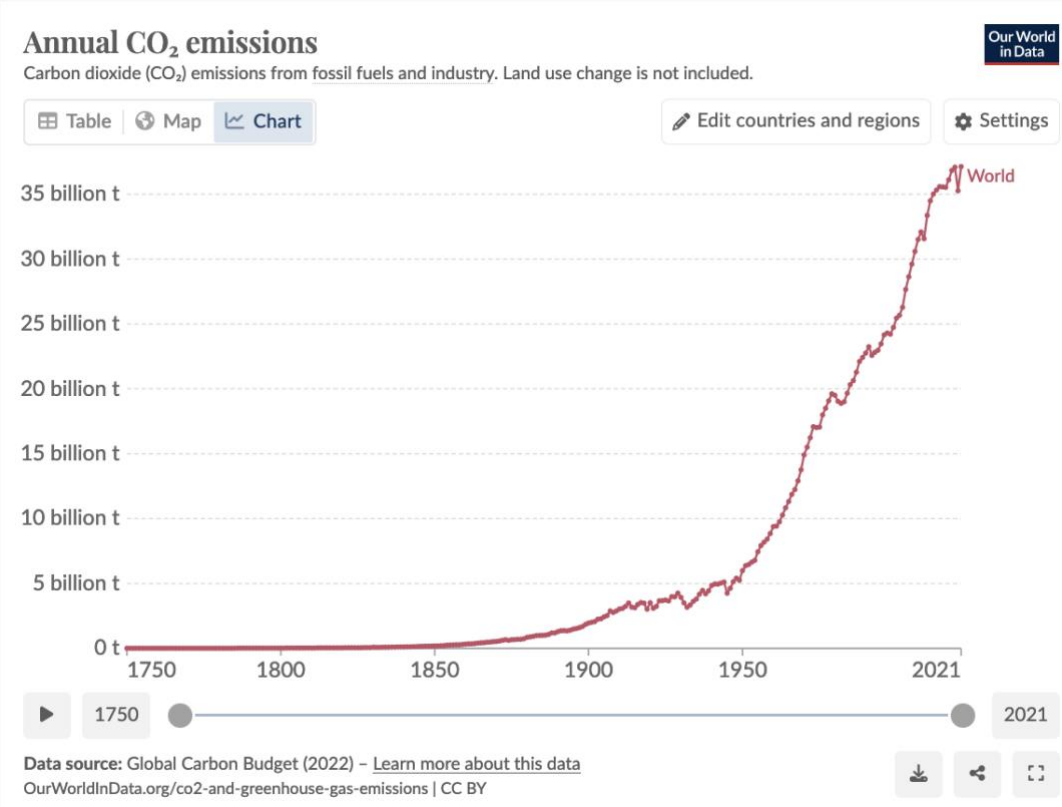
LL forecasts



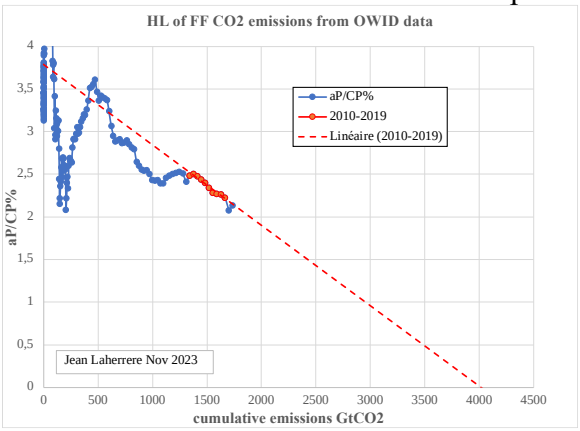
	HL U Tcf	LL U Tcf	HL peak year	HL peak Tcf/m	LL peak year	LL peak Tcf/m
US shale	630	1000	june 2025	2,6	july 2028	2,8
Marcellus	170	250	june 2023	0,8	oc 2026	0,9
Permian	90	200	july 2025	0,6	ja 2031	0,8
Haynesville	85	200	oct-25	0,5	ja 2031	0,8

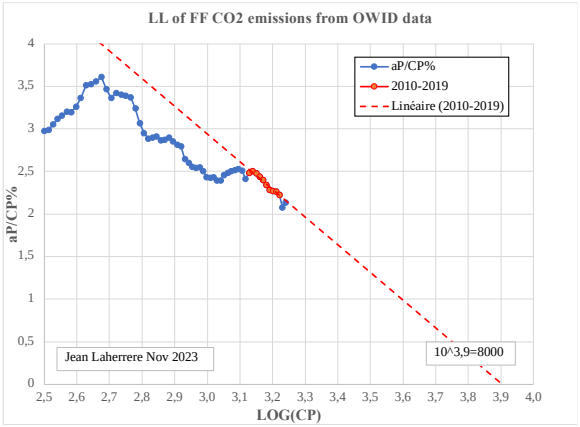
-FF CO2 world emissions

OWID reports Fossil fuels CO2 emissions since 1750



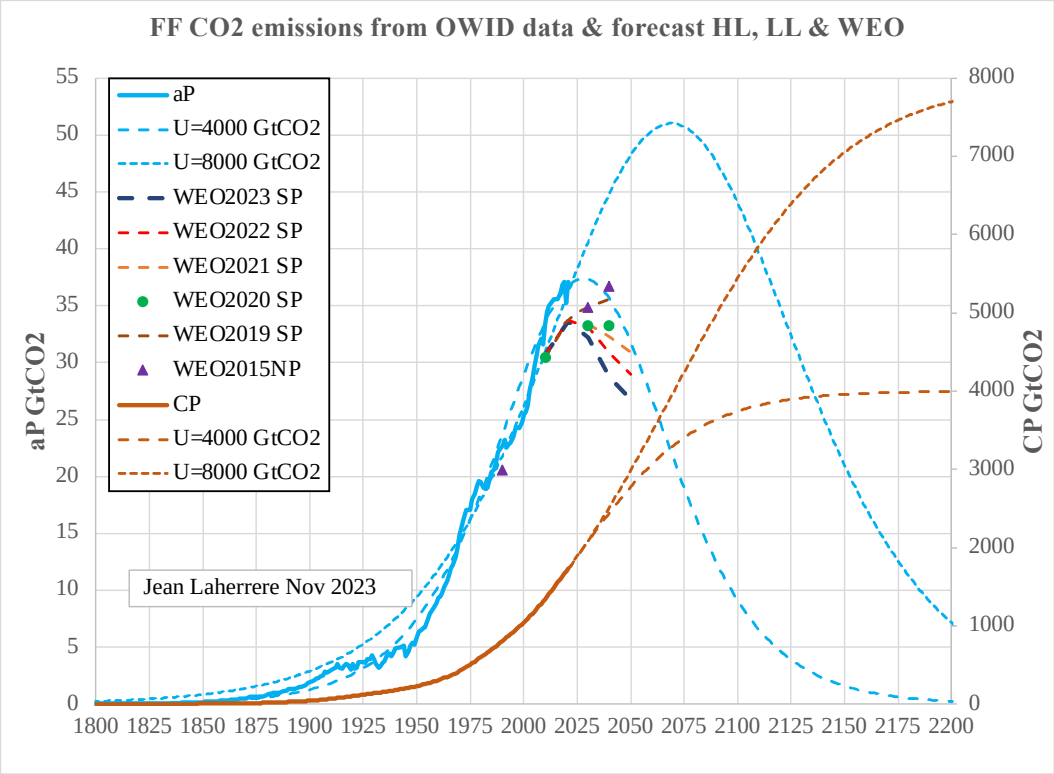
HL of FF CO2 emissions trends for the period 2010-2019 towards 4000 GtCO2





But LL trends for the same period towards 8000 GtCo2= double: it looks too high as an ultimate of 4000 GtCO2 fits well the past

Forecasts for U=4000 & 8000 GtCO2, compared with WEO 2015 to 2023



The forecast LL U=8000 GtCO2 looks too high but fits the past as HL. WEO2023 SP is lower than HL, in contrary with WEP2015 SP. IEA forgets that China CO2 emissions are planned to peak in 2030 in Paris Agreement.

-Conclusion

Forecasting future production needs to estimate the ultimate. In the past ultimate was estimated using backdated 2P reserves plus yet to find, but now 2P reserves are manipulated and it is necessary to rely on the past production data

HL technique to estimate the oil ultimate before peak is not easy to handle as the extrapolation of past data is complex, as linear data is rarely there and the range of uncertainty is wide

LL brings a new way to look at ultimate in few cases, where it opens the range of uncertainty, which is a good thing, but it appears that before peak LL ultimate could be too high, without finding why

But in cases of oil production in past peak, countries close to the end and where the uncertainty is small, LL gives in majority the same ultimate as HL.

LL should be looked at to get the high value of the range.

As most countries are past peak, extrapolation of decline should be always considered with HL and LL.