Jean Laherrere 2 November 2022

World natural gas recovery factor in 2010
& updated graphs on production, price

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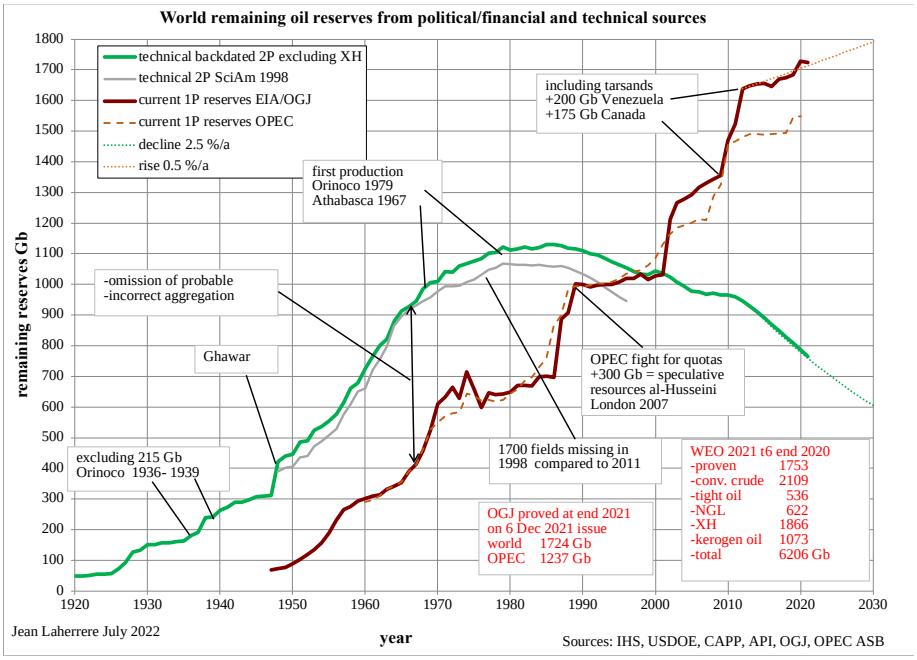
-oil recovery factor and remaining reserves

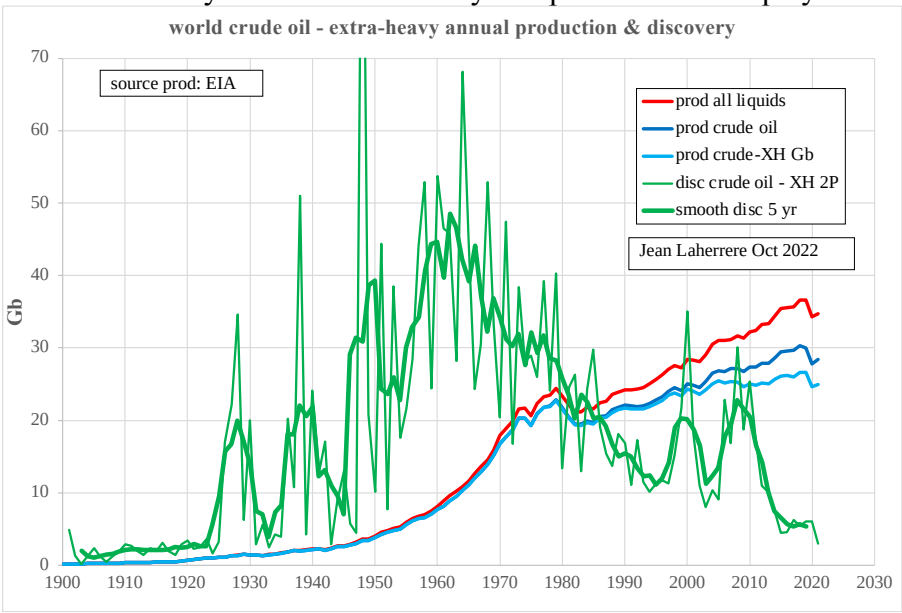
I plotted, in an old paper, the oil recovery factor (RF) using 2P reserves (EDIN 2010) for the world excluding the non-frontier (too many fields) of US = USL48 onshore and of Canada = West Canadian Sedimentary basin (WCSB) see pages 11 & 12.
But EDIN data was corrected to exclude Orinoco extra-heavy oil, to convert grossly exaggerated FSU ABC1 reserves = Russian classification (Khalimov 1959 & 1993) ~ 3P (using the maximum theoretical recovery) into 2P and to reduce overestimated OPEC reserves by 300 Gb (fight 1985-1989 between OPEC members on quotas based on oil reserves).

World remaining crude oil reserves backdated 2P (technical data) and current 1P (political OPEC & financial SEC) reserves behave quite differently



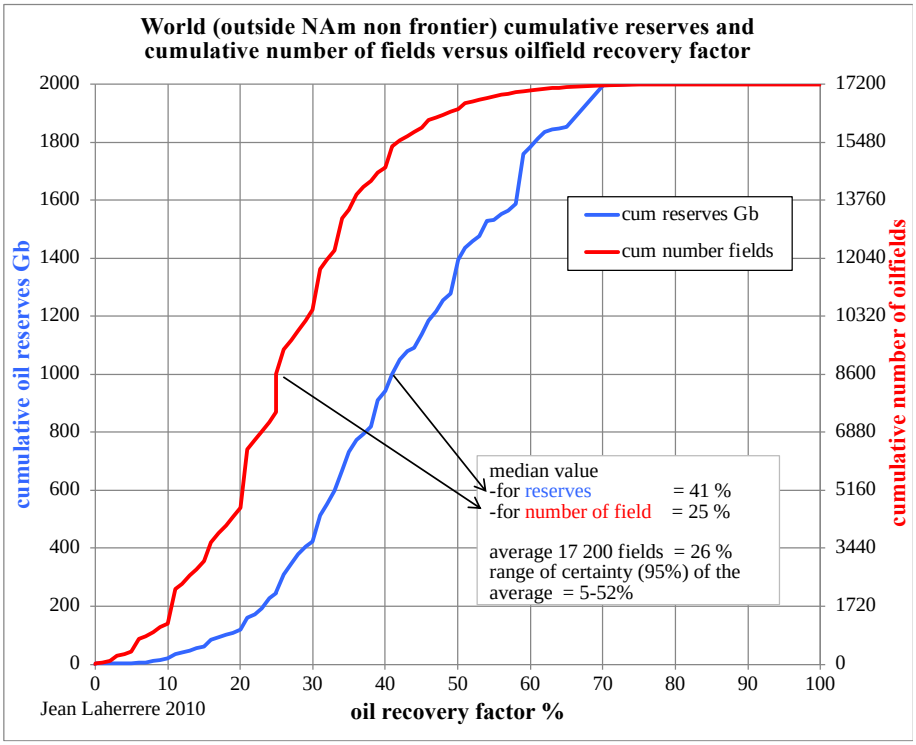
Technical 2P reserves peaked in the 1980s, when political-financial 1P reserves are still rising.

World crude less extra heavy oil annual discovery and production is displayed

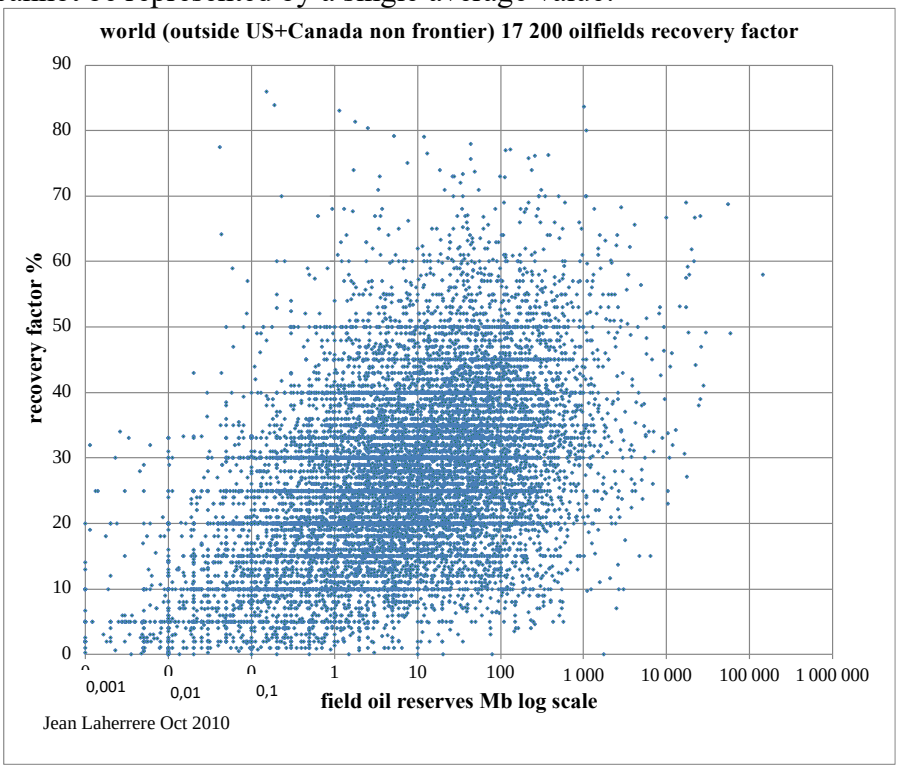


The median oil recovery factor is 25 % when using the number of fields, but 41 % when using the 2P reserves, meaning that speaking about a world RF average is unrealistic! An average is a single value that summarizes the general significance of a set of unequal values.

RF can be anything between 25 and 41 % or even beyond!



But the range of oil recovery factor and the plot of the 17200 oilfields displays a wild cloud, from 0% to 85 %, with the highest concentration about 10 Mb and 30 %
This cloud cannot be represented by a single average value!



Reporting an average within this huge cloud appears to be unrealistic

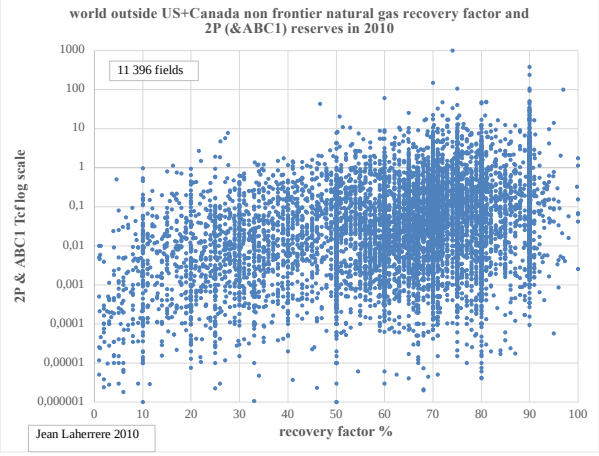
-natural gas data

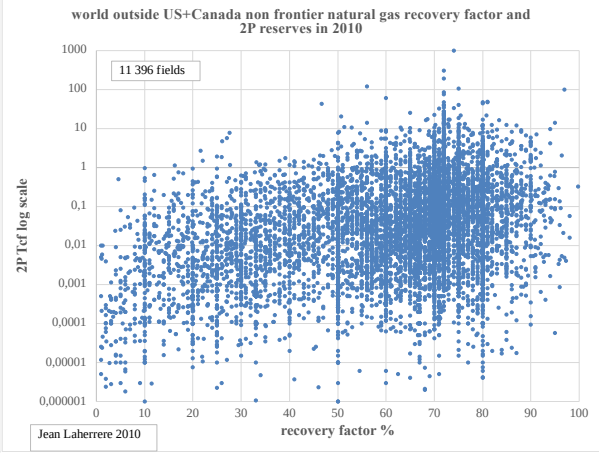
Today I do the same for natural gas from the same data and the EDIN data must be corrected as the CIS (Commonwealth of Independent States = 11 countries of former USSR) reports ABC1 reserves and not 2P. But there is no need to correct OPEC data because there is no

quota for NG OPEC production. The original data with ABC1 and the corrected data are shown.

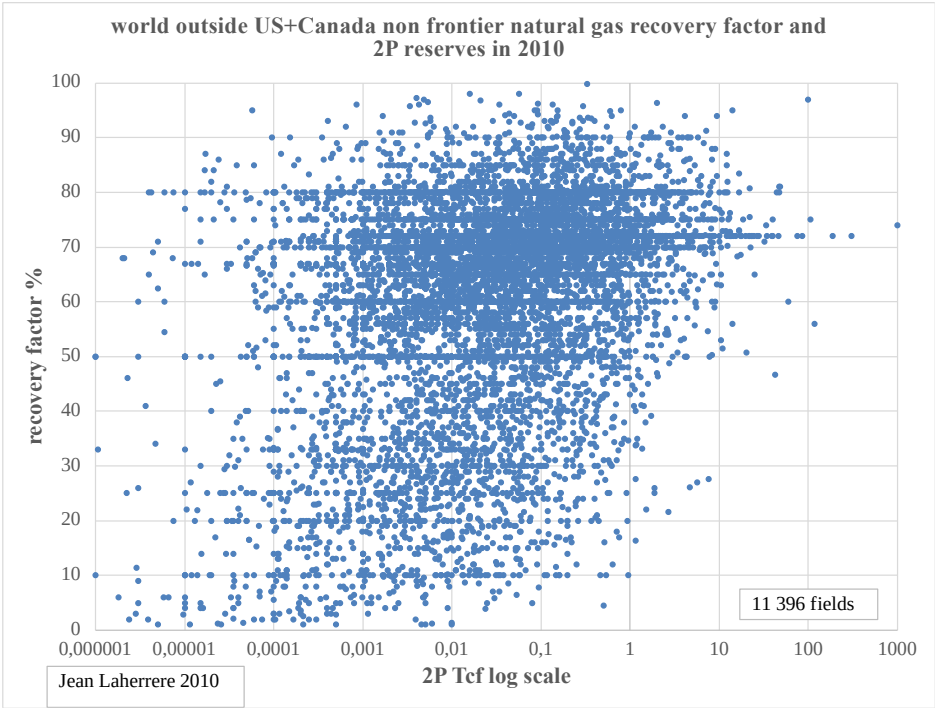
The median NG recovery factor is 68 % when using the number of fields but 72 % when using the reserves

The plot of the 11 396 fields for 2P & ABC1 displays a huge cloud from 1% to 100 %, with the highest concentration is about 0,1 Tcf 2P reserves and 70 %
The plot with ABC1 corrected into 2P being multiplied by 0.7 is slightly more concentrated (less 90%)? The cumulative 2P is 6200 Tcf.



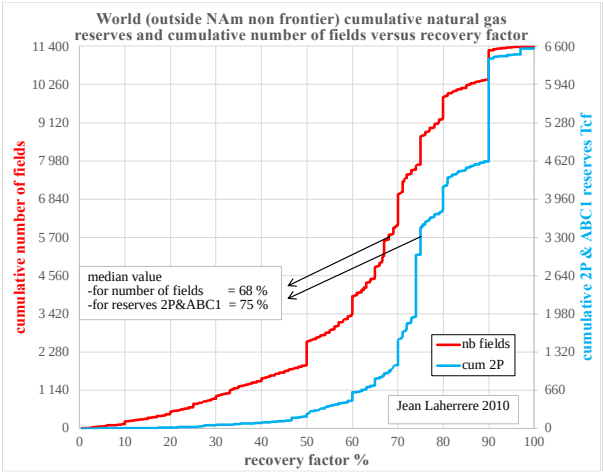


It is obvious that round recovery in tens are often used
The display with recovery factor in Y axis (to compare with oil RF graph) is different with a the highest concentration around 2P = 0.1 Tcf and 70%

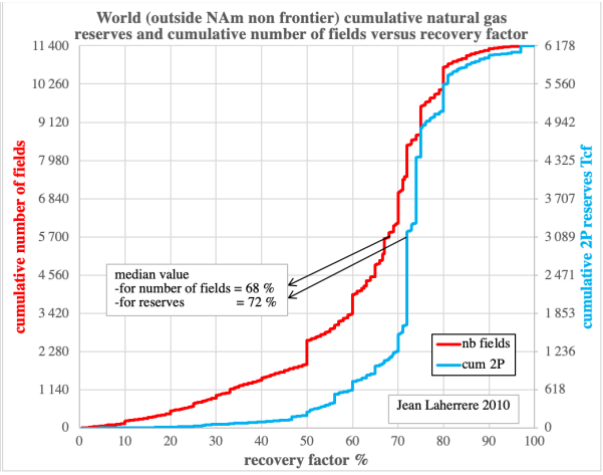


The plot of cumulative NG reserves and cumulative number of fields versus recovery factor reports that the median RF is 68 % for number of fields and 75% for reserves, when using EDIN values. But it is obvious that the 90% recovery is often used (by CIS). But with ABC1 corrected into 2P (x0.8) the median RF is 68 % for fields and 72 % for reserves

2P & ABC1 reserves



2P reserves

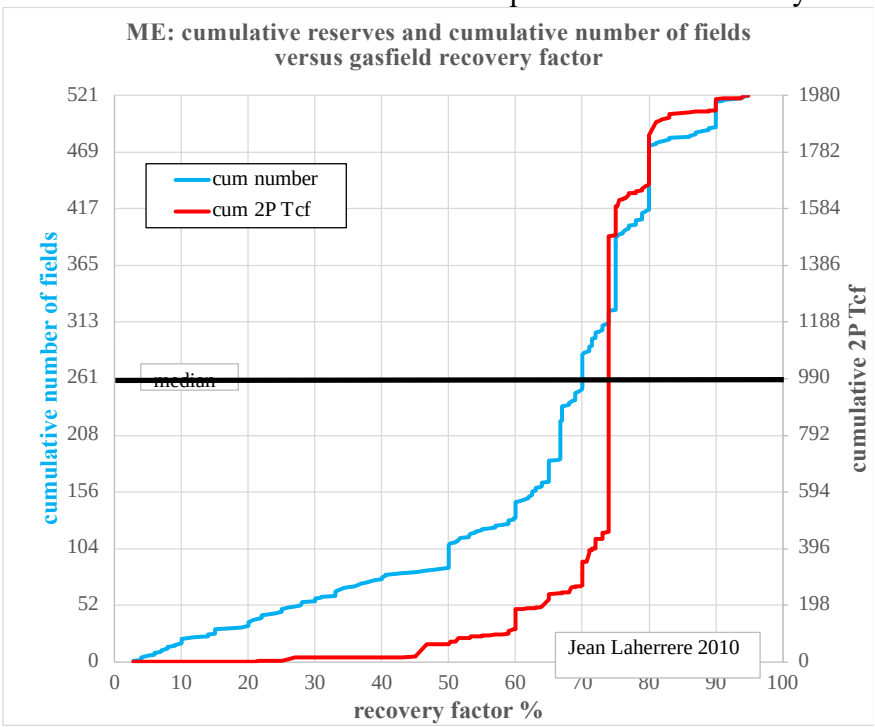


The breakdown by regions gives the cumulative value in 2010 of number of fields and 2P reserves with the median RF for number of fields and for 2P reserves

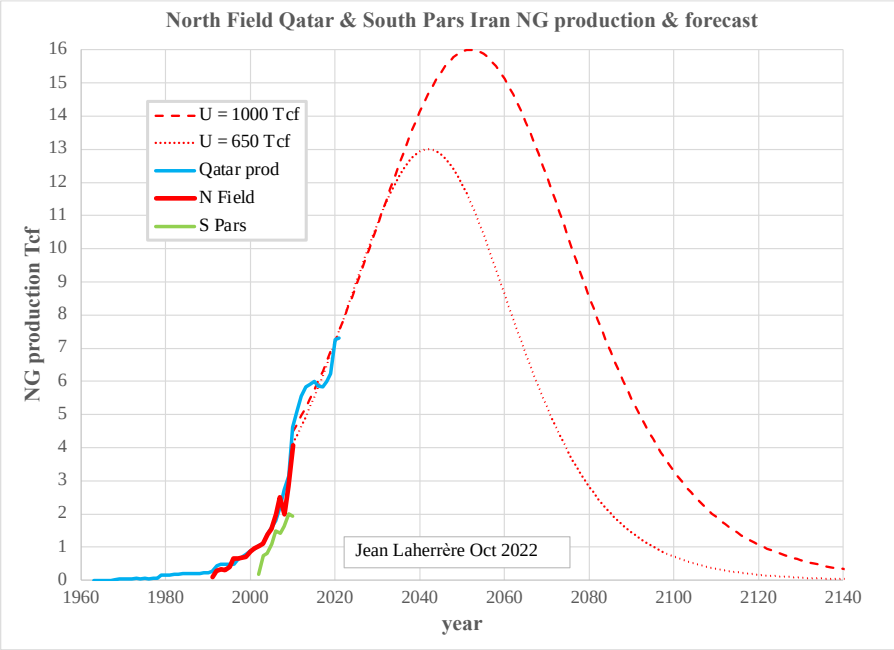
regions	number fields	2P Tcf	median fields	median res
Middle East	521	1980	70	74
CIS 2P = 0.8 ABC1	950	1555	72	72
Far East	2689	802	66	72
Europe	3125	593	68	80
Africa	1035	451	70	75
Latin America	1876	440	65	70
Australasia	902	244	60	70
North America frontier	298	68	60	65
total	11396	6133	68	72
CIS ABC1	950	1944	90	90

-Middle East

The cumulative number of fields & 2P reserves are plotted versus recovery factor:



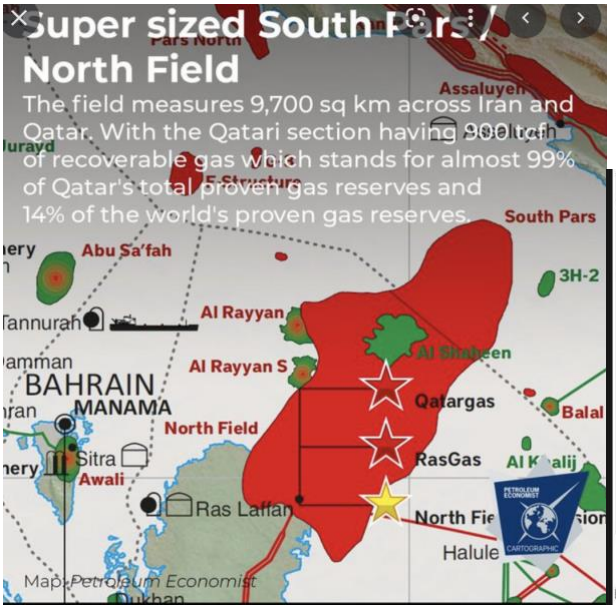
The world largest gas field is North Dome, being mainly in Qatar as North Field (discovered in 1971 but also in Iran as South Pars (reported discovered in 1991, but it should be in 1971)
The NG recovery factor of North Dome is 72 %, which is the world median value for reserves.

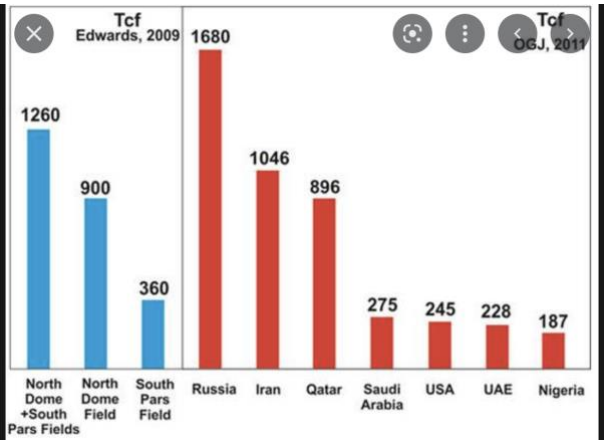


North Field NG production peak could occur around 2050.

North Dome 2P reserves are about 300 Gboe against 170 Gboe for Ghawar

2P	North Field	South Pars	North Dome	Ghawar
oil Gb	0	22,2	22,2	145
condensate Gb	26	18	44	5,7
gas Tcf = Gb/6	1000	500	1500	154
Gboe	193	124	316	176

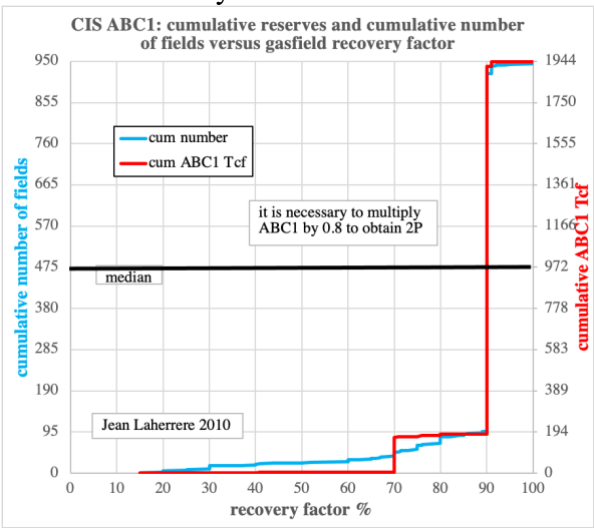




North Dome is by far the largest oil and gas accumulation
North Field alone is larger than Ghawar!

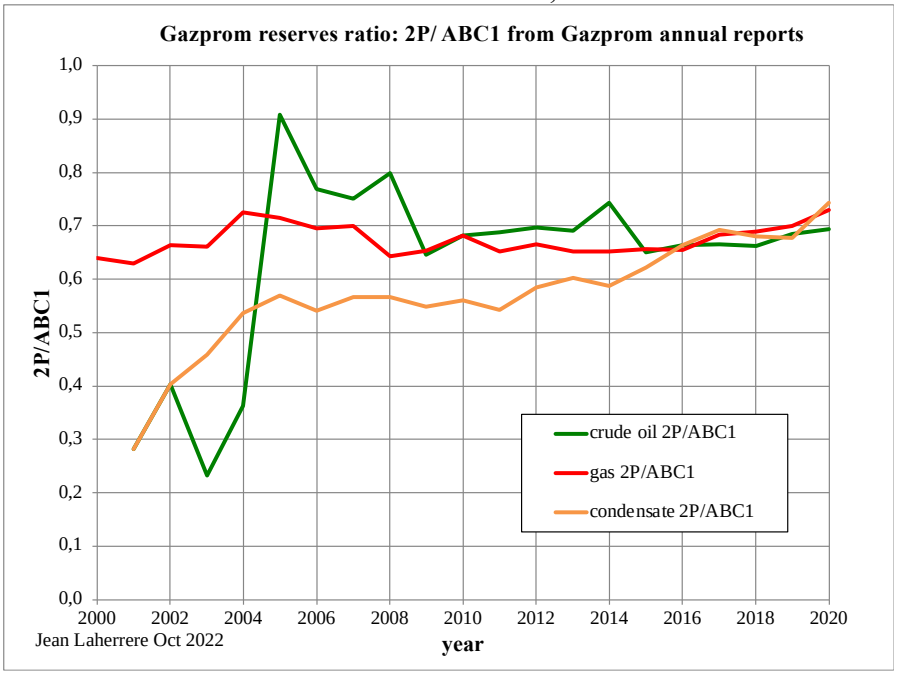
-CIS = Commonwealth of Independent States

CIS was created in 1991 including 11 countries: Armenia, Azerbaijan, Belarus, Kazakhstan, Kirghizstan, Moldavia, Uzbekistan, Russia, Tajikistan, Turkmenistan, Ukraine, following the dissolution of the Soviet Union. Formally Ukraine withdrew from CIS in 2018

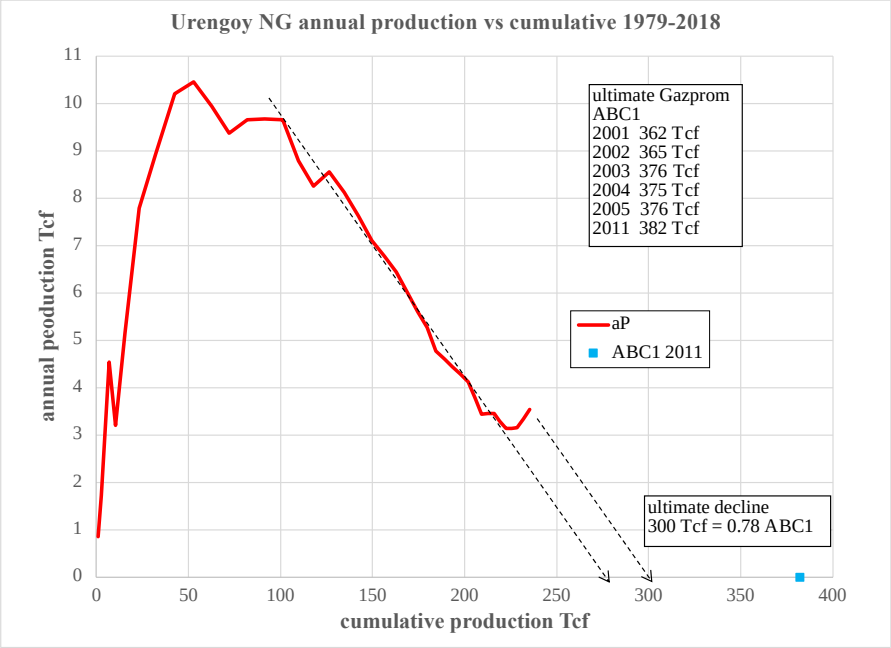


The CIS ABC1 recovery factor is reported as 90% for about 90% of the fields: it is unreal. CIS has a different method of classification where reserves estimate is ABC1 and not 2P. The Russian classification by Khalimov in 1979 was claimed at the time at the best in the world, but in 1993 Khalimow said that the ABC1 is grossly exaggerated as the recovery is taken at the maximum, meaning 3P.

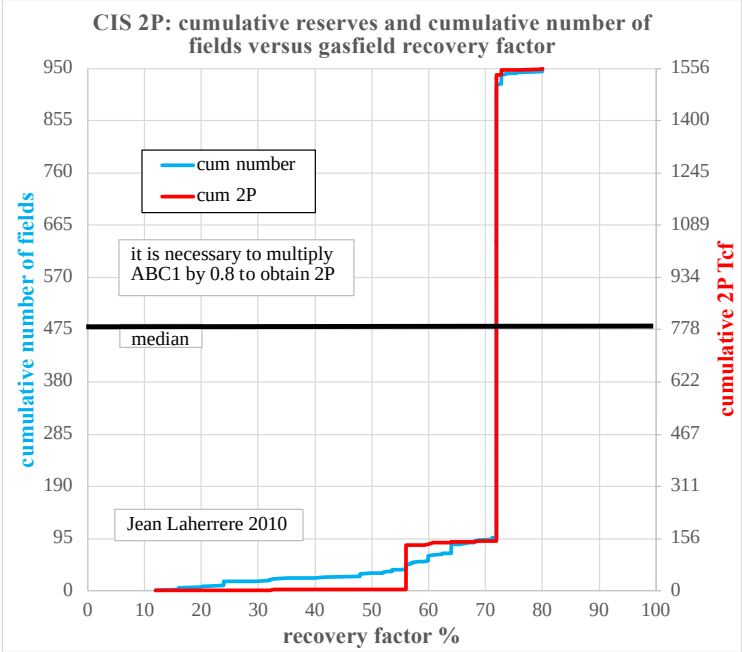
IHS and Rystad reports CIS scouted reserves data as 2P when in fact they are ABC1 and should be reduced to 30 % to represent 29 as it is reported by Gazprom in their annual reports 2000-2020 where in 2020 2P = 0.7 ABC1 for crude oil, condensate and NG



The giant gas field Urengoy annual NG production 1979-2018 is plotted versus cumulative production: the trend up to 2010 is towards 275 Tcf, but with a new deeper extension (Achimov) of the field, the trend is assumed to be now towards 300 Tcf, being about 0.8 ABC1 2011

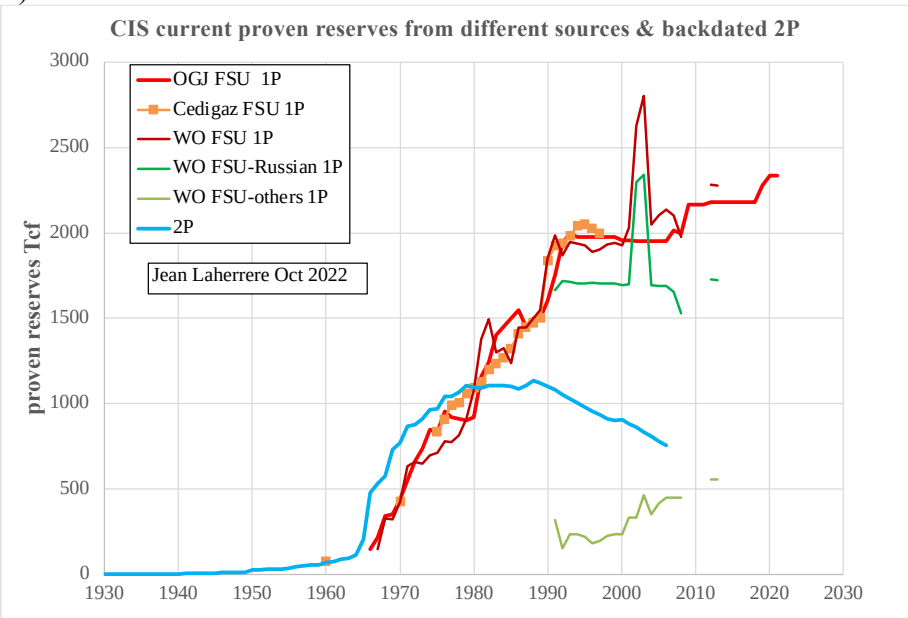


A correction by 2P = 0.8 ABC1 was applied (and not 0.7 as reported by Gazprom) giving a better fit of RF compared with other regions. But it is obvious that Russian use the same RF ABC1 value of 90 % for 90% of the gas fields, meaning poor practice, leading to 3P!

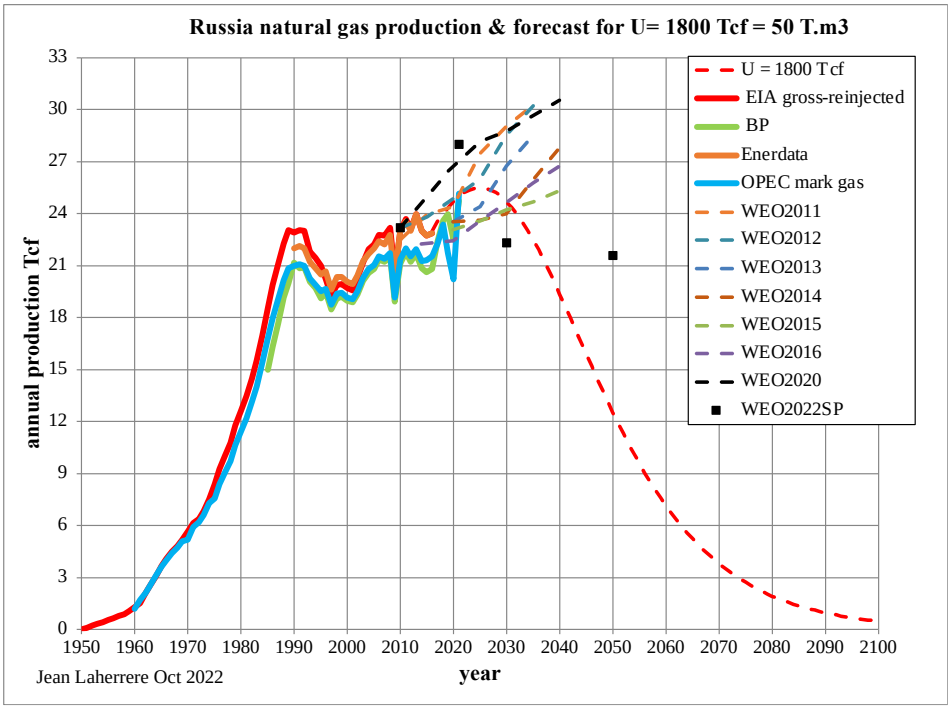


A new Russian classification was introduced in 2016: The New Classification of Reserves and Resources of Oil and Combustible Gas – Movement Onward or Backward? https://geors.ru/media/pdf/01_Muslimov_en.pdf, but Khalimov E.M. 1993, "Classification of oil reserves and resources in the Former Soviet Union" AAPG 77/9 Sept p.1636 and Khalimov E.M., M.V.Feign 1979 "The principles of classification and oil resources estimation" WPC Bucharest, Heyden London 1980 p263-268) are not quoted
This new classification RF2013 is compared with UNFC 2009 classification which is too complex and never used by oil producers. It is pure intellectual thinking with no connection to oil practice
https://unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC.RF.BD/UNFC_RF.BD_e

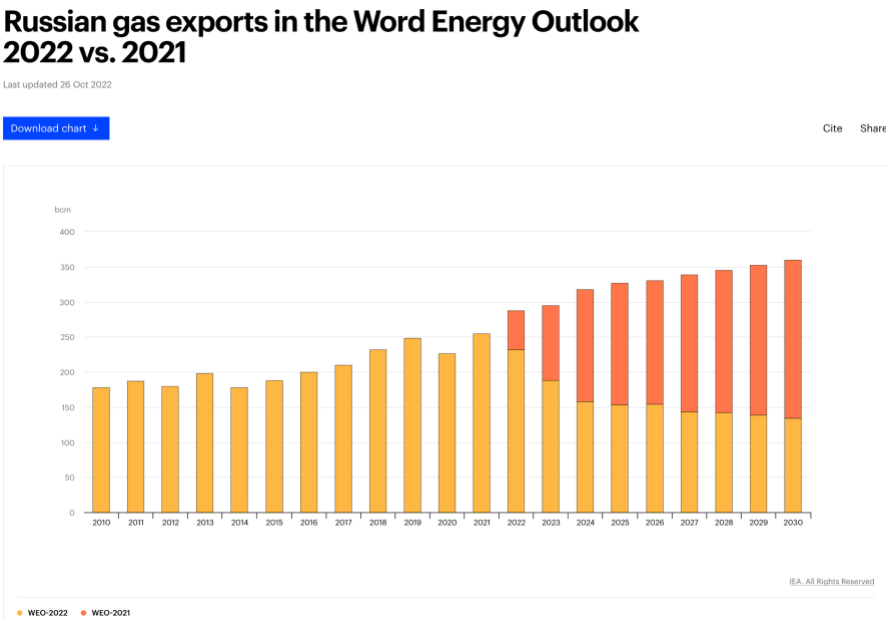
CIS NG are current proven reserves are compared with the backdated 2P reserves (my data stops in 2007)



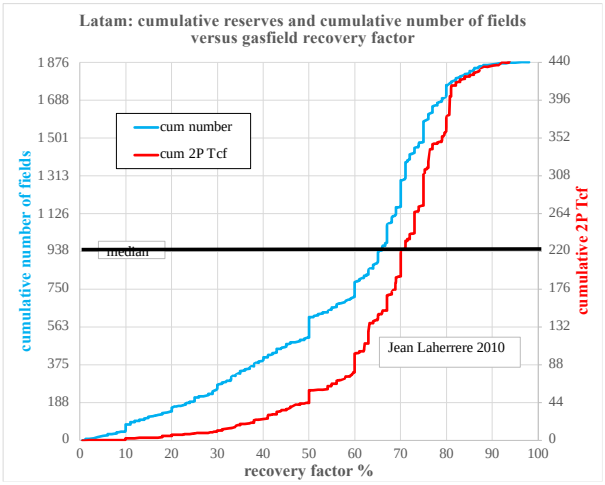
In 2019, Russia has discovered giant gas fields in the Kara Sea, as Dinkoff 13.7 Tcf
Russia has still undeveloped giant gas fields as Shtokman 130 Tcf discovered in 1988 because too far (600 km needing better helicopter) from coast in the Barents sea (project closed in 2019)
Russia NG peak will be around 2025, but over 2040 for IEA/WEO2020
WEO2022SP is much lower in 2030 and 2040 than WEO2020SP



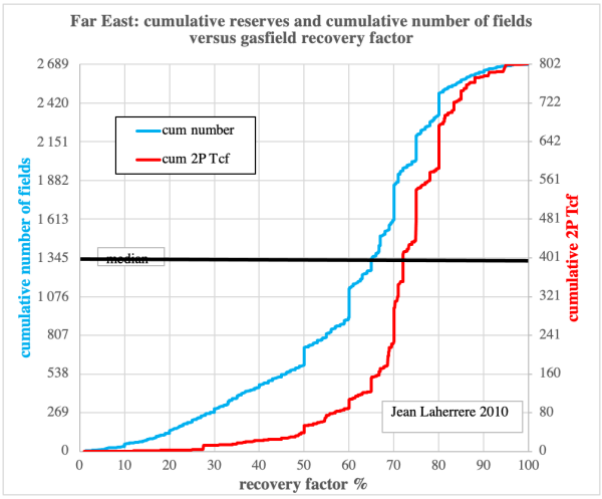
WEO22 forecasts Russian NG exports much lower than WEO2021



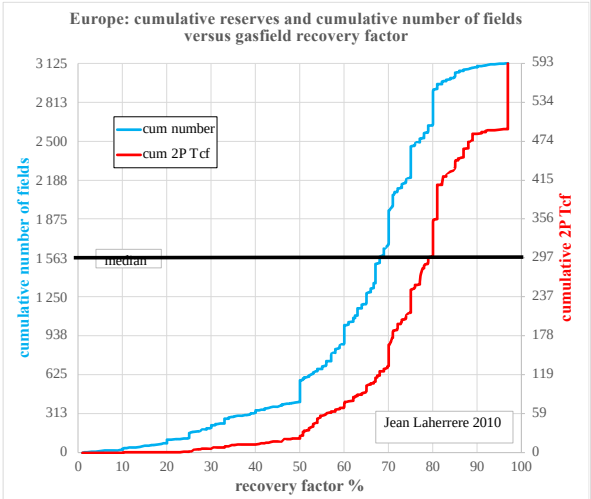
-Latam = Latin America



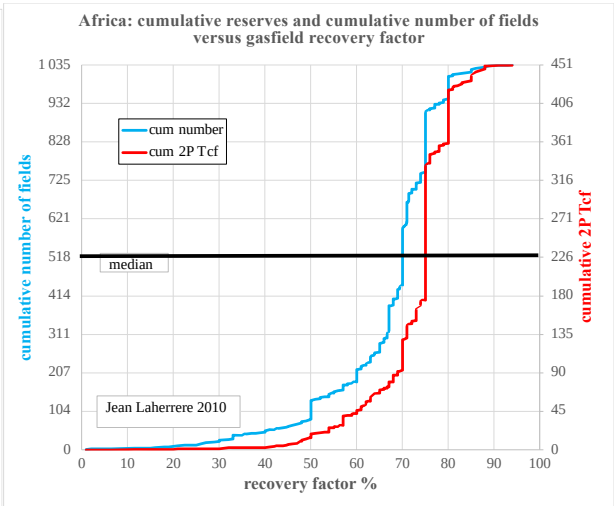
-Far East



-Europe

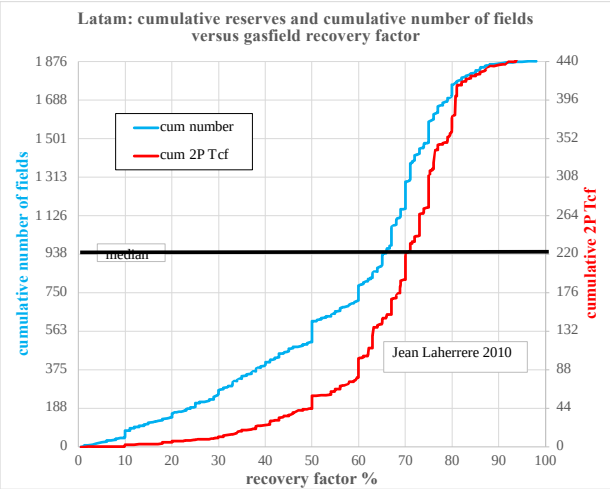


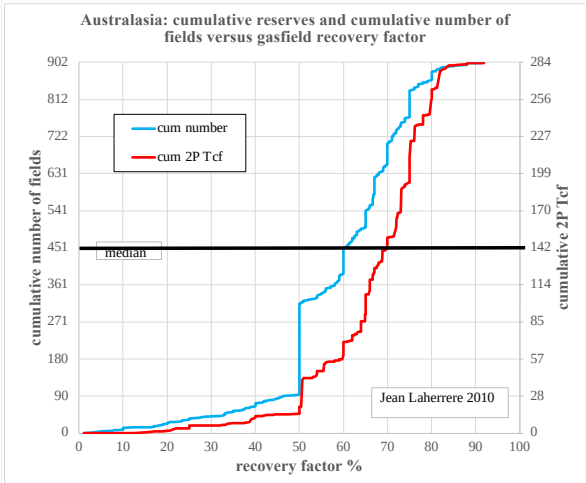
-Africa



-Latin America

-Australasia

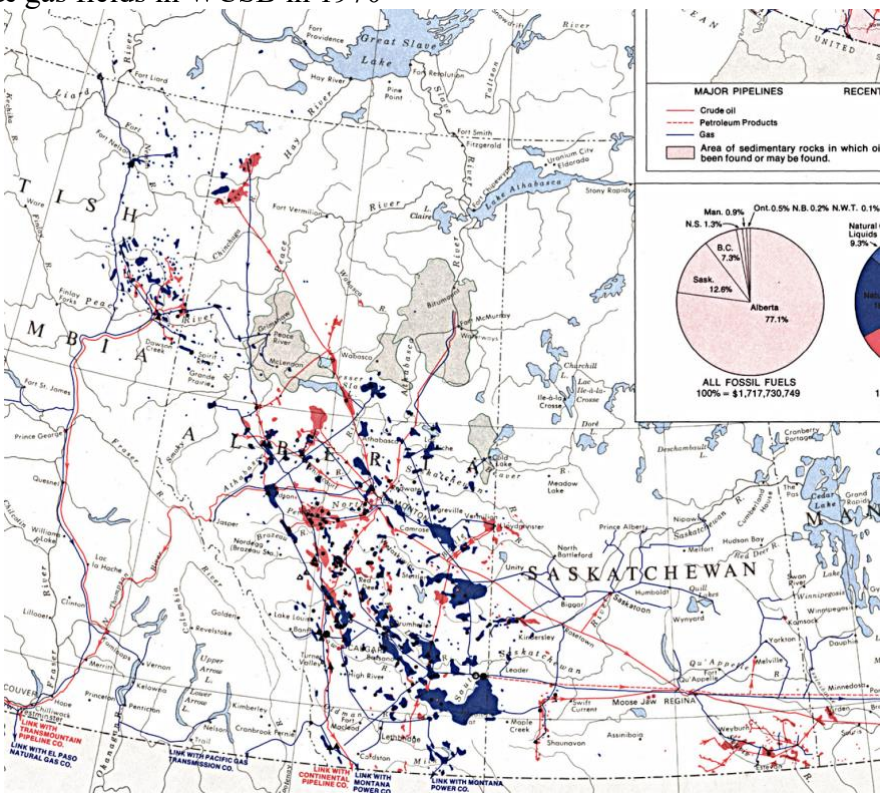




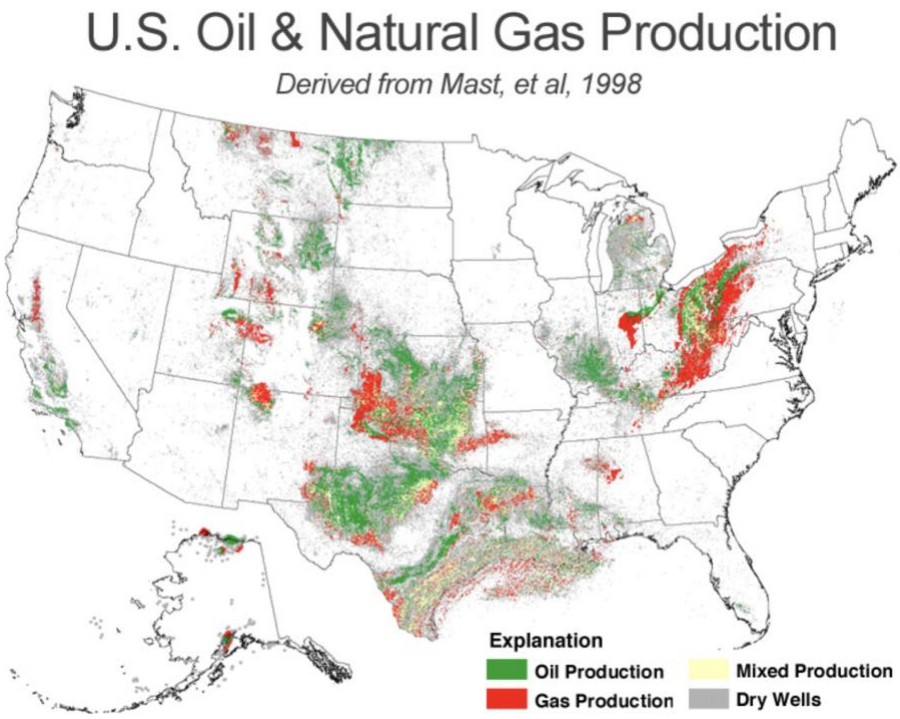
-North America frontier

EDIN reports only the US and Canada frontier, excluding because too many fields the US L48 onshore and the WCSB = Western Canada Sedimentary Basin (1.4 million km2, up to 7 km thick).

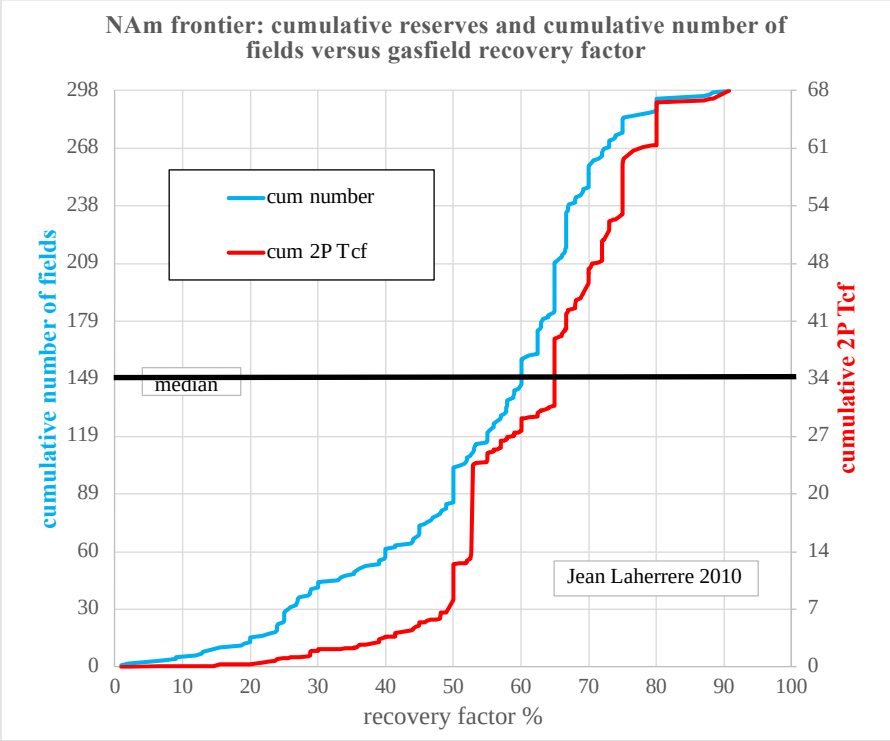
map of oil & gas fields in WCSB in 1970



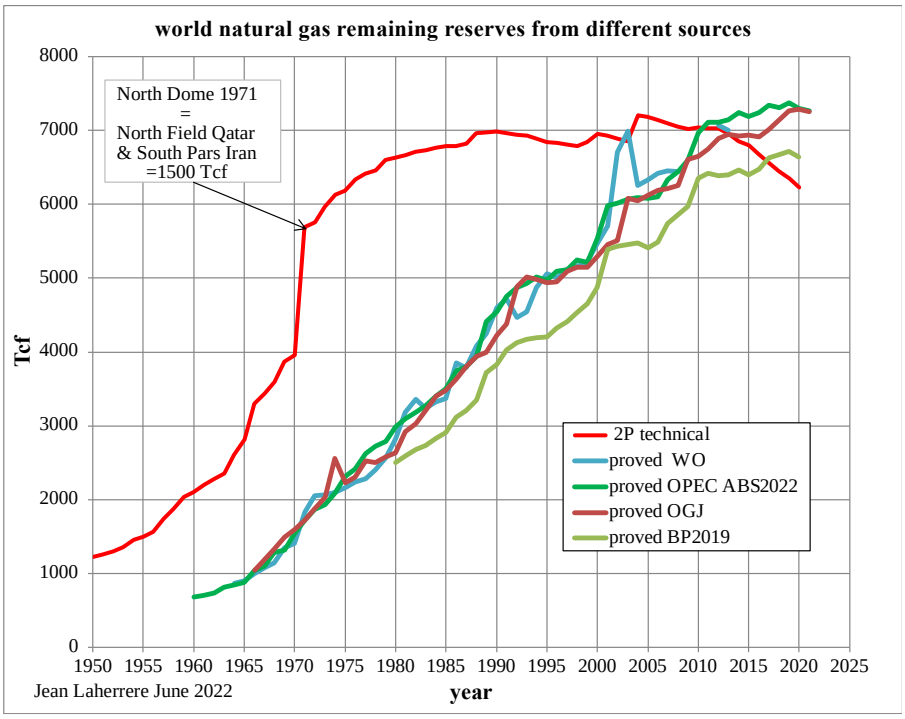
map of oil and gas fields in the US in 1998



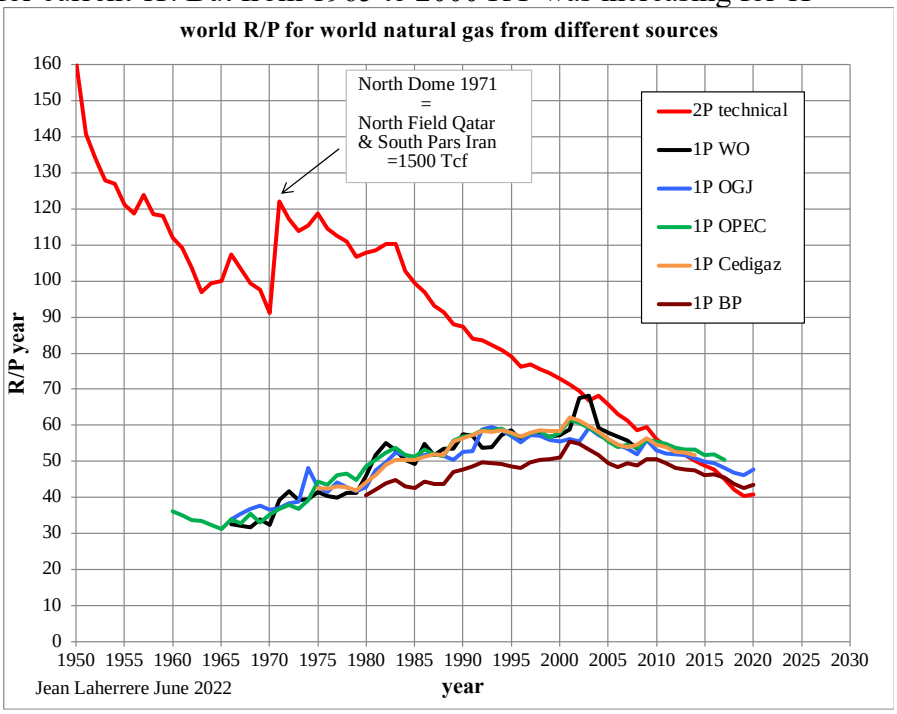
In 1993 (OGJ) Ivanhoe & Leckie reported 31 370 oil fields and 15 879 gas fields (and about 6 000 oil fields unlisted)
The NAm frontier median RF is 60 % for number of fields and 65 % for reserves, but for only 300 fields (68 Tcf) in frontier areas when about 50 000 fields in non-frontier!



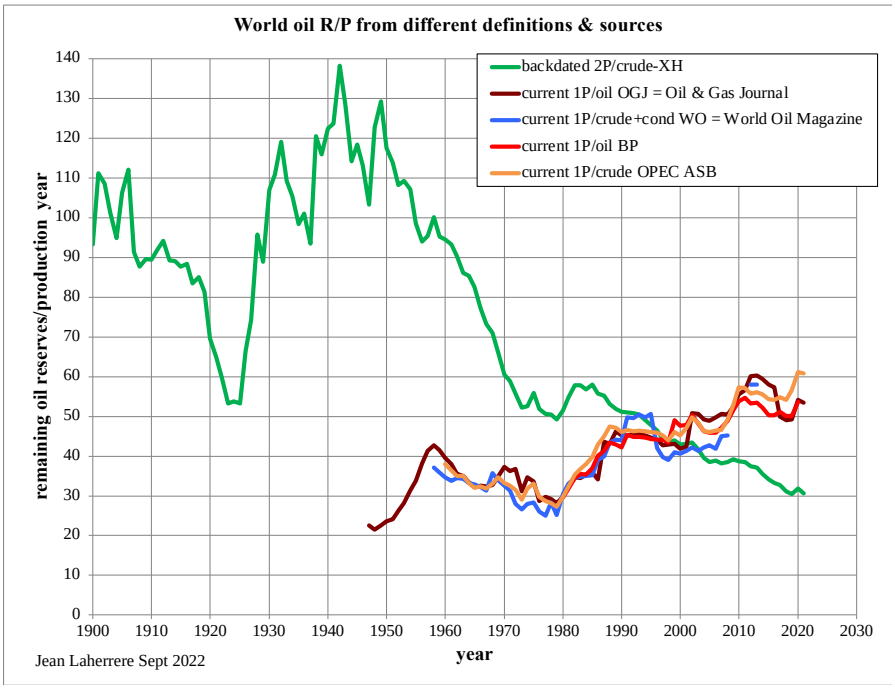
-comparison world current 1P and backdated 2P NG reserves
As for oil, world NG proven reserves are increasing since 1960 when the backdated 2P remaining reserves were flat from 1988 to 2012, but decreasing since



The world NG R/P is decreasing since 1971 (North Dome discovery) for backdated 2P and since 2002 for current 1P. But from 1965 to 2000 R/P was increasing for 1P

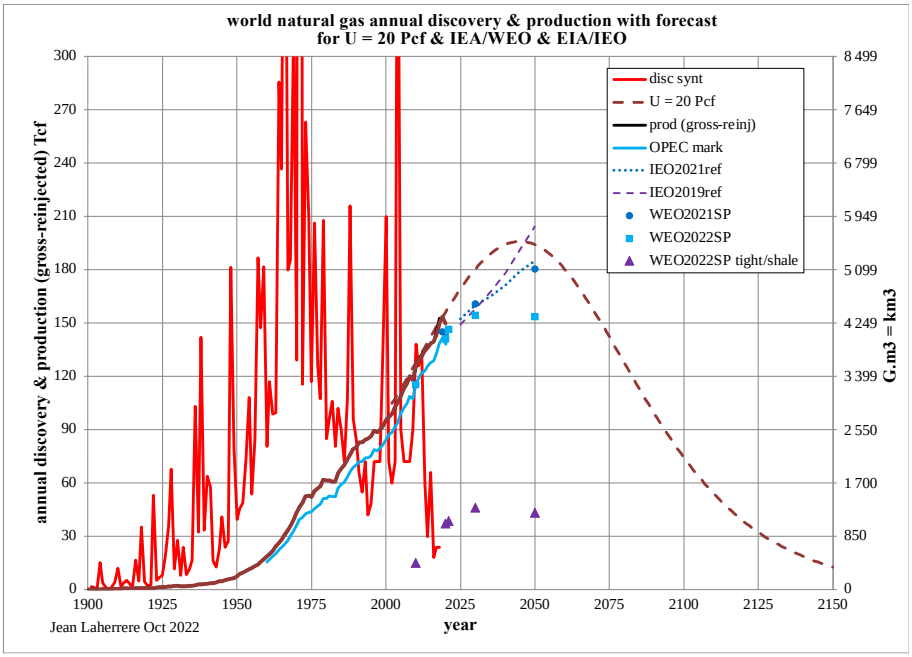


Presently NG R/P is about 40 years for 2P and 1P, both in decline
In contrary crude oil R/P is about 30 years for 2P and 60 years for 1P OPEC ASB, in increase since 1980 (mainly because the fight 1985-1989 between OPEC members for quotas based on oil reserves)



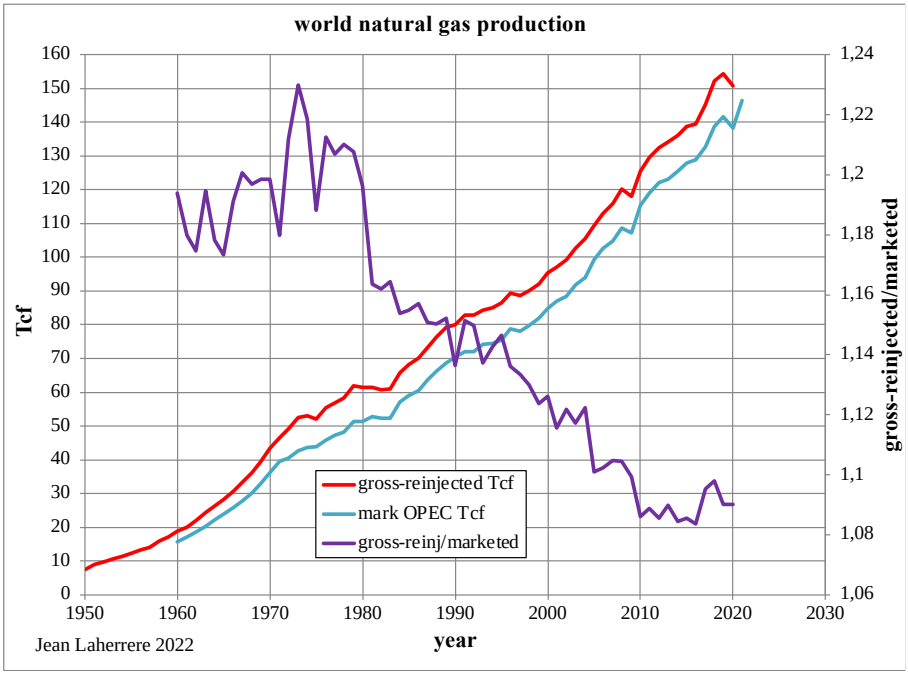
My forecast for world NG production is a peak before 2050 at 195 Tcf against 180 Tcf for WEO2021SP and 150 Tcf for WEO2022SP, but my production is gross less reinjected when IEA production is marketed, which is about 10 % lower because the removal of NGL and flaring

WEO2022SP forecasts for 2050 tight/shale gas production (purple) higher than in 2021; I doubt it!

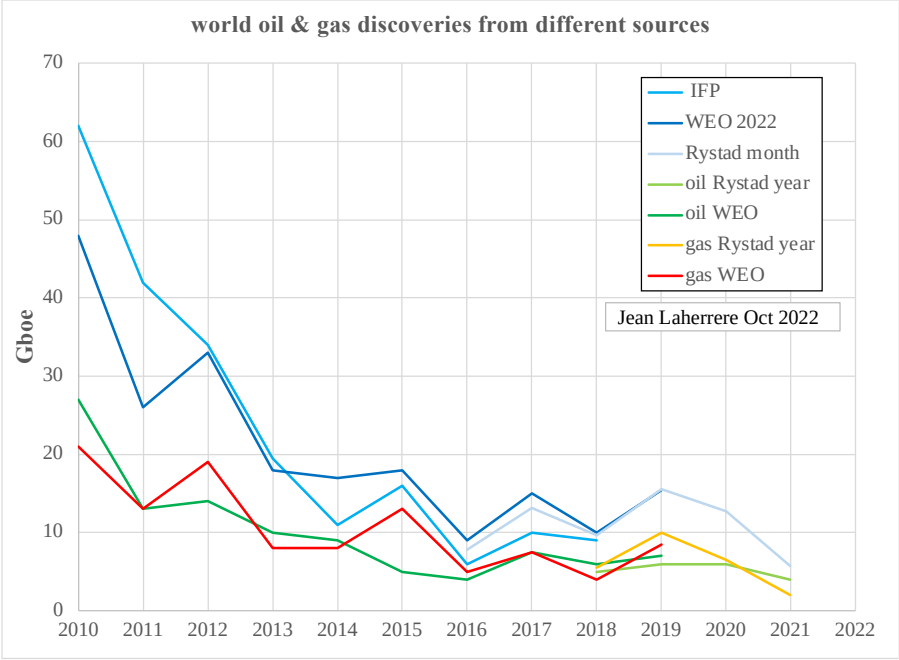


The peak of discoveries occurred around 1965 and the peak of production will occur around 2045, 80 years later

OPEC ASB and IEA reports NG production as marketed when it is necessary to plot gross less reinjected to compare with NG reserves



World oil and gas discoveries since 2010 from different sources display a sharp decline, being divided by more than 5



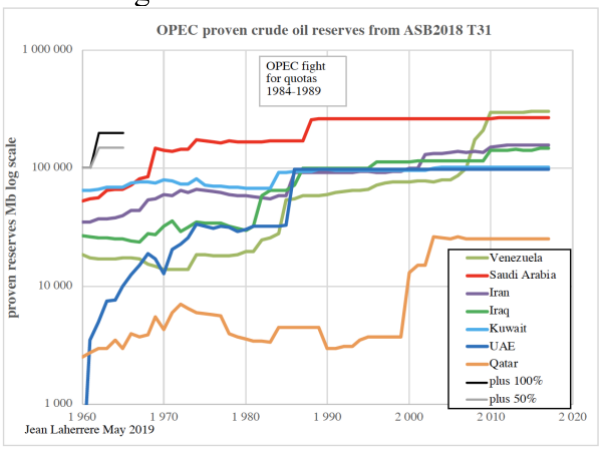
-NGL = natural gas liquids

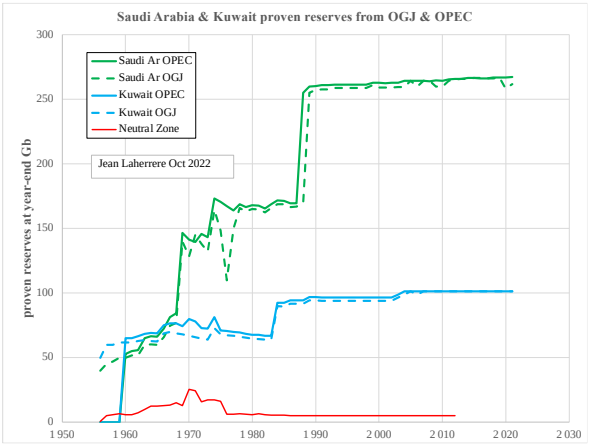
NGL production data are very unreliable, for several reasons:

-1-historically US oil and condensate productions were stored together by small producers at the well site and measured together: EIA reports oil and condensate together and separately the liquids from NG produced in processing plant (=NGPL). In its international browser EIA reports crude oil (including lease and plant condensates) and NGPL

-2-politically OPEC members have quotas for oil production but not for condensate, during 1985-1989 OPEC members fought for reserves (to increase their OPEC quotas) by increasing their reserves by 50 % without making any significant discovery: Kuwait started the fight, which was finished by Saudi Arabia, but it is funny to see that the Neutral (Divided) Zone

offshore owned 50/50 Kuwait & Saudi did not increase their reserves, because lack of common agreement!





It is amazing that Saudi Arabia reports their crude oil remaining reserves since 1988, for more than 30 years, about 260 Gb, meaning that every year they discover exactly what they produce: it is a joke, but coming from a State, it just politics, but sovereignty and nobody can argue! The same for Kuwait with about 100 Gb since 1985

OPEC monthly report gives for Non-OPEC liquids production + separately processing gains and for OPEC: NGL + non-conventional (at 0,1 Mb/d in oct 2022 since 2015 but it is said by Reuters to be the Orinoco tar sands) + crude oil production (with 2 sources: secondary and direct communication).

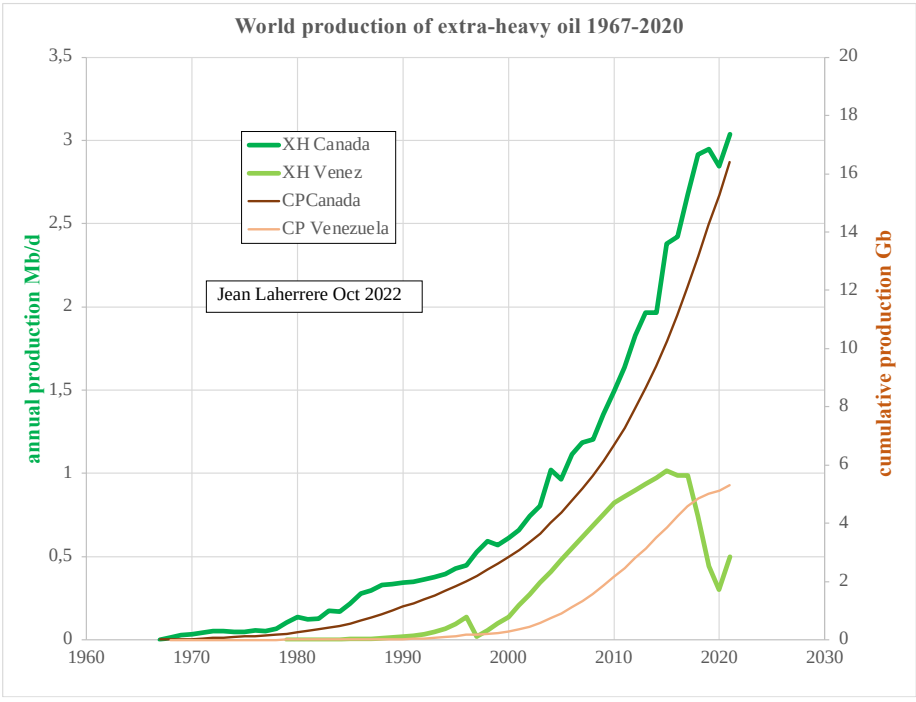
This OPEC non-conventional (Orinoco) production constant at 0.1 Mb/d since 2015 is wrong

Monthly Oil Market Report, February 2019

Table 11 - 4: Non-OPEC supply and OPEC natural gas liquids, mb/d

	2015	2016	2017	3Q18	4Q18	2018	Change 18/17	1Q19	2Q19	3Q19	4Q19	2019	Change 19/18
OPEC NGL	4,6	4,7	4,8	4,8	4,9	4,8	0,0	4,9	4,9	4,9	5,0	4,9	
OPEC Non-conventional	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,1	0,1	0,1	0,1	0,1	
OPEC (NGL+NCF)	**4,7**	**4,8**	**4,9**	**5,0**	**5,1**	**5,0**	**0,0**	**5,0**	**5,1**	**5,1**	**5,1**	**5,1**	

In 2015 Orinoco extra-heavy oil was producing 1 Mb/d, 10 times more than reported by OPEC MOMR



But OPEC general notes https://asb.opec.org/ASB_GeneralNotes.html where the definition of crude oil includes both condensate and extra-heavy oil.

Crude oil: a mixture of hydrocarbons that exists in a liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities. For statistical purposes, volumes reported as crude oil include:

The definition of non-conventional

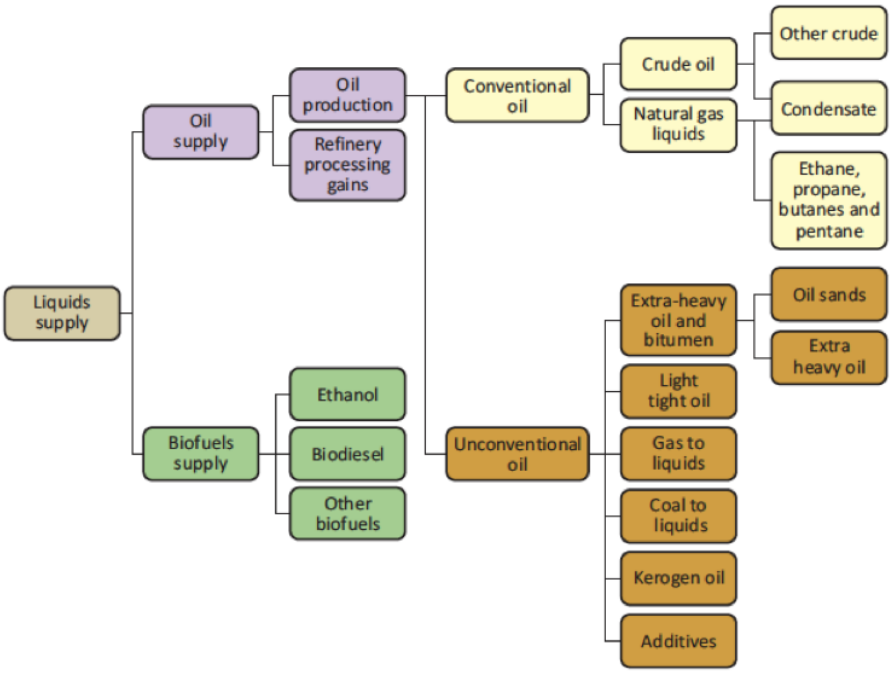
Non-conventional oil: includes synthetic crude oil from tar sands, oil shale, etc, liquids derived from coal liquefaction (CTL) and gas liquefaction (GTL), hydrogen and emulsified oils (eg Orimulsion), non-hydrocarbon compounds added to or blended with a product to modify fuel properties (octane, cetane, cold properties, etc) of substances like alcohols (methanol, ethanol), ethers (such as MTBE (methyl tertiary butyl ether), ETBE (ethyl tertiary butyl ether), TAME (tertiary amyl methyl ether) or esters (eg rapeseed or dimethylester, etc) and chemical compounds such as TML (tetramethyl lead) or TEL (tetraethyl lead) and detergents.

includes only the synthetic crude from tar sands, which is not the case of most Orinoco oil which was produced by Total without steam (cold production, less recovery) using a progressive cavity pump (1000 b/d for one horizontal well drilled in one week) https://www.researchgate.net/publication/266669426_Producing_Extra_Heavy_Oil_using_Bottom_Drive_Progressive_Cavity_Pump_from_Orinoco_Belt_Cerro_Negro_Area_Venezuela
The definition of NGLs includes condensate which is also in crude oil: it does not look clear at all!

Natural gas liquids (NGLs): those reservoir gases liquefied at the surface in lease separators, field facilities or gas processing plants. NGLs consist of field condensates and natural gas plant products such as ethane, pentane, propane, butane and natural gasoline.

OPEC ASB reports NGL only for OPEC countries, no detail for Non-OPEC.
-3-IEA (following the NDP in Norway) has a very ambiguous definition of condensate, being either crude oil if sold with crude oil or NGL if sold with NGL: it means that crude oil changes of value with a change of condensate sale! It is a wrong practice!
IEA definition on liquid fuels

Figure 13.2 ▷ Classification of liquid fuels



IEA crude oil production data is unreliable, only the crude oil +NGL
-4-IEA browser reports oil production in energy: crude oil, NGL, other primary oil displaying some strange graph as for France because of discontinuous other primary oil)
IEA Energy Statistics manual lists in primary oil products: crude oil, NGL & other hydrocarbons

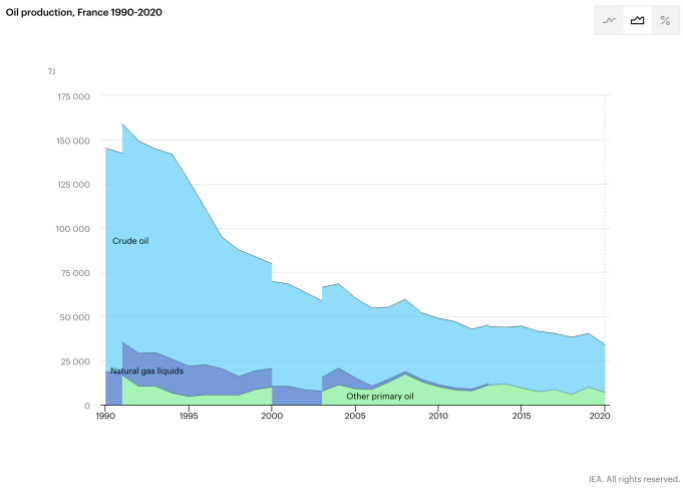
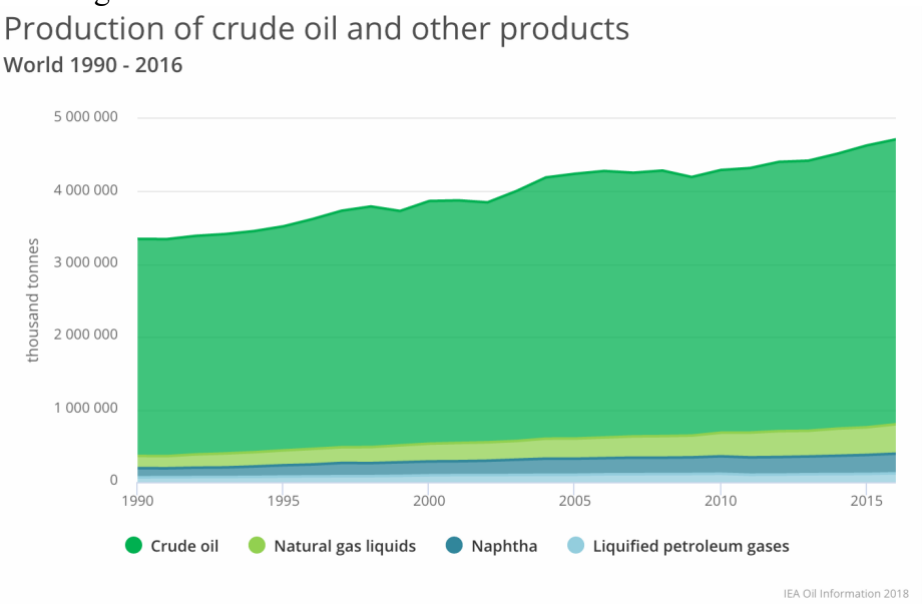


Table A2.3 • Primary and Secondary Oil Products

PRIMARY OIL PRODUCTS	Crude oil
	Natural gas liquids
	Other hydrocarbons

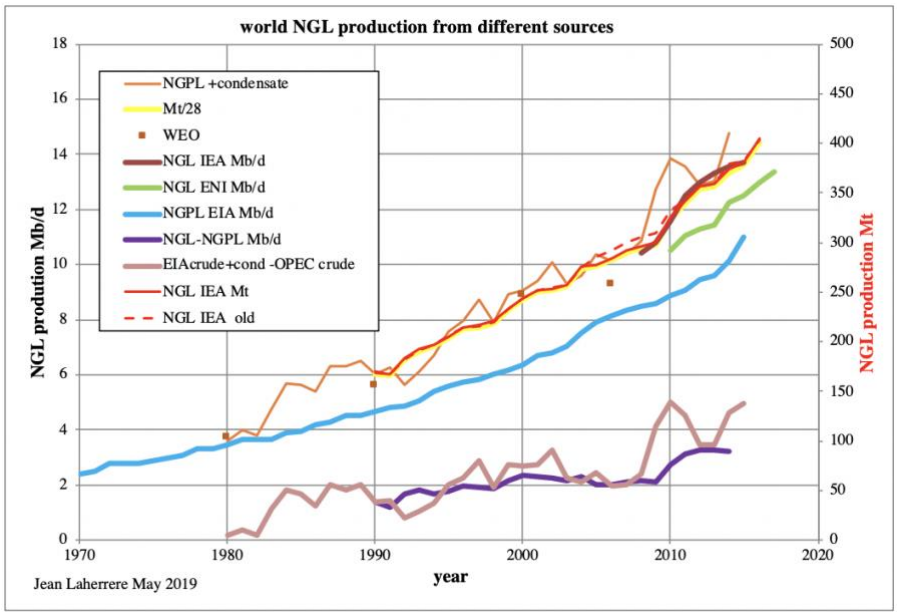
In 2016 IEA was reporting world production in weight with crude oil, NGL, naphtha & liquified petroleum gases!



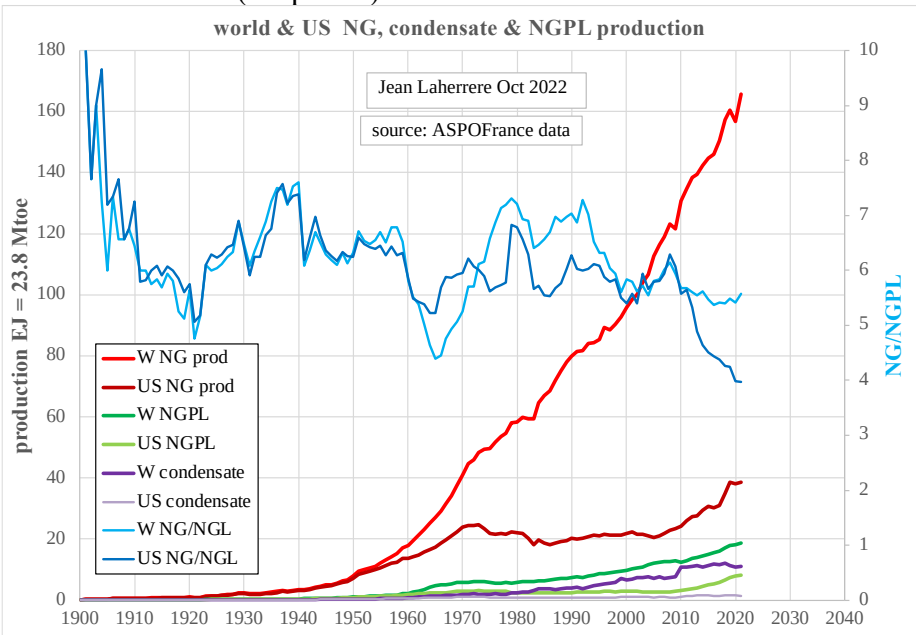
-5-IEA in its annual 2022 WEO (world energy outlook) reports for oil supply in volume

-conventional crude oil
-tight oil
-NGL
-extra-heavy oil & bitumen
-other production
-processing gains

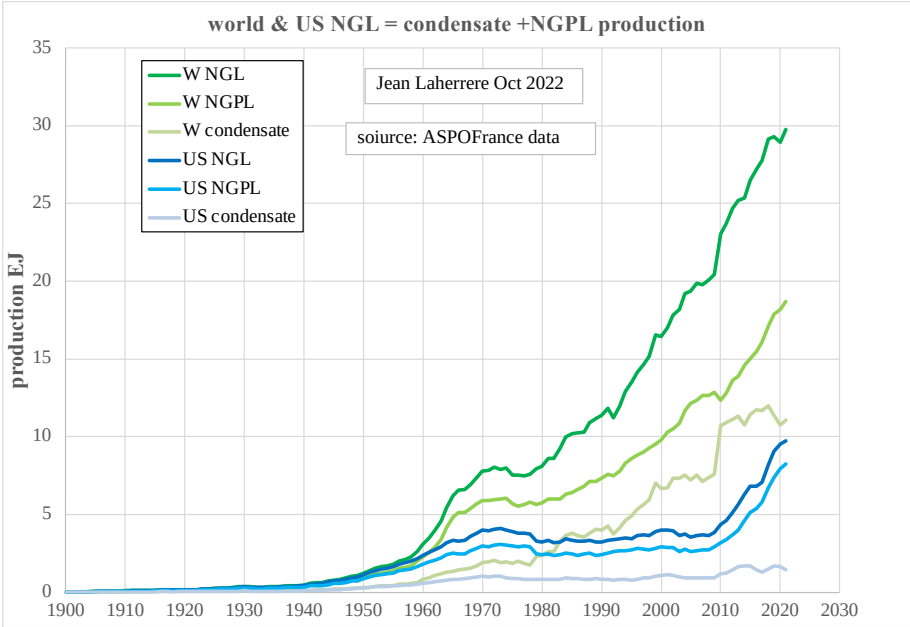
It is obvious that there is no consensus on the way to report oil and gas data and the result is a mess. The data on NGL varies widely with the sources: see my 2019 paper "World NGL production" https://aspofrance.org/2019/06/17/world-ngl-production/



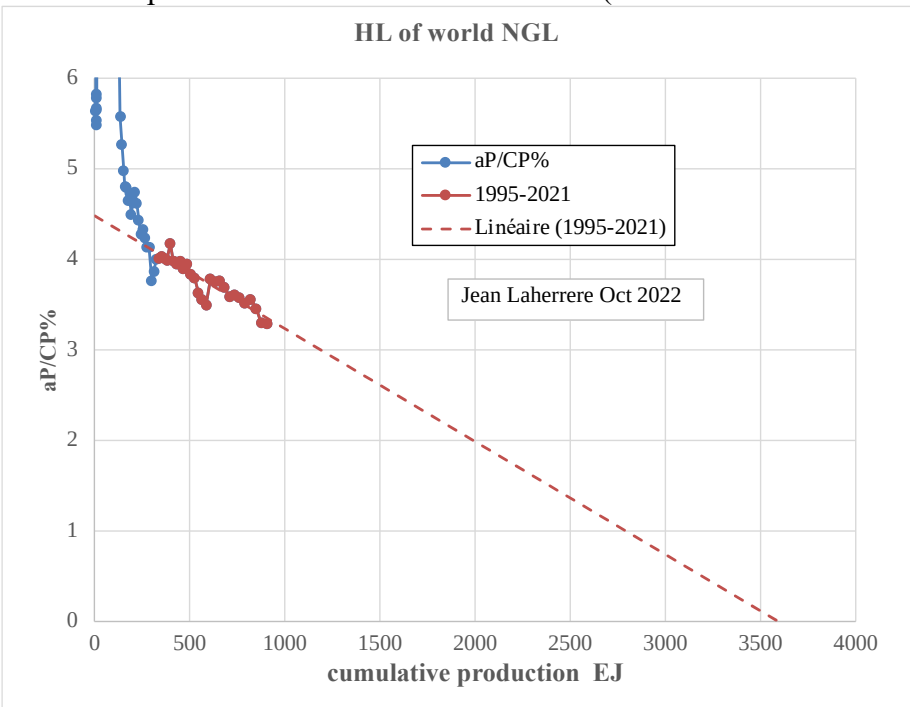
The world and US NG; condensate & NGPL productions are plotted from ASPOFrance data in energy (EJ = 28 Mtoe). The ratio NG/NGL is between 5 and 7 since 1905 for the world and US, when it declines for US (deep blue) since 2010



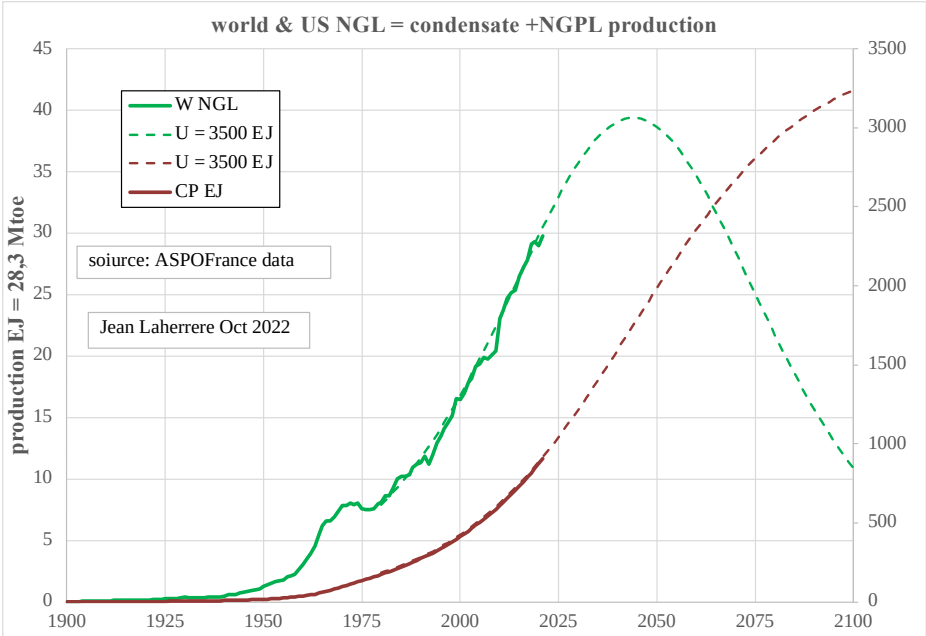
World & US NGL = condensate + NGPL are plotted



The HL of world NGL production trends towards 3500 EJ (



With 3500 EJ = 100 Gtoe, the peak of NGL will be around 2045, which is in line with the forecasted NG peak page 14



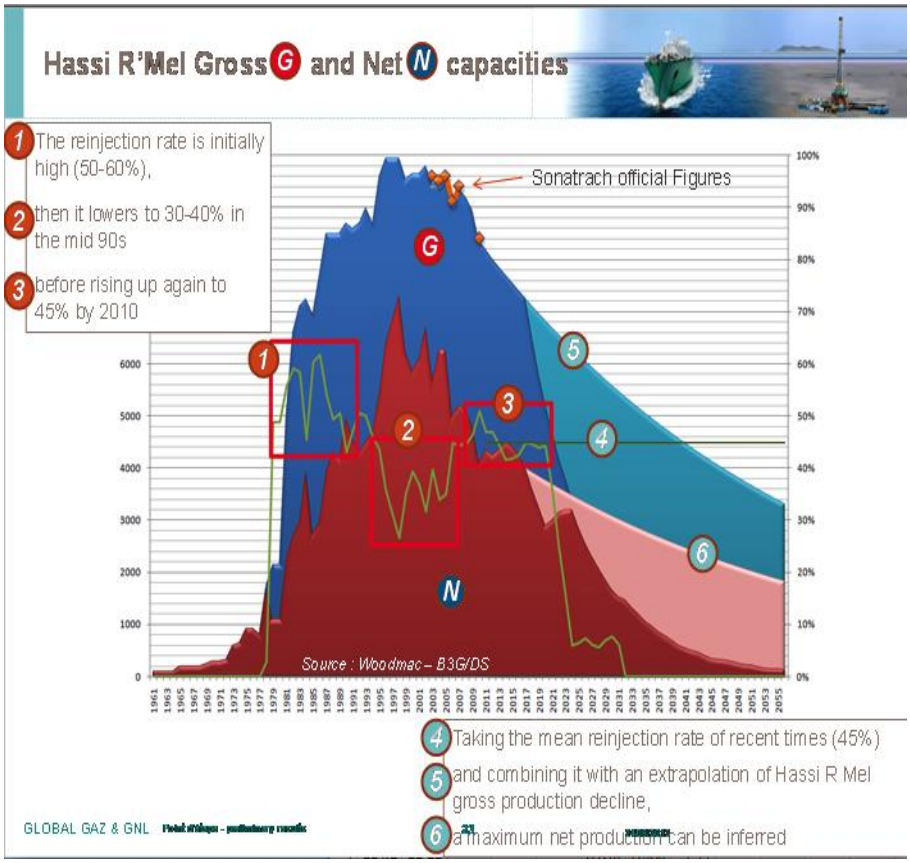
-example of Algeria NG

Hassi R'Mel gas field in Algeria is the largest in Africa, found in 1957 (I participated in its discovery) with 105 Tcf in gas reserves (RF = 75%), 2400 Mb in condensate (RF ?) and 90 Mb in oil (RF = 16%).

See my papers: -Laherrere J.H. 2014 "Refraction sparked huge African discoveries" AAPG Explorer September p 48 https://explorer.aapg.org/story/articleid/11829/refraction-sparked-huge-african-discoveries

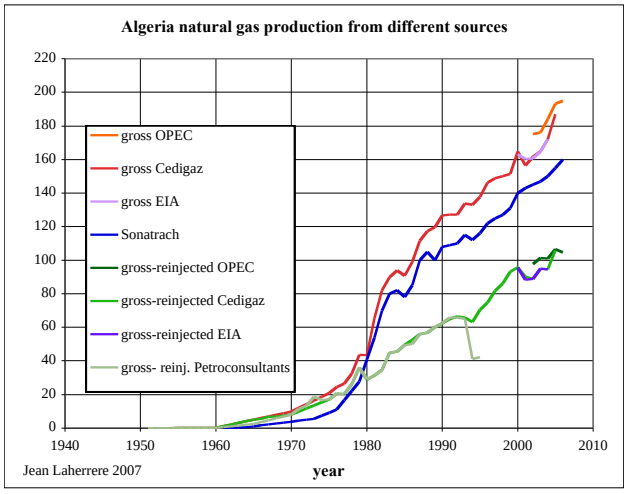
-Laherrere J.H. 2014 "History of the French discoveries in the Sahara" Sept http://aspofrance.viabloga.com/files/JL_2014SaharaLong.pdf

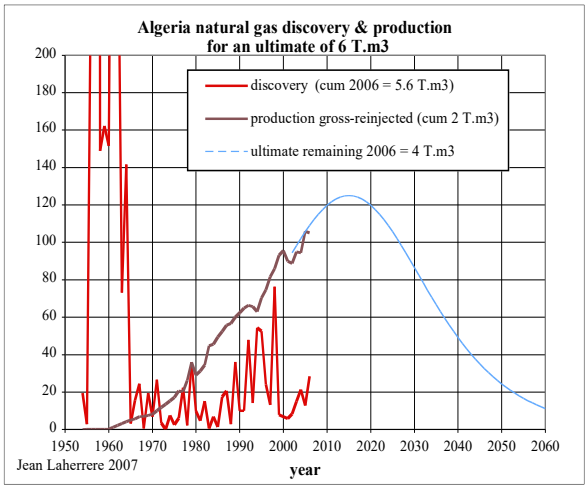
As shown in the next graph, the rate of reinjection was very high initially= 50-60 % (when OPEC members fight on reserves) , lowers to 30-40 % in the mid 90s and rising again to 45% by 2010



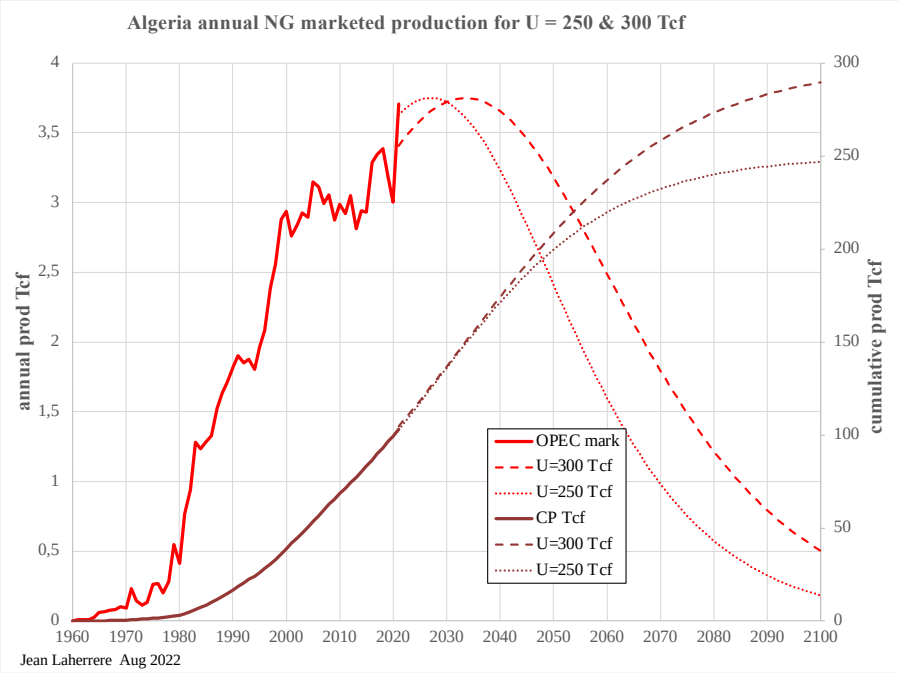
The problem is to know if the large volume of dry methane reinjected into the reservoir will be totally recovered later and if the pressure is still good enough. A recent report by DeGolyer and MacNaughton warns about the bad management of Hassi R'Mel with only 10 Gcm left
A new NG discovery was announced by Sonatrach in June 2022 above R'Mel main reservoir (Triassic) in the Liassic: but a second well was a failure, meaning that the so-called discovery was not!

This 2007 graph shows the Algeria discrepancy of NG production from different sources and a second my 2007 forecast before 2020



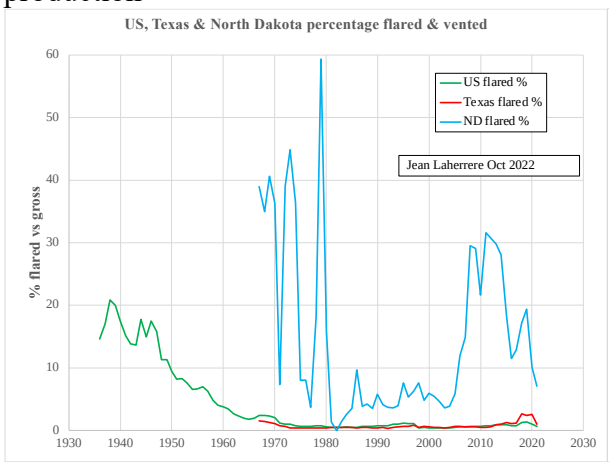


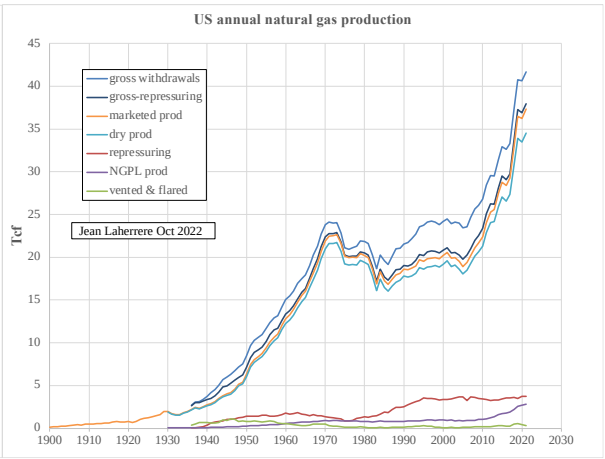
I was too pessimistic: Algeria NG production peak is soon.



-flaring

US is the best example of evolution of the percentage of flaring & vented versus gross production



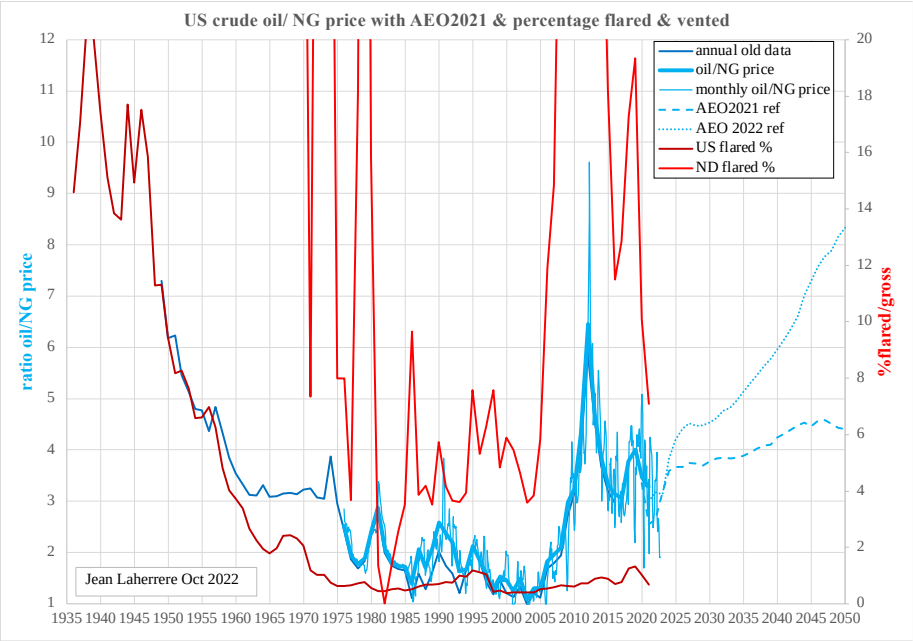


Some US NG are vented or flared when there is no gas pipeline available (which needs a long-term investment, which is not reliable for gas shale). NG production is often associated with oil production which is more wanted and its production is sacrified!

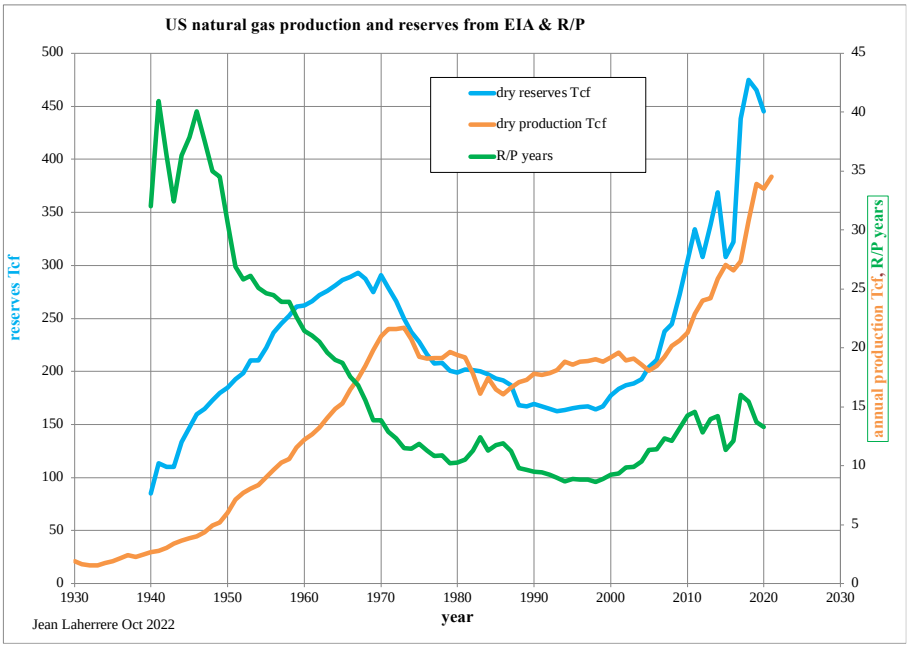
In 1950 more than 15% of US NG was flared and oil price was over 6 times more expensive (in $/MBtu). It is only in 2003 for few months that gas price was equal at oil price. The correlation % flaring (red) and oil/NG price (blue) is good from 1949 (start of price) to 2003, beyond it is the North Dakota flaring which correlates.

It is surprising to see the USDOE/EIA AEO2022 reference forecast in 2050 with oil price being more than 8 times higher than NG price (as in 2012 or before 1950)!

US NG price on the future should be equal to oil price in energy (MBtu) as it was in 2003, or less than half from 1977-2008



US NG R/P, which was about 10 years (like oil) from 1973-2005, is around 15 years since 1970.

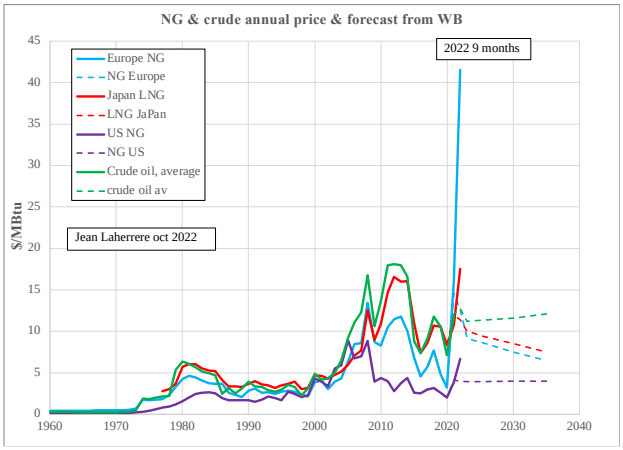


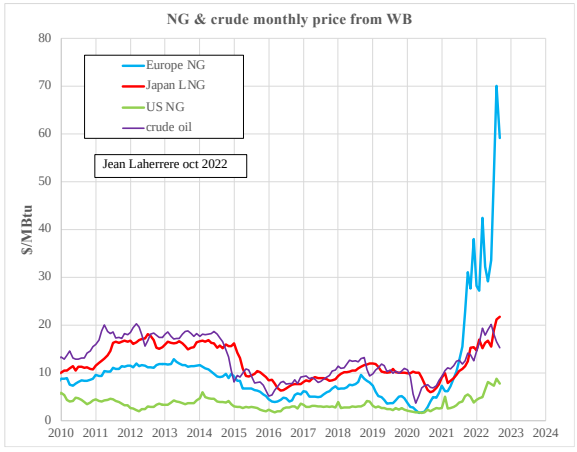
-NG price

World Bank annual data shows from 1980 to 2003 NG prices were similar and flat, from 2004 to 2008 similar and rising from 2010 US was flat when others burst, in 2020 back together but burst again in 2021

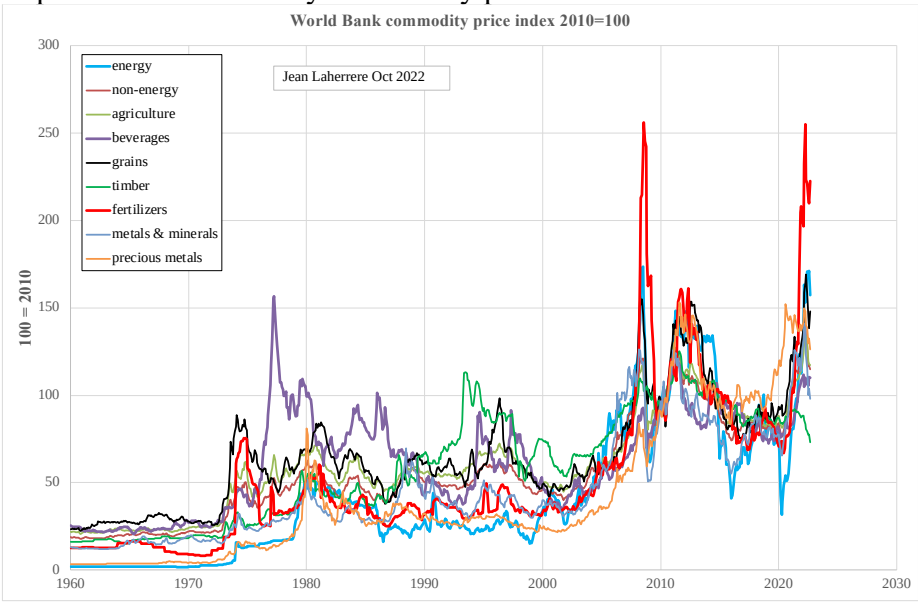
World Bank monthly data shows that Europe NG price overpassed since June 2021 Japan before the Ukraine invasion

annual 1960-2022 (9 months) & forecast WB monthly 2020- September 2022





Europe NG price started to rise in October 2020 (>10 $/MBtu) to about 30 and again (>30) in March 2022 because Ukraine invasion but declines in September 2022 after a peak at 70 in August.
World Bank forecasts to 2035 a decline of Japan & Europe NG price, a flat of US NG price and an increase in crude oil price
World Bank reports also the monthly commodity price indices with 2010 = 100

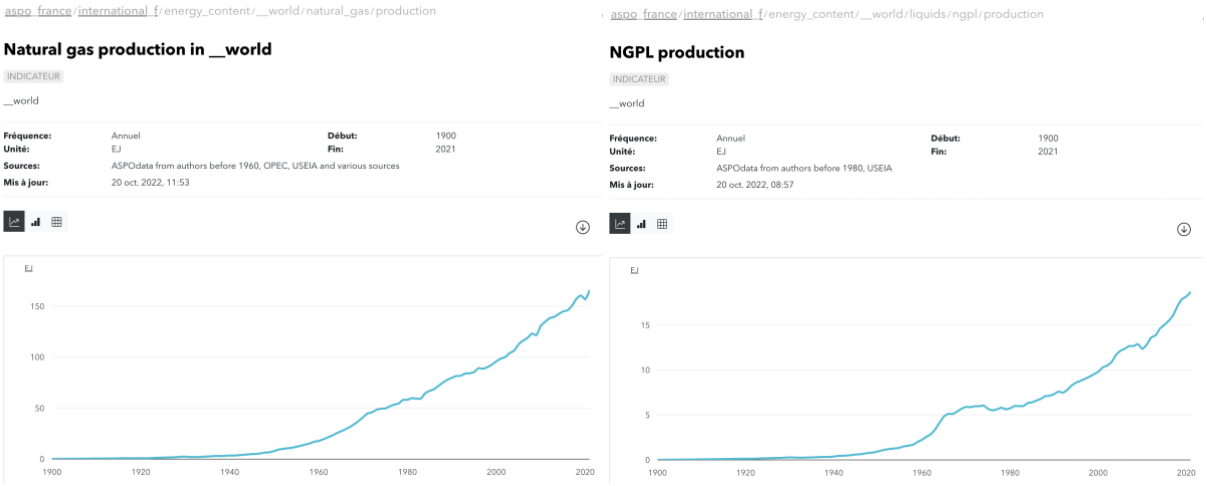


The highs are grains in 1960-1976, beverages in 1977, fertilizers in 2008 and 2022, timber in 1993 and 2022, precious metals in 2020, energy in 2022
The lows are energy 1960-1979, 1986-1999, 2016, 2020

-Conclusion

NG recovery factor is much higher than oil RF because NG molecule (methane size = 0.38 nm (nm = nanometer = 10^{-9} m)) is smaller than oil molecule (>2 nm) and can move better out of the reservoir.
NG recovery factor median is about 60-70 % when plotting number of fields and 65-80% when plotting 2P reserves.
But the range of the RF data is huge, between 1 and 100 %.
World NG and NGL production will peak around 2040.
IEA definition of condensate is ambiguous, being either crude oil or NGL, depending of the sale, meaning the IEA crude oil production data is not reliable, only crude oil +NGL data.
Reporting only crude oil production could be wrong!
Europe NG price overpassed Japan price in June 2021, well before Ukraine invasion.

NB:
Raphael Darley (17 years old) has listed for his father Julian Darley (writing a book on NG) all my graphs which can be found on Google since 2006: he has found more than 10 000 graphs: http://alpha.energystats.co:1973/display-2.php
ASPOFrance data reports energy historical for the world and by regions (run by Hugo Duterne); the data can be loaded at
https://www.gostatit.com/aspo_france/international_f/energy_content/__world/natural_gas/production



Annex:
My oil 2004 paper "Future of natural gas supply" IIASA-IEW 22-24 June 2004

Figure 5: R/P from technical and political sources

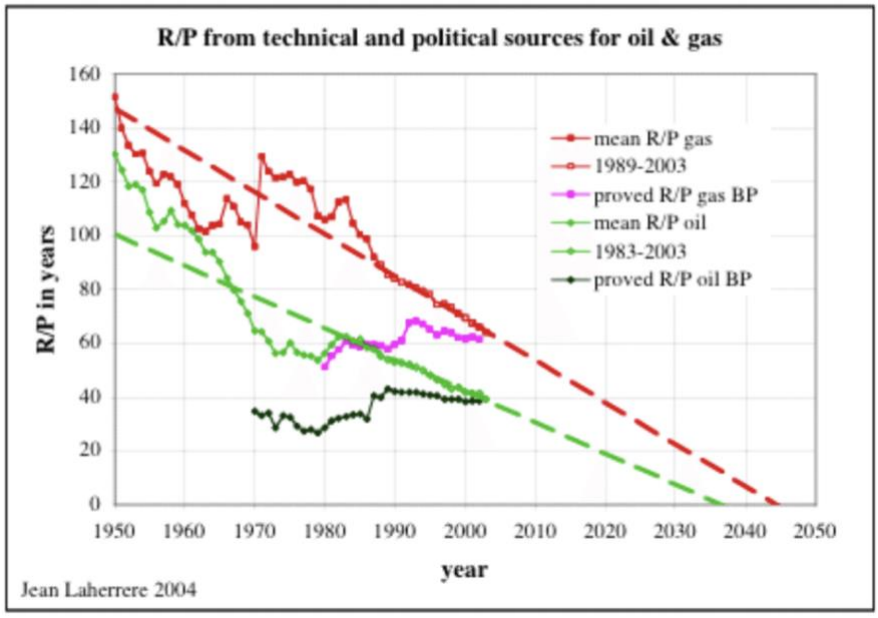


Figure 7: World conventional oil & gas “mean” discovery and production

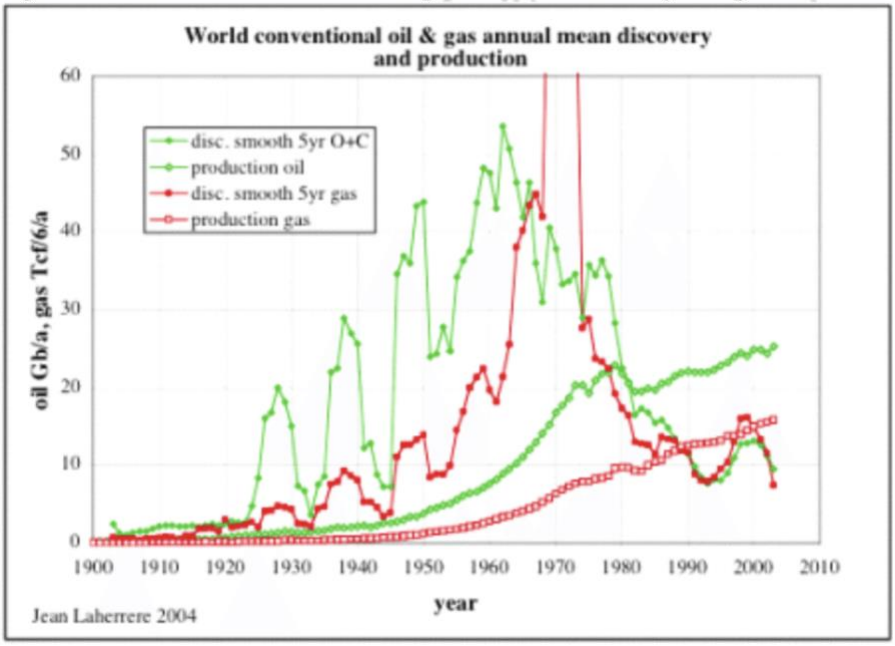


Figure 8: Cumulative conventional NG discovery by continent

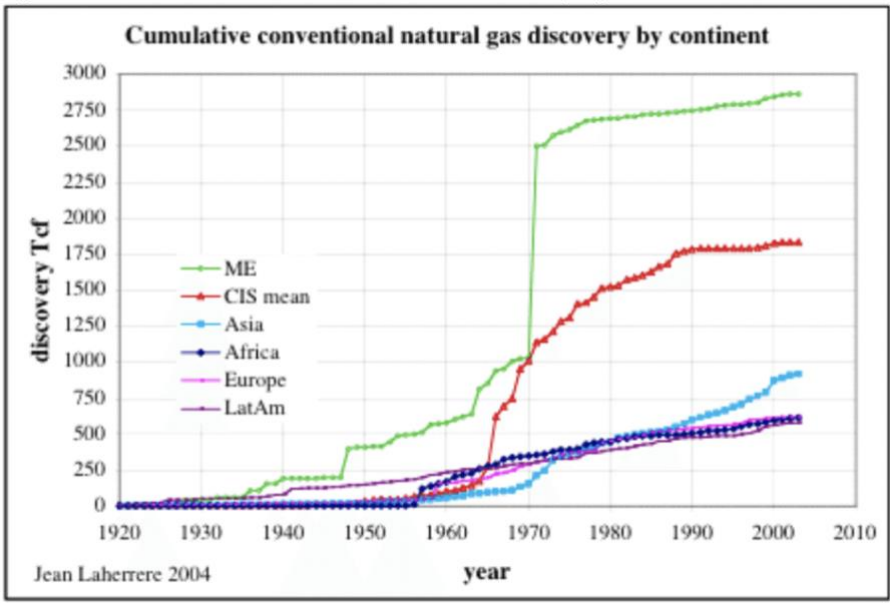


Figure 9: Conventional NG creaming curves

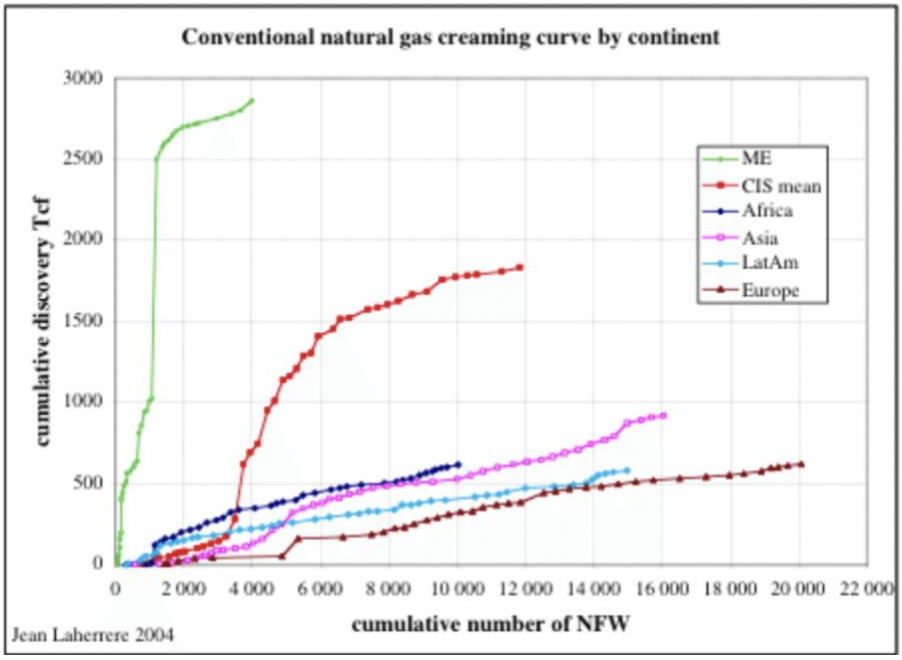


Figure 10

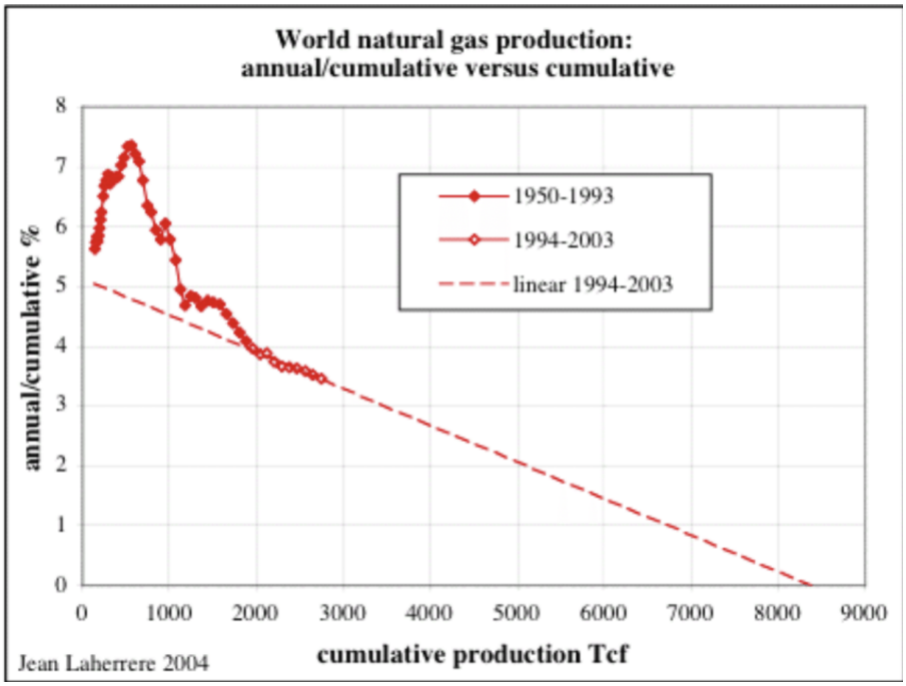


Figure 11

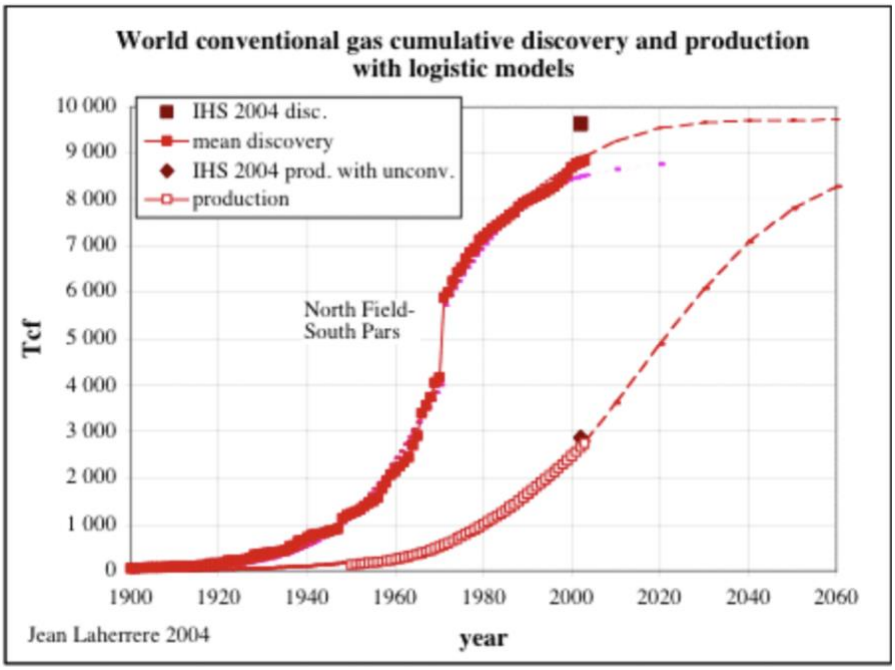
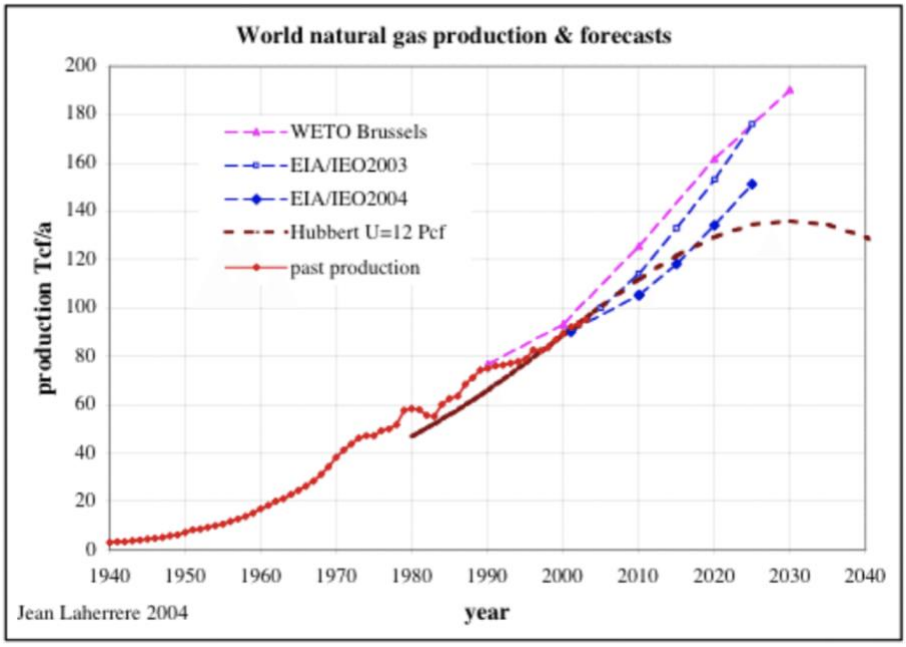
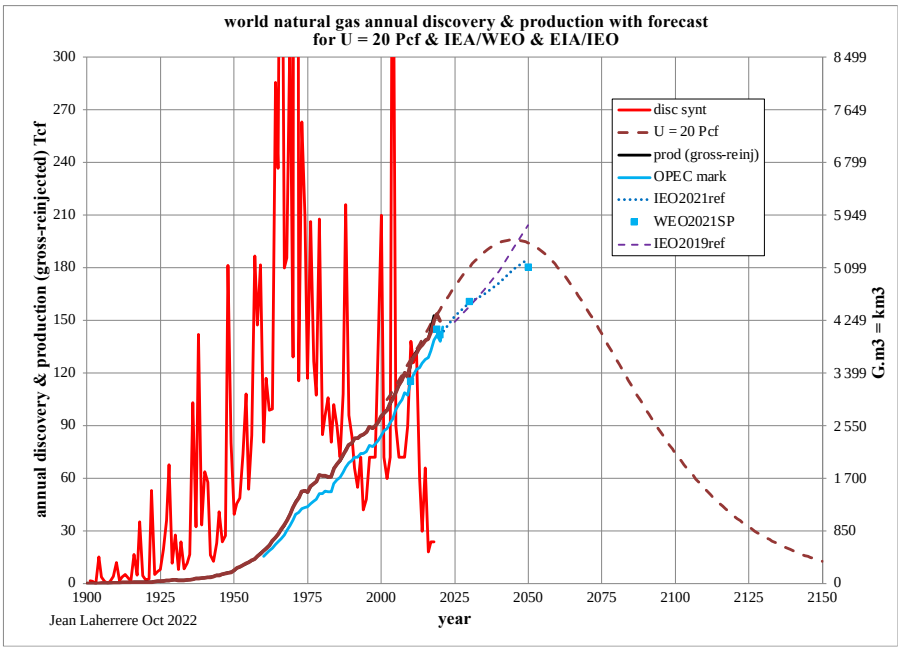


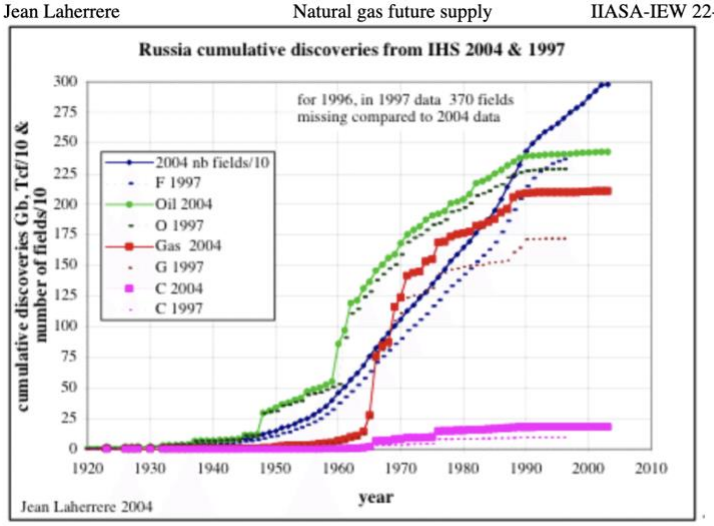
Figure 12



In this 2004 graph the peak in 2030 was forecasted at 135 Tcf for gross-reinjected, when the updated NG production peak is now at 190 Tcf thanks to giants NG discoveries in deep water. I was too pessimistic in 2004

My forecast for 2020 was 130 Tcf against 150 in real, but the 2000 data was reported too low





The problem with Russian reserves under their 1979 classification (stated as grossly exaggerated by Khalimov in 1993, despite that he presented this classification in WPC 1979 as the best system) is that ABC1 corresponds to 3P (maximum theoretical recovery) and should be corrected to get the mean value (2P) by reducing it by 30%.
Our technical mean data is obtained after reducing the ABC1 values by 30%.

figure 22

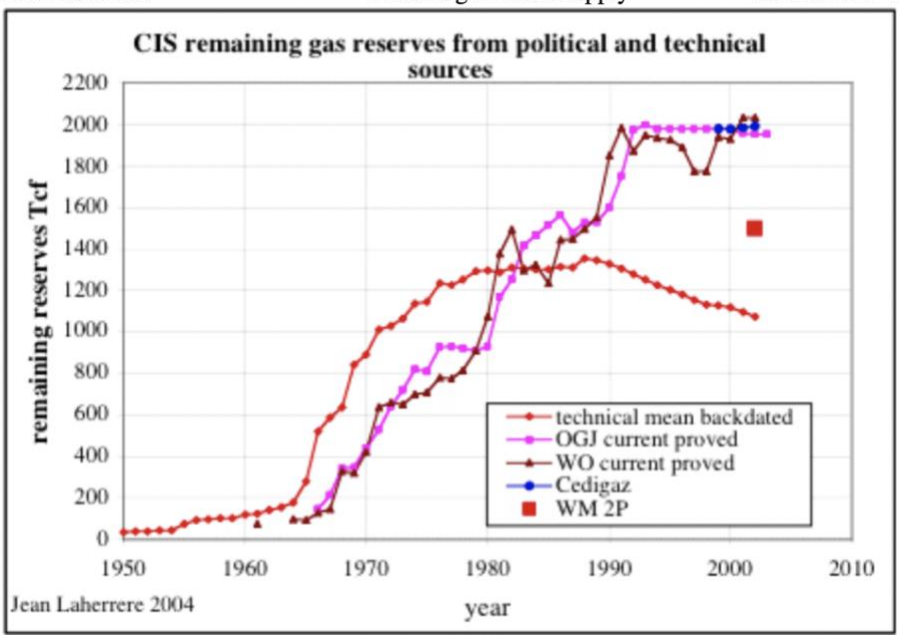


Figure 24: CIS creaming curve (ABC1) 1860-2002

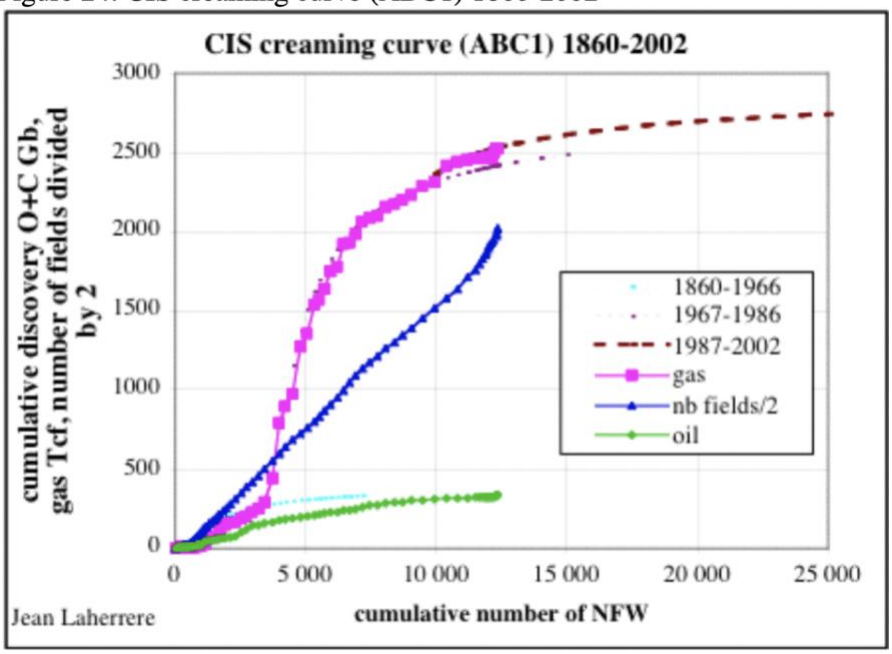


Figure 35: Europe NG cumulative discovery & production