CLUB DE NICE Energy & Geopolitics 7th Energy & Geopolitics Forum
Energy relations between Europe and Russia: from difficult dialogue to vital partnership
12-14 November 2008

Forecasting world oil and gas production under strong economic constraints

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-Oil as reported

Most of published oil & gas data is politically or financially motivated and is therefore not reliable. Technical data is mostly confidential and can only be bought from *scout* companies

-production

-OPEC production for each member country is ruled by quotas, but because OPEC members have been cheating on quotas, OPEC past oil production figures are flawed and unreliable. Real data on oil transported by tankers must be bought from spy companies (Petrologistics in Geneva). Real data on field production and field reserves must be bought from IHS (former Petroconsultants), which is the only company to provide worldwide data, and others.

-words such as **energy, oil, reserves, resources, conventional, proved, probable, light, heavy, reasonable, sustainable, dangerous are badly or not defined on purpose**

Data is either flawed by finance (stock market) or politics (quotas), or it is simply missing. Ambiguity is often favoured on purpose

Oil and liquids: **oil 2007 production** can vary from regular (former conventional) oil as defined by Campbell (65,9 Mb/d) to crude oil (73 Mb/d) and finally to all liquids (85 Mb/d) including NGLs, synthetic oils from coal (CTL), biomass (BTL), and refinery gains.

World oil production for **2007**	definition	Mb/d
OGJ Oil & Gas Journal	oil	72.361
WO World Oil magazine	crude/condensate	74.515 796
BP Statistical Review	liquids (excl BTL. CTL)	81.532 910 152 325 8
USDoE (Depart of Energy)/EIA	crude oil	73.573 844 712 166 8
	all liquids	84.597 461 4
IEA International Energy Agency	oil	85.4

The number of significant digits is ridiculous in front of the real accuracy of the data, when the difference between IEA and EIA is about 1 Mb/d for 2006

-reserves

There is no consensus on oil reserves definition and estimates:

Published proved oil reserves at **end 2007**

Oil **Gb**	OGJ	BP	WO
World	1 331.698 077	1 237.875 464 625 99	1 183.891
Russia	60.000 000	79.432 084 5	76.000
Norway	6.865 325	8.171 588 188 604 87	6.693
Canada	176.592 000	27.664 029 323 866 1	25.157
China	16.000 000	15.493 4	18.052

Again ridiculous number of significant digits in front of the divergence

There are 4 different classifications on oil reserves in use:

-US: all energy companies listed in the US stock market are obliged by the SEC (1978 rules) to report only proved reserves (**1P**), assumed to be the **minimum;** these reserves are audited. SEC is presently changing the rules allowing the report of probable reserves in 2009

-OPEC: because quotas depend upon reserves, OPEC members report proved reserves (**1P**), which corresponds to their wish since it is not audited.

-FSU classification: ABC1 (Khalimov 1979) reports **maximum** theoretical recovery, being about equal to proven plus probable plus possible (**3P**). Khalimov in 1993 stated that Russian reserves were *grossly exaggerated.* Russian oil reserves are State secret (7 year jail).

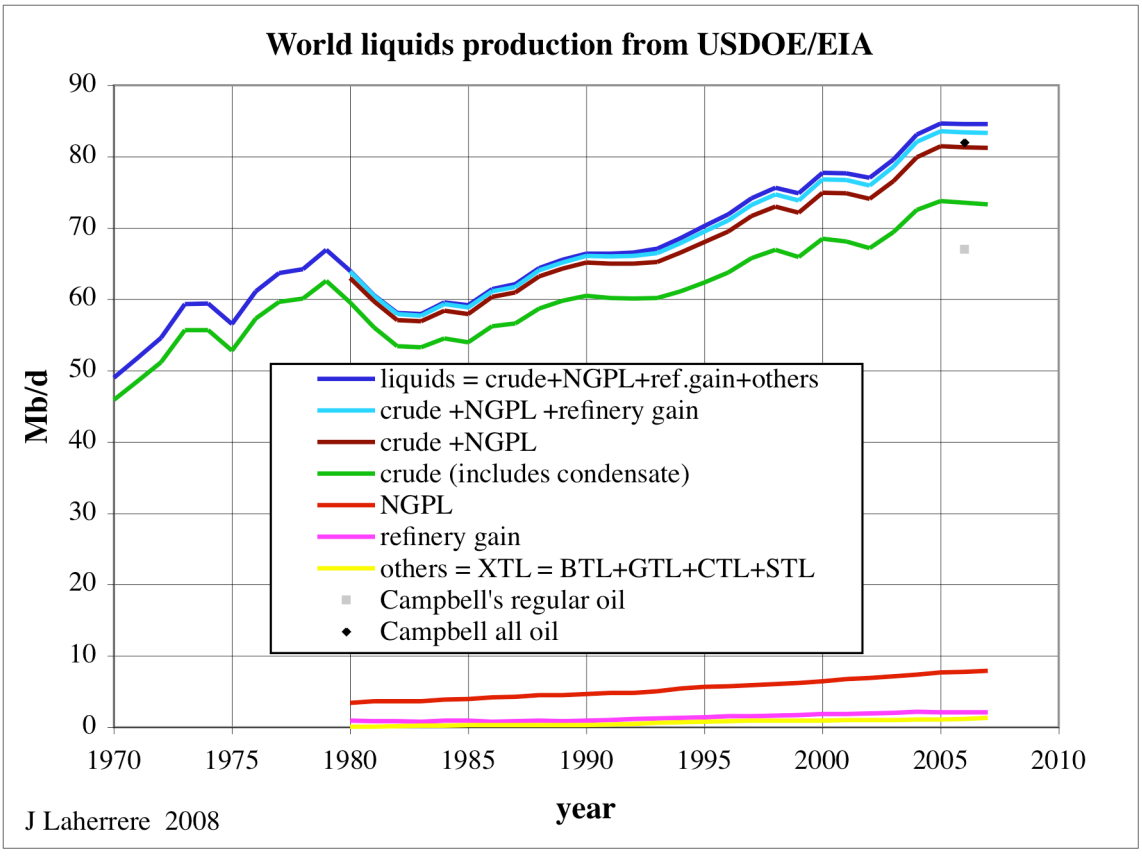
-Rest of the world: reports reserves as proven plus probable (**2P** close to the **expected value** used to compute the net present value of the development, when decided) following the 1997 SPE/WPC classification, definition and guidelines (I was a member of the task force). Field developments are decided on the value of 2P reserves which is the base of the net present value of the project (mean value).

-"oil demand" = "all liquids"

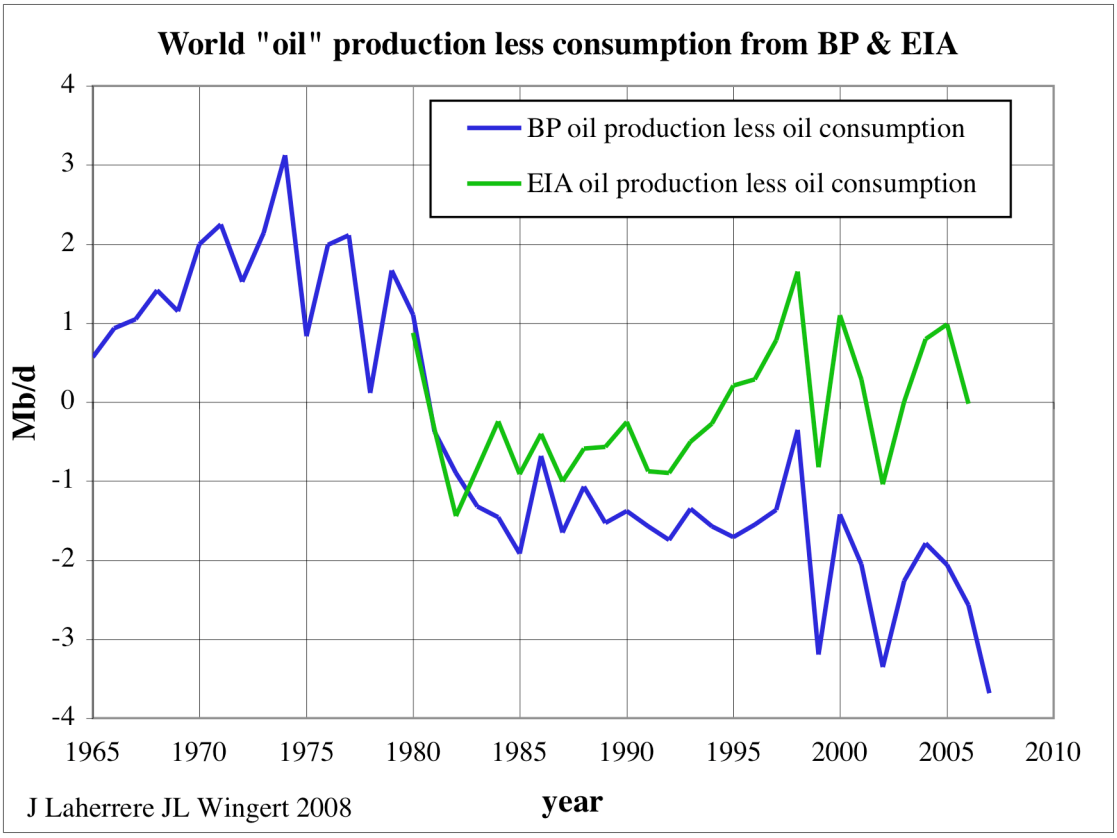
There are many definitions of oil. The most relevant definition to be used, as far as peak oil is concerned, is "all liquids", because it is important to know when the oil supply will not be able to satisfy the oil demand that is reported in all liquids (in 2007 84.6 Mb/d for USDOE/EIA and 85.4 Mb/d for IEA). Focussing on restrictive definition of oil leads to pessimistic production forecasts and misleads on the answer to *when oil demand will not be supplied?*

Types of oil taken in account in our "all liquids" definition
Here are the types of oil :
Crude oil (including condensate in USDOE/EIA report because it is not separated in the US)
Extra heavy = EH
Natural Gas Plant Liquids = NGPL
Refinery gains
Other liquids being synthetic oils = XTL = GTL, CTL, BTL, STL

The following graph shows differences in the past production according to the type of "oil".
Figure 1: "**oil" production from USDOE/EIA**



On a worldwide basis oil production and oil consumption should be about equal, the only possible differences are caused by the storage of oil, but this is fairly insignificant, since the strategic reserves of IEA member countries only cover 3 months of imports and do not change very quickly. But there are large differences between world consumption and world production for two sources BP and EIA. BP oil production is in 2007 3 Mb/d less than BP oil consumption.
Figure 2: "**oil" production minus "oil" consumption in BP and EIA**

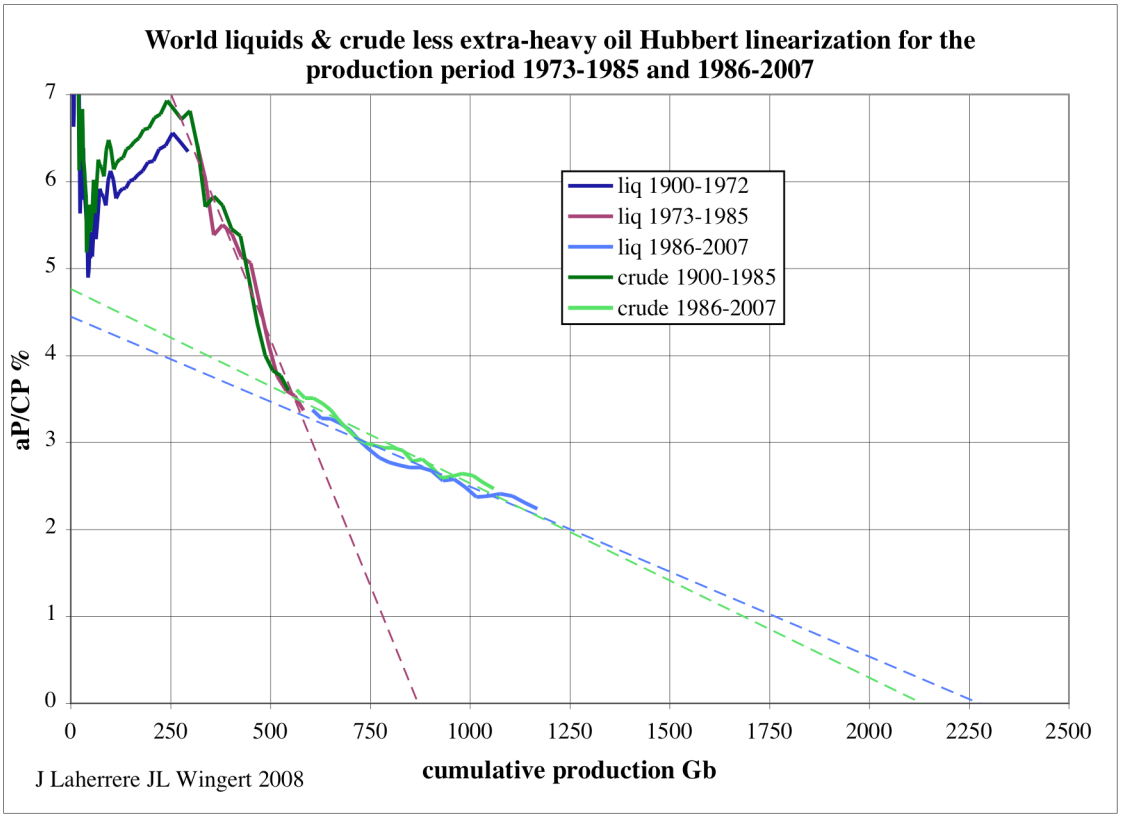


If the long term average of EIA statistics varies around zero as it should be, it's not the case for BP statistics. The main reason is that they do not include synthetic oil in the production but they do in the oil consumption. All the economists who rely on the growth of BP oil reserves to deny peak oil, should wonder, when finding that oil production is less than oil consumption, why BP reported proved reserves are growing.
"*All liquids*" is the relevant data for oil consumption as we explained above. We will work with "*All liquids*" data for the production side also.

-Assessment of ultimates
To forecast the future oil production we need to estimate the ultimate oil reserves, which includes the oil already produced, the oil discovered and oil to be discovered. Some authors use the linearization method which has some weak points, so we will prefer using the creaming curve method.

-Hubbert linearization
The risk of this method, that we will only present shortly, is that the plot is not linear, because production does not follow a logistic curve, or because production follows several logistic curves. Past production is also disturbed by economic crises or wars. Production follows rarely a perfect logistic pattern which leads to only one linear trend in the so-called Hubbert plot (annual growth versus cumulative production). Some portions are linear, but not all the curve, so it is hard to believe that the last linear portion will be the last one.
World *liquids* or *crude oil less EH* productions display a Hubbert linearization far from being one simple linear trend. There is a roughly linear portion from 1973-1985 (first oil shock to the oil

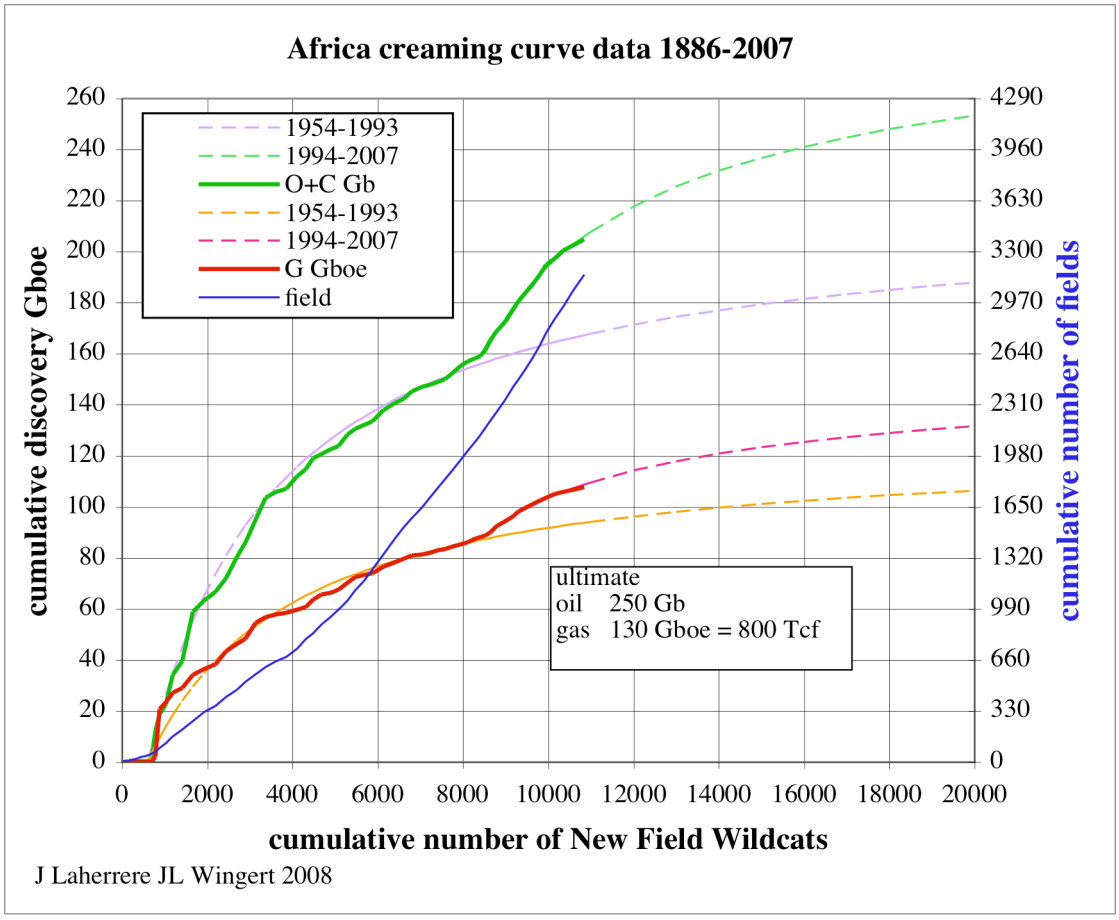
counter shock) and another rough linear portion from 1986 to 2007. The coming depression could change this trend as 1985 did.
Figure 3: World *liquids* and *crude oil less EH* Hubbert linearization for 1973-1985 and 1986-2007



For *crude less EH oil*, the Hubbert linearization (green) for the period 1986-2007 is about 2100 Gb, but the extrapolation of the cumulative discovery fits better with a 2000 Tb, yet the accuracy is not good enough to exclude 2100 Gb. But it is obvious that the linearization for liquids (blue) trending towards 2250 Gb is wrong, because the difference between *liquids* and *crude less EH oil* is much higher than 250 Gb including EH (about 500 Gb), NGL (about 250 Gb) and refinery gains + synthetic oils (= GTL, CTL and BTL) that are difficult to estimate. We believe that the *crude less EH oil* ultimate is about 2 Tb = 2000 Gb and *liquids* ultimate about 3 Tb. The accuracy of such an estimate is less than 10 %, so 100 to 200 Gb can be added (or subtracted) in the future without changing much this rounded estimate
Hubbert linearization of oil production is a poor way to estimate ultimate recovery. It is done by many because it is the only data they have.

-Ultimate with creaming curves

Extrapolation of discovery data (in particular the creaming curve = cumulative discovery versus cumulative number of pure exploration wells = New Field Wildcats) is a much reliable tool, when reserves estimates are close to the mean (expected value) and are backdated. It is also fascinating to find that creaming curves can be easily modelled with several hyperbolas, allowing to get the ultimate assuming that there is no new cycle. Africa displays two cycles, the last one is mainly deepwater. An important third cycle is unlikely.
Figure 4: **Africa oil creaming curve 1886-2007**

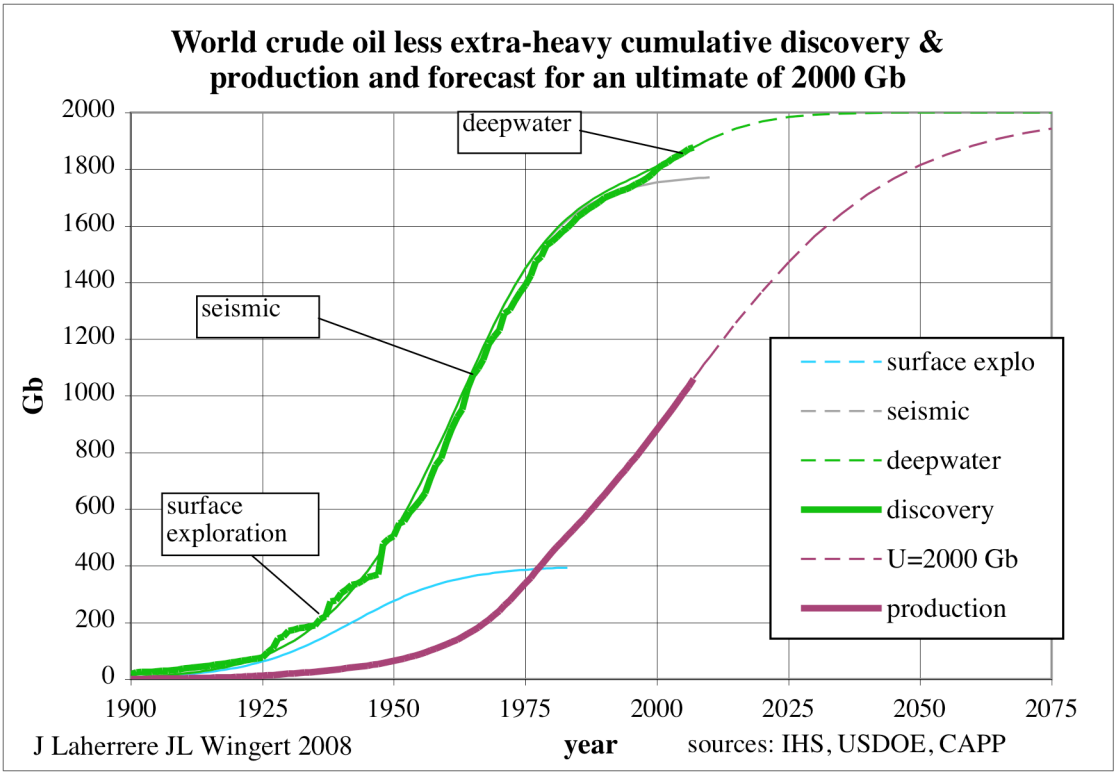


-Ultimate with cumulkative discovery versus time

Cumulative mean backdated discovery can be also modelled versus time with one or several S curves (logistic curve). The world crude less extra-heavy oil, is modelled with three S curves, the first one corresponding to the surface exploration up to 1945, the second with seismic exploration up to 1995 and the last one being deepwater. If there is no new cycle: most of the petroleum systems have been drilled, even Antarctica with JOIDES and their potential evaluated looking at the possible source-rocks: a few wells are enough for that. The yet to find (YTF) can be deducted from the known cumulative discovery (about 1,9 Tb) and the rounded 2 Tb ultimate. YTF is less than 200 Gb for easy oil, and subsalt deepwater (not easy oil) is easily within this volume.

The *crude less EH oil* is the **cheap** (or **easy**) oil and is properly reported.

Figure 5: World *crude less extra-heavy oil* **cumulative** discovery and production with forecast for an ultimate of 2 Tb



-Another cycle ?

Is there a possibility that a new cycle linked with a new type of oil or new technology could change the ultimate significantly ? Let's make a short assessment of the possibilities:

-Extra heavy? The extra heavy fields (known before 1750) which have not been produced yet for some technical reasons.

-Polar oil? It is already included in the second cycle (seismic).

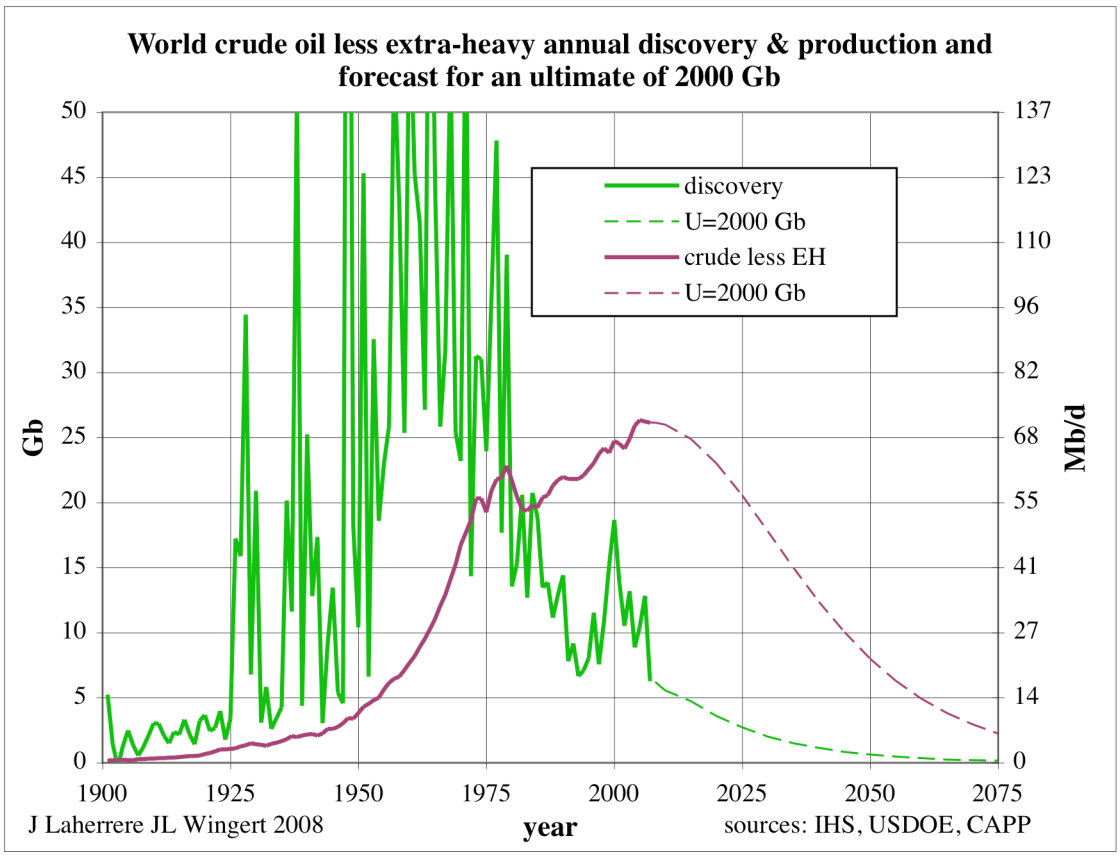
- Deepwater subsalt reservoirs? The recent discoveries in Brazil were quite a surprise as for the volume, but these subsalt reservoirs were already known in Angola (close before Atlantic break-up)…

-Technology? The impact of technology has already been answered many times (Laherrère, 2008). Briefly, technology can help to increase conventional today production, but usually decreasing tomorrow production (East Texas, Brent, Yibal, Rabi-Kounga, Canterell).

-Annual production forecast of "conventional oil" or "easy oil" only

The annual production forecast with the same ultimate shows that the *crude less EH oil* has peaked in 2006 at 71 Mb/d (discovery has peaked in the 1960s) and the 2 Tb ultimate forecasts a production of 55 Mb/d in 2025.

Figure 6: World *crude less EH oil* **annual** discovery and production with forecast for 2 Tb

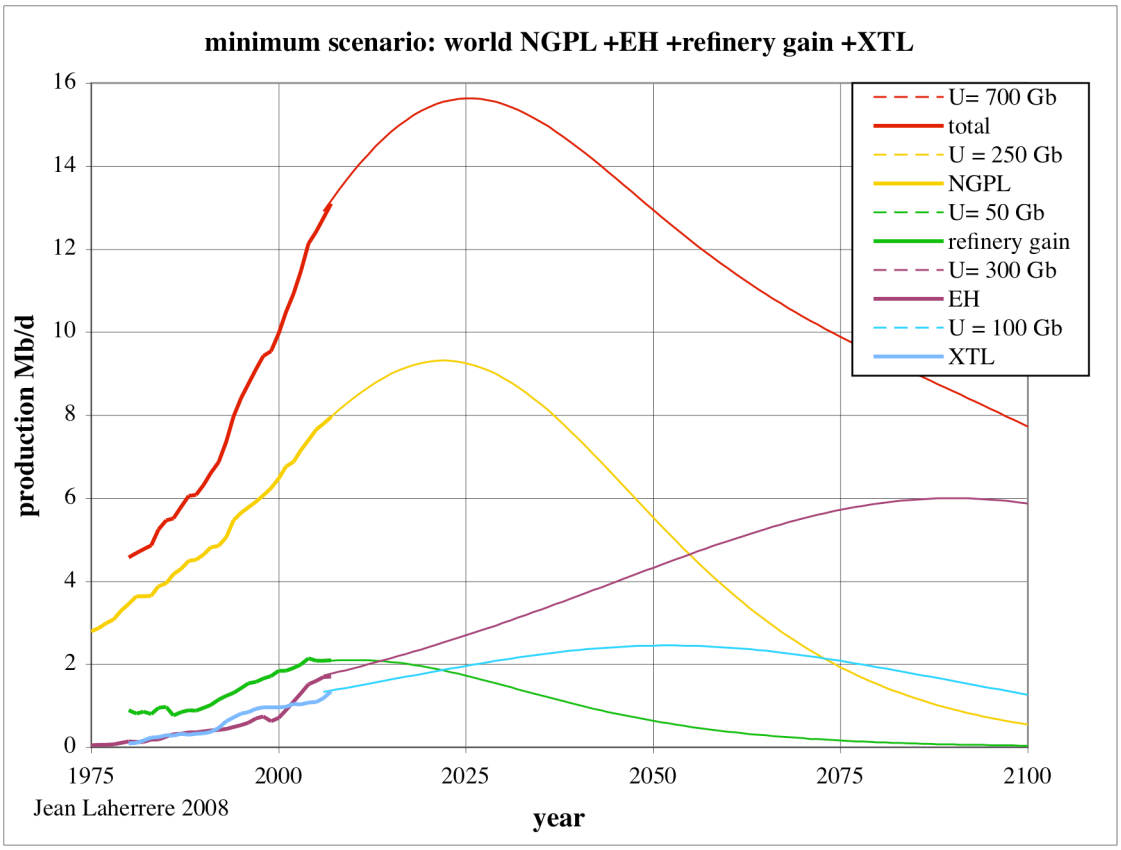


-Hypothesis for some types of "non conventional" or "expensive oil"

The gap between *crude less EH oil* and *all liquids* represents EH, NGPL, refinery gains and others = XTL as defined before.

We have estimated a minimum scenario of 0.7 Tb, using the ultimate from natural gas for natural gas liquids (250 Gb) and from crude oil for refinery gain (50 Gb), and taking 300 Gb for EH and 100 Gb for XTL. For unconventional oil, the size of the tank (reserves) does not matter much, it is the size of the tap (above-ground) that matters.

Figure 7: minimum scenario for world NGPL, EH, refinery gain and XTL



-"all liquids" forecasts

But *liquids* is the aggregation of "*cheap oil*", "*expensive oil*", *NGL*, *refinery gain* and "*synthetic oils*". The difference between the *liquids* and the *crude less EH oil* represents the *expensive liquids* and can be modelled (in red) with an ultimate of 1 Tb (likely) or even 2 Tb (maxi), but the peak is not changed because expensive liquids need time.

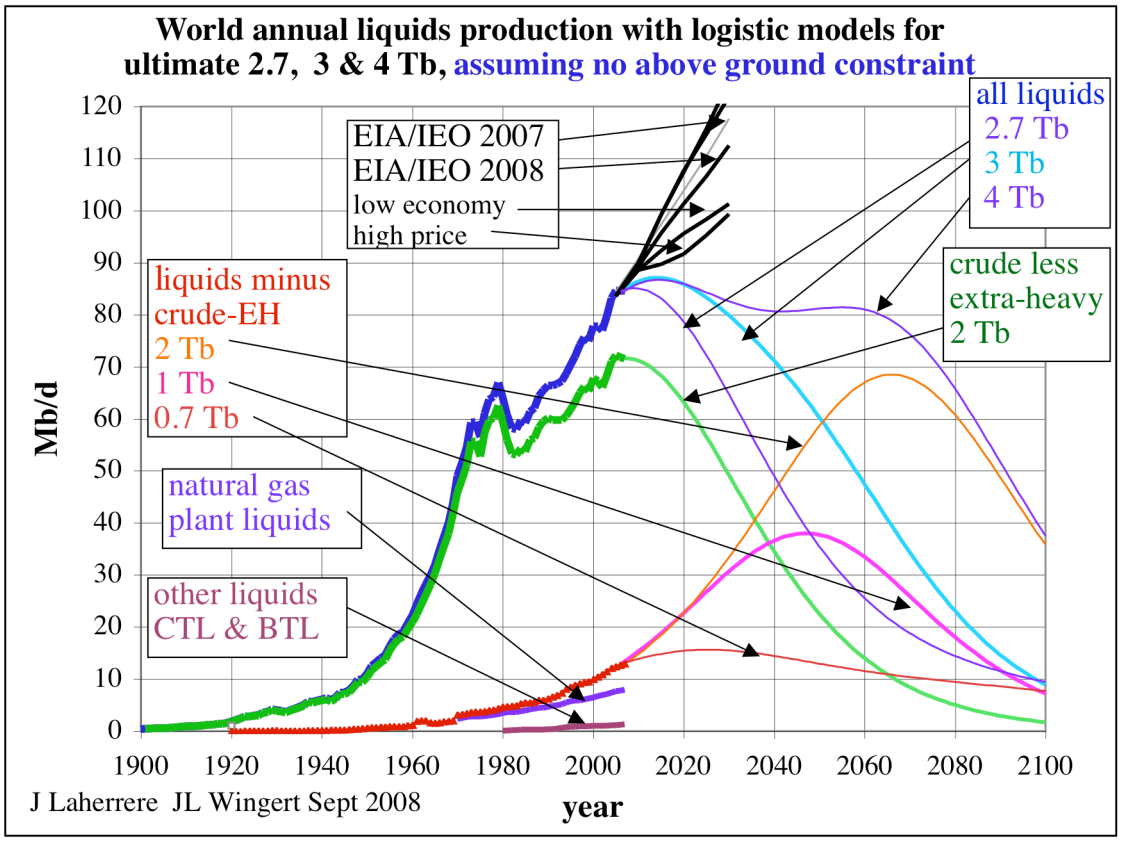
All liquids most likely ultimate is estimated at 3 Tb being the sum of :

crude less extra-heavy	2000 Gb
extra-heavy	500 Gb
natural gas liquids and GTL	250 Gb
synthetic oil (BTL, CTL, STL) & refinery gains	250 Gb

Crude oil less extra-heavy (cheap oil) is modelled in the previous graph with an ultimate of 2 Tb. The rest (being **expensive oil)** is modelled (red curve) with an ultimate of 1 Tb (most likely) with a peak around 2050. The all liquids (2 Tb +1 Tb ultimate) peak is around 2015 and over 90 Mb/d, but this is theoretical assuming no constraint from demand or from investments (above-ground). We consider that the area below the curve which represents the ultimate is reliable but that the curve can vary for sometimes (down or up), yet the change in area will be recovered later. This is why, for the short term, it is better to rely on the study of already planned large oil developments = *megaprojects*. Skrebowski (Petroleum Review 2006) has done it and forecasted an oil peak in 2010 at 94 Mb/d. The Oil Drum megaprojects (crude oil +NGL) has updated the study with a peak around 2010 at 81 Mb/d

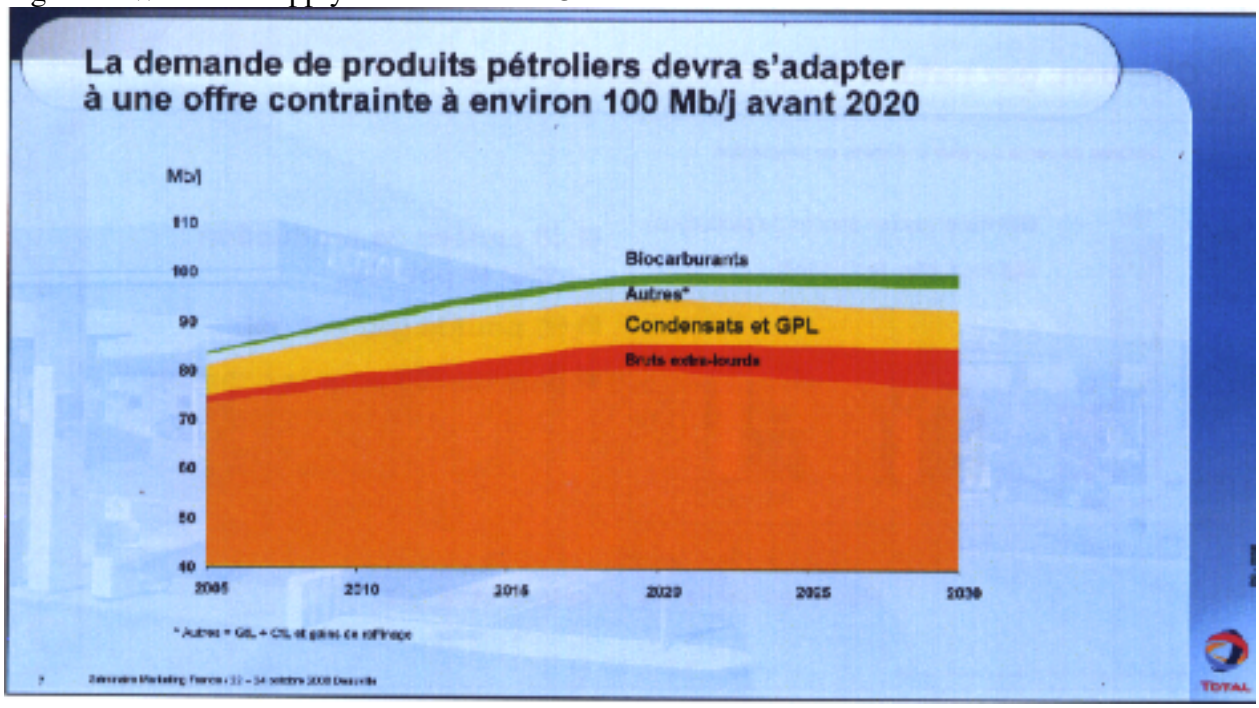
Doubling the ultimate of expensive oil (red curve), making the all liquids ultimate at 4 Tb, **will not change the oil peak date**, changing only the slope after the peak.

Figure 8: World *liquids* production for ultimates 2.7, 3 & 4 Tb assuming no above-ground constraint & USDOE IEO 2008



This graph is plotted like the previous one with the assumption that constraints are only from the resources (below-ground), assuming that above-ground constraints from demand, investments or politics will not occur, which is unlikely. That is why since 2001 I forecast a bumpy liquids plateau with chaotic oil price.
USDOE has changed its 2008 forecast by adding two more scenarios (high & low economy) and decreasing its reference. The low economy or high price indicate a large change being about or less than 100 Mb/d.

TOTAL forecasts a plateau below 100 Mb/d from 2018 to 2030
Figure 9: World oil supply forecast from TOTAL 2008



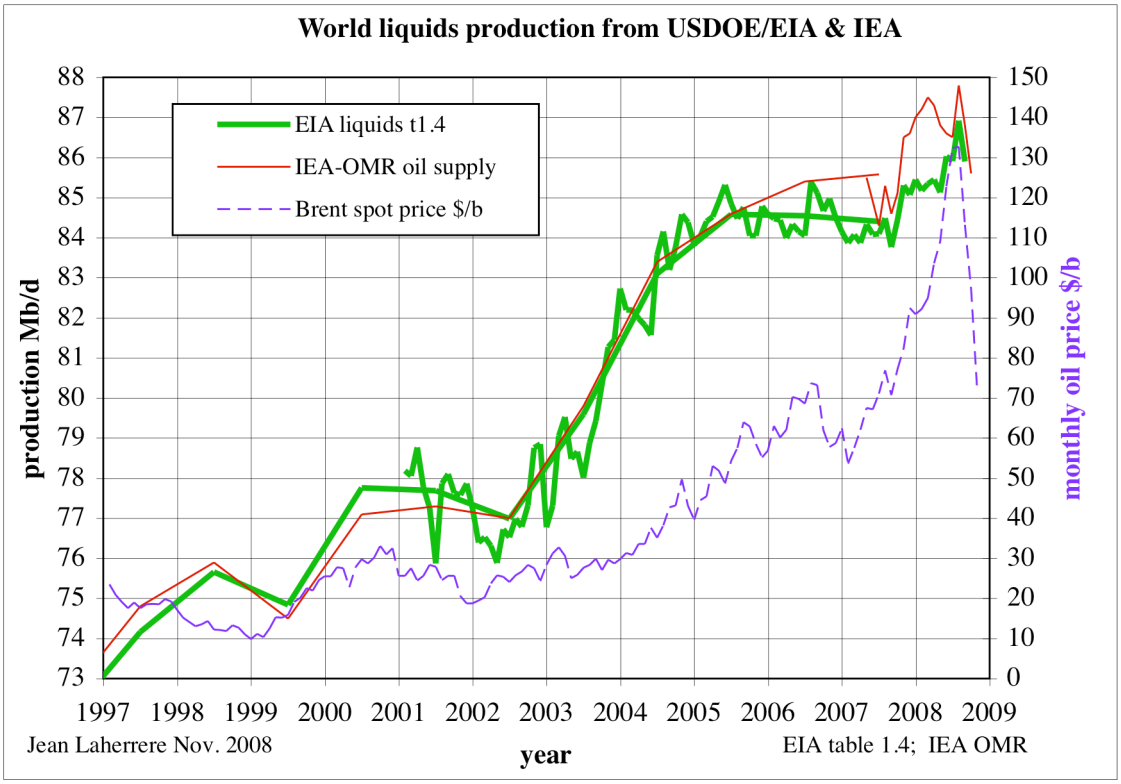
IEA/WEO 2008 forecasts for 2030 106 Mb/d for the reference scenario, 98 Mb/d for the 550 ppm scenario and less for the 450 ppm scenario. Global warming is now replacing economy constraints! However CERA (Oct 2008) continues to forecast a capacity of 114 Mb/d in 2020, despite their refusal to accept ASPO bet (100 000 $) challenging this value stated already in 2007.

-Has the world production already peaked?

Some said that oil peak was behind us. Of course if we mention only a part of oil production, let's say very conventional oil, yes we can see a peak, but working "all liquids" shows that the "all liquids peak" has not clearly happened yet.

On the last monthly data from USDOE on liquids, what do we see: a plateau? or just one more step as in 2001?

Figure 10: **World liquids production from USDOE & IEA**

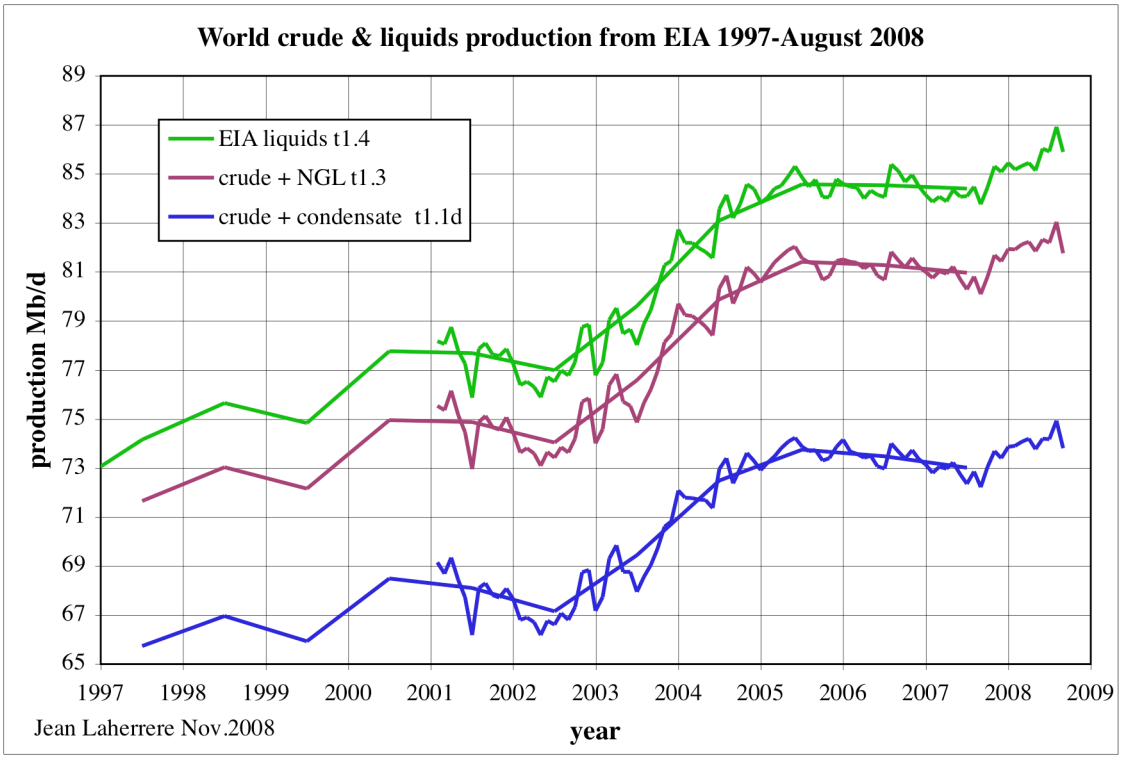


The liquids production seems to be entering a bumpy plateau, with one more step, but is July 2008 the peak? (China did fill up its strategic reserves before the Olympic Games). August's production fell by more than 1 Mb/d and same fall was observed for September (OPEC MR Oct 2008).

Last oil price increase was connected to the dollar decrease in value. Oil price fell drastically for the last three months due to the oil consumption decreases, but also because dollar value has increased compared to euro (fall from 1,6 to 1.27). This dollar increase seems queer when US consumer is deeply in debt (negative savings) compared to Europe, and US credit card bubble will burst like US housing bubble.

The claim made by some for a 2005 peak for crude oil (which includes condensate in USDOE report) seems to be contradicted by the crude production of July 2008 (in blue).

Figure 11: **World crude oil & liquids production 1997-August 2008 from EIA**



-underestimating technical problems ?

Many actors of the oil scene minimise or are not conscious of the technical challenges. The oil industry has made some huge improvements in the last century and a half, and will still do in the future. The age of easy oil is clearly behind us.

Oil infrastruture is mainly made of iron and most are rusting (Alaska pipeline).

Time of development is always considered too optimistically, hoping that everything will be all right. But there is Murphy's law! In Nature it is not possible to make one baby in one month with nine women!

Time is an important factor which is usually underestimated.

The Mc Namara law (from NASA experience) said for frontier projects that the ratio between initial proposals and reality is about π (pi = 3,14…) for cost and e (Euler number = 2,7) for time.

Furthermore this modelling assumes that *below-ground* constraint is only geological, but *above-ground* constraint is political (civil war in Iraq and Nigeria, nationalisation in Russia and Venezuela), financial (investment on supply, depression on demand) could also change the curve, still the area below the curve has to stay the same being equal to the ultimate.

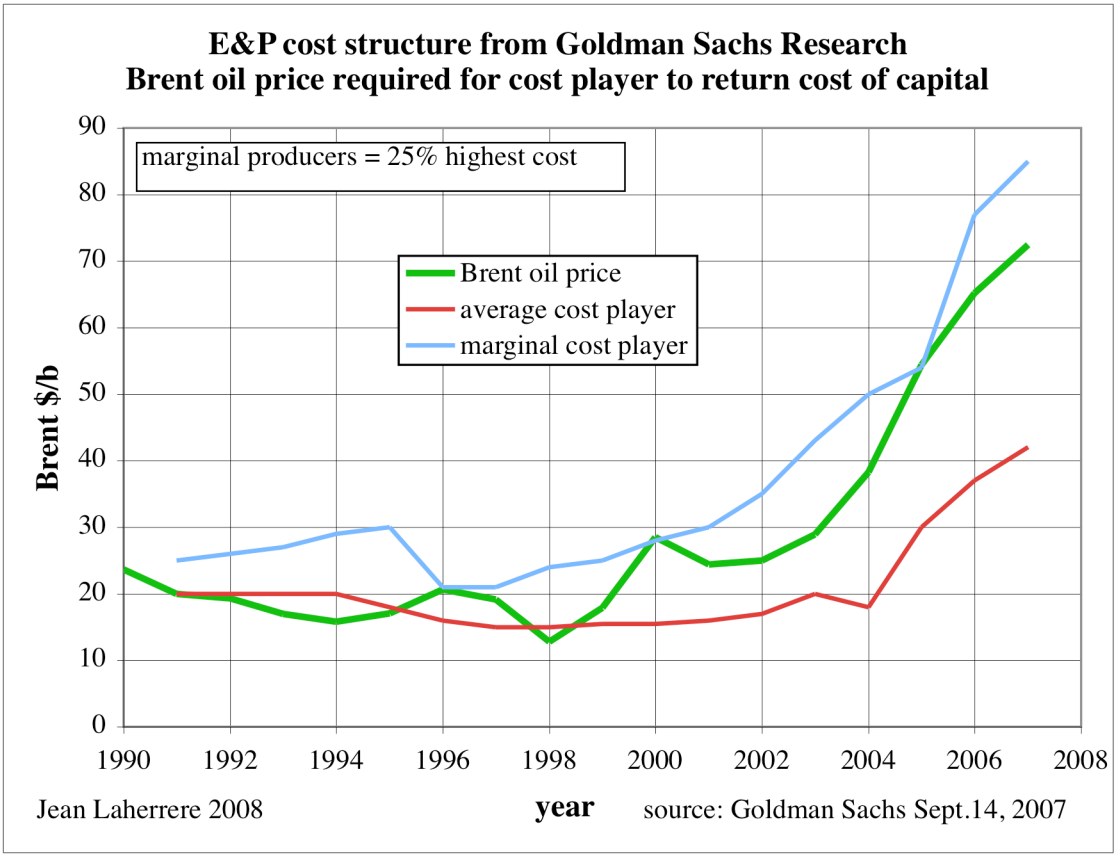
The reference forecast by USDOE/IEO 2008 (as IEA 2007) is mainly political, called Business as Usual (BAU) to please our society of consumption addicted to growth. But EIA is now adding two more scenarios, accepting an economic low. IEA WEO 2008 decreases 2006 forecasts.

-marginal cost or breakeven point

Goldman Sachs has studied oil costs for 60 oil companies (IOCs). With the increases in oil, iron, services and equipment prices, the marginal players (25% highest cost) (blue curve) need 85 $/b in 2007 to get a fair return on capital (Brent 2007 = 72 $/b).

It means that, if oil price goes down below 80 $/b, many operators will be bankrupted.

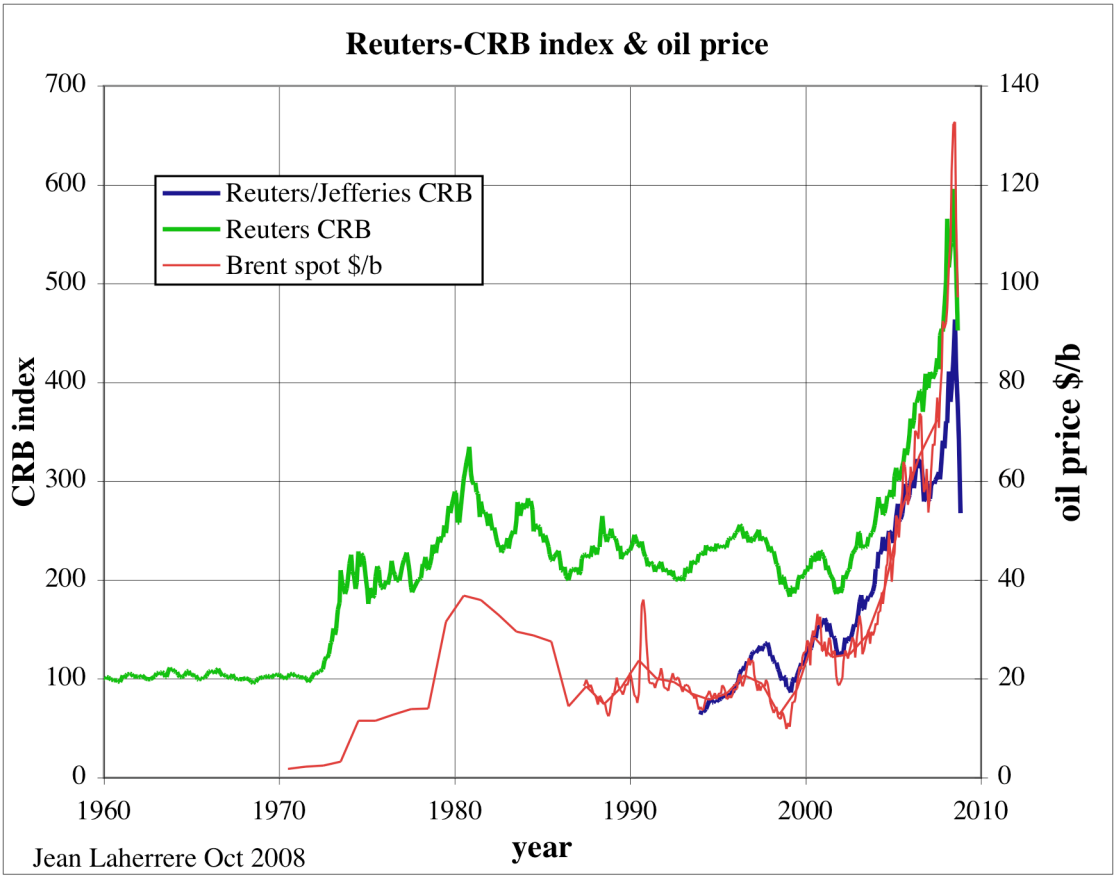
Figure 12: E&P cost required for a return on capital from Goldman Sachs 2007



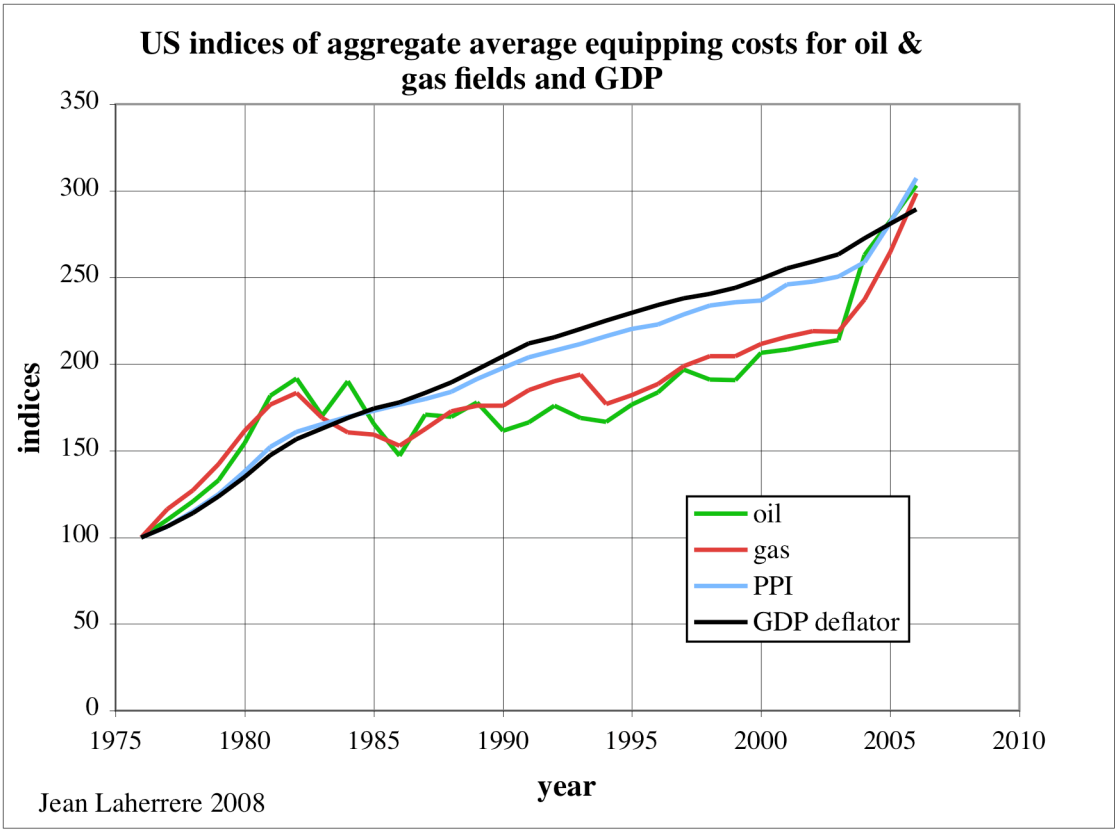
TOTAL has declared that their tarsands projects need 90$/b and deepwater 70 $/b to achieve a ROR of 12%, few years ago their breakeven point was 20 $/b!
US natural gas breakeven point has increased from 4 $/Mbtu in 2002 to 8 $/Mbtu in 2007 (Credit Suisse) close to NG US price!
For the country the breakeven (positive budget) point is reported to be: Qatar 24, Kuwait 33, Libya 47, Saudi Arabia 49, Venezuela 80, Iran 90, Iraq 110 $/b.

-**commodities price index**

the breakeven point depends mainly upon services and commodities cost.
The Reuters/Jefferies CRB index is a commodity price index and it has increased sharply since 2001 but falling for the last months.
Figure 13: Reuters commodities index and oil price



It is likely that oil services cost will decline also as the breakeven point.
It is interesting to find that the US oil & gas fields costs which raised sharply since 2003 in fact are in line with GDP increase since 1976
Figure 14: US oil & gas fields costs compared to GPD since 1976



-2-Natural Gas = NG

-data

Natural gas is different from oil because

-energy content range is larger

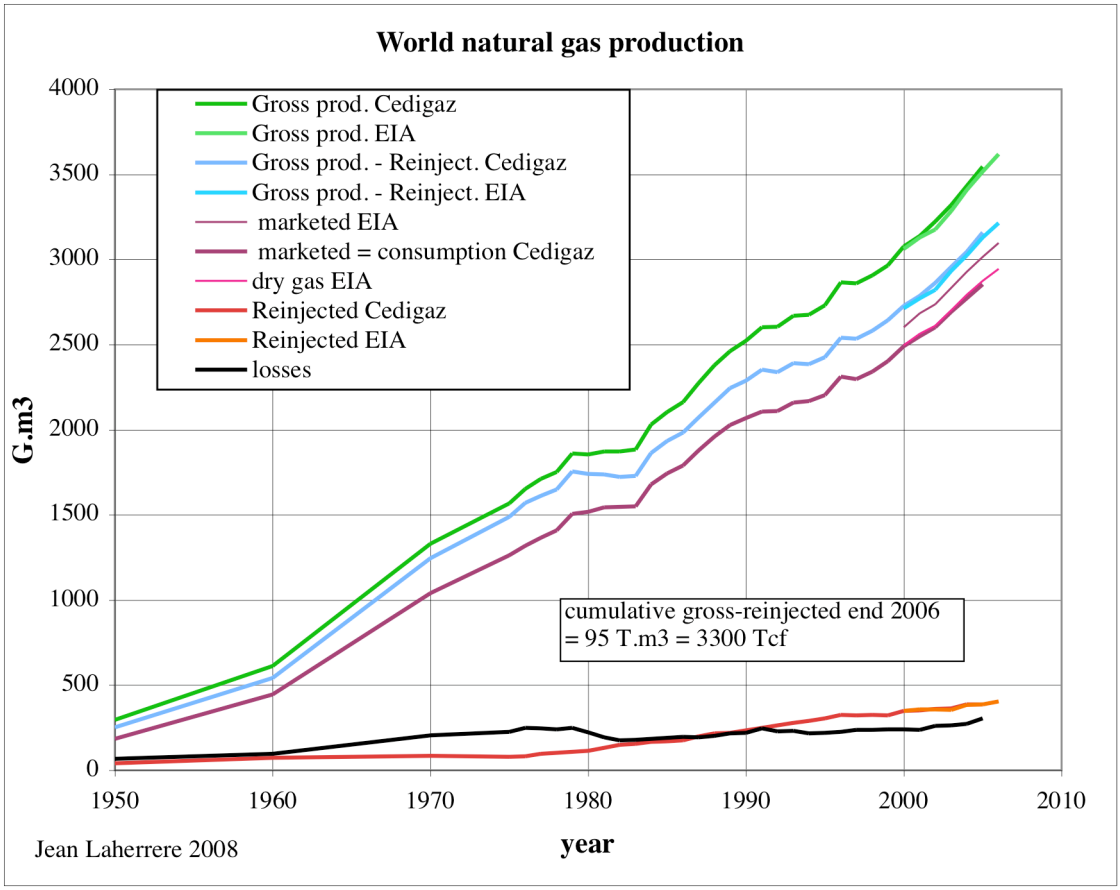
-transport cost is 10 times higher, so there are 4 NG markets against one global for oil market and many gasfields are stranded in remote places

NG gas in Ecuador is 62% more energetic than in Colombia. The heat content varies from 800 to 1300 Btu/cf with a median at 1025 Btu/cf

There is the same ambiguity on natural gas production data: unreliability for reinjected, flared, marketed and dry because numbers vary with sources.

Flared volumes vary between official number and measures from satellites (NOAA site)

Figure 15: world natural gas production



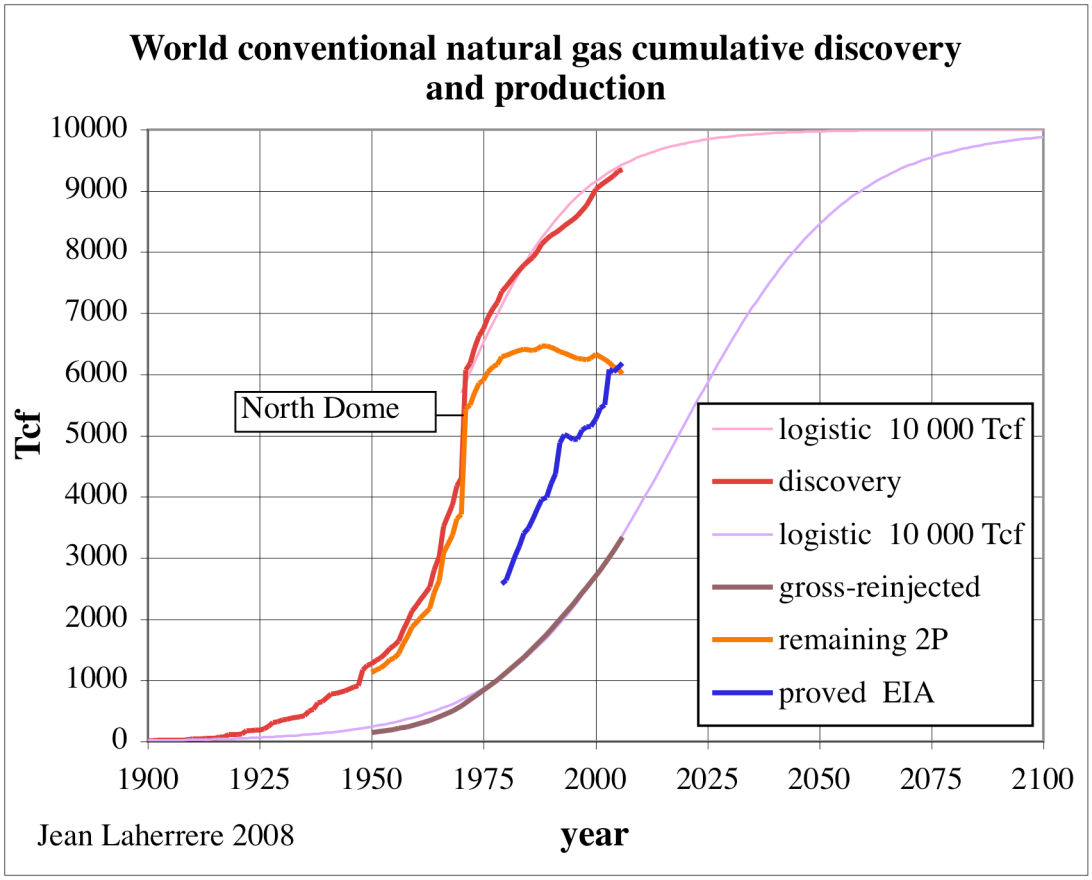
The question of how much of the reinjected gas could be fully recovered in the future is still unanswered. In our study we assume that 100% will be recovered after reinjection.

-world forecast

Using (like for oil) technical databases to plot the cumulative **conventional NG** discovery, the past can be easily modelled with a S curve for an ultimate of 10 000 Tcf = 10 Pcf. The YET (yet to find) is less than 10 % of the present discoveries (like for oil).

Cumulative production forecast fits also well with a 10 Pcf ultimate

Figure 16: world conventional natural gas **cumulative discovery and production**

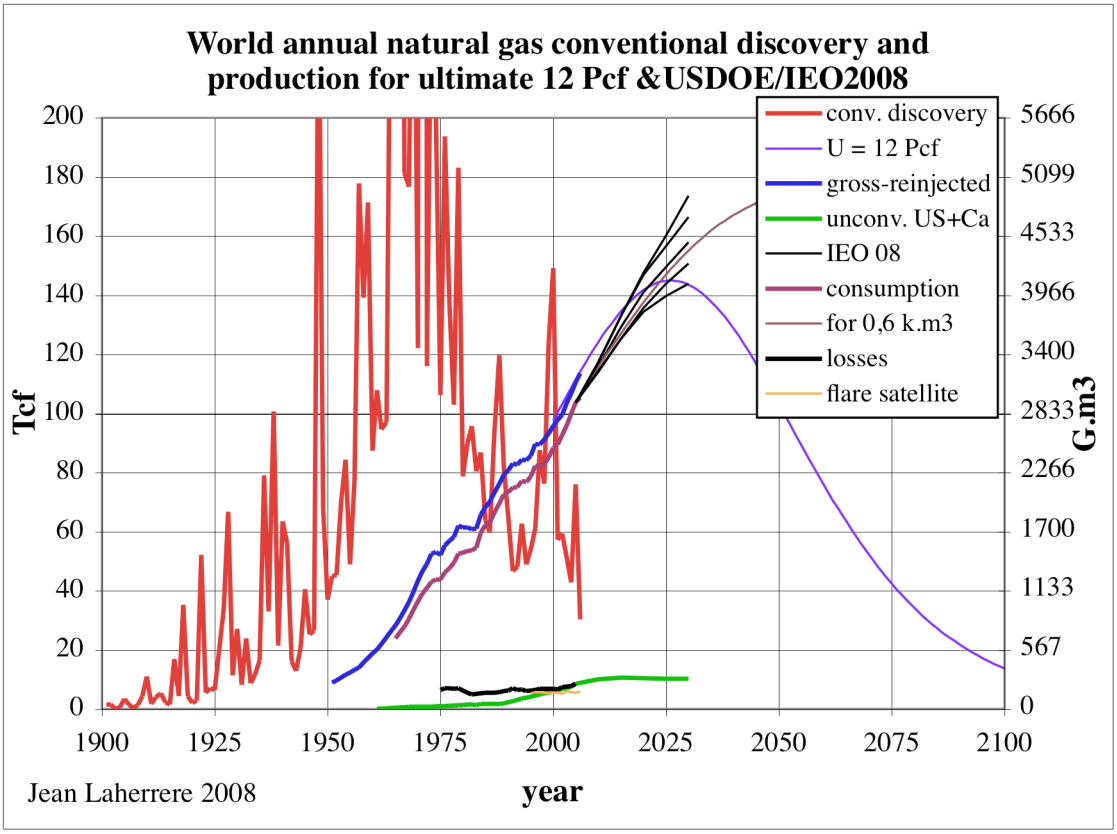


The remaining technical data (in orange) is, as for oil, completely the opposite of the political data (EIA) (in blue) as for trend, but in agreement for 2006 value (in contrary with oil)

If the ultimate for conventional NG is estimated at 10 Pcf, unconventional gas ultimate is harder to guess, but the official forecast for US unconventional NG is far from the published volume of resources and we estimate the unconventional ultimate at 2 Pcf, for a total global of 12 Pcf.

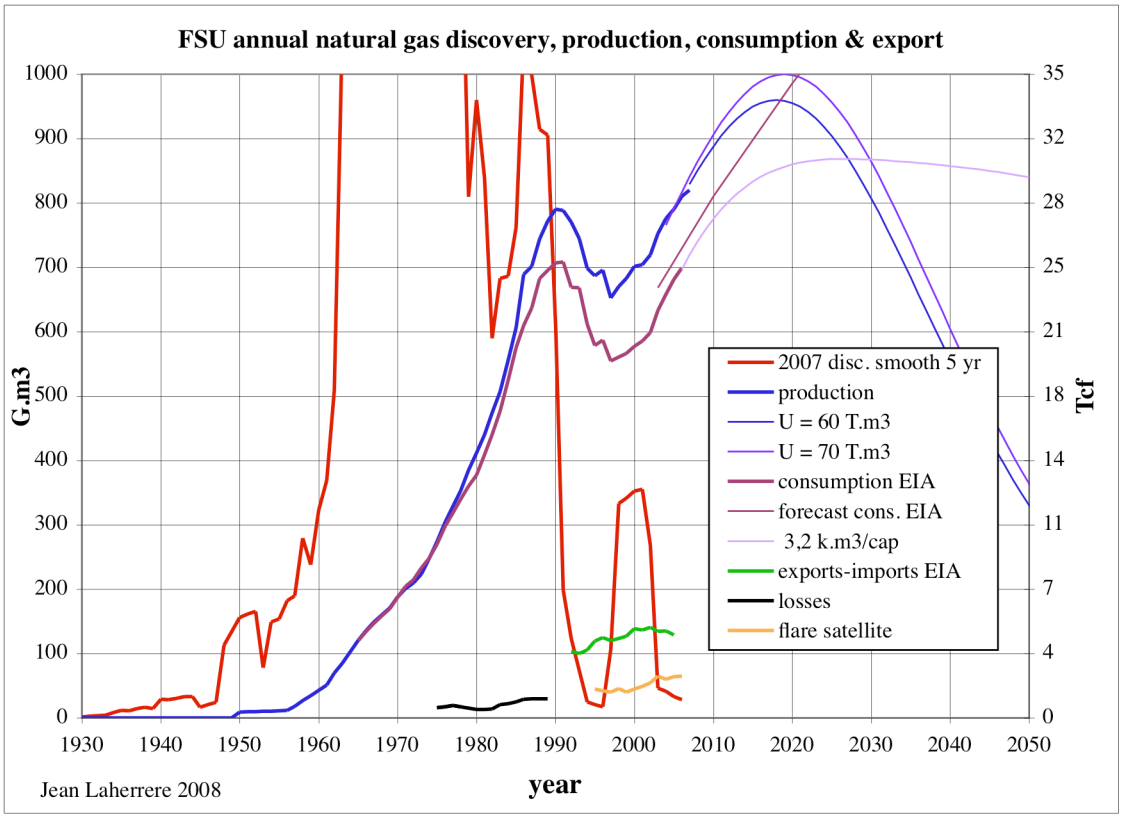
The annual conventional discovery & gross-reinjected production are plotted with forecast for U = 10 & 12 Pcf. The NG peak is around 2025 at around 140 Tcf/a. NG consumption is also forecasted from population UN forecast assuming a NG consumption per capita at 0.6 k.m3/a. NG peak in 2025 will oblige the world to decrease NG consumption. EIA/IEO 2008 reference production is in agreement with our consumption forecast, but low economy and high price forecast for 2030 are close to my NG peak.

Figure 17: world conventional natural gas **annual discovery and production** for an ultimate of 12 Pcf and USDOE/IEO 2008



But there are three main NG markets in the world being North America, Europe and Asia Pacific, a fourth market is starting in South America.
The problems of NG supply will occur soon in Europe, because the uncertainty of the NG suppliers, in particular Russia on which Europe is counting too much.

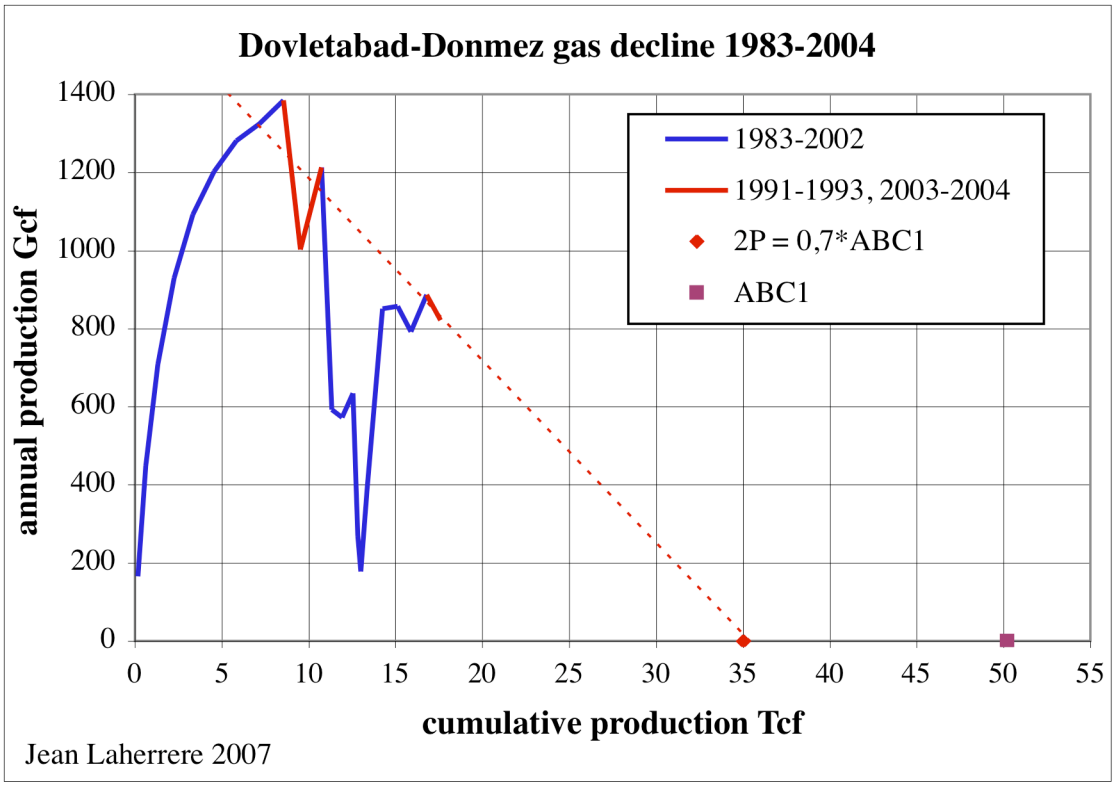
But last year I presented the production of the main gas exporters to Europe. The FSU ultimate was estimated to be 60 T.m3 (45 T.m3 for Russia), where consumption reaches production around 2025, leaving no export to Europe or China.
But there is a recent drastic increase of gas reserves in Turkmenistan and the FSU ultimate could be now taken at 70 T.m3.
Figure 18: FSU annual gas discovery, production, consumption and export



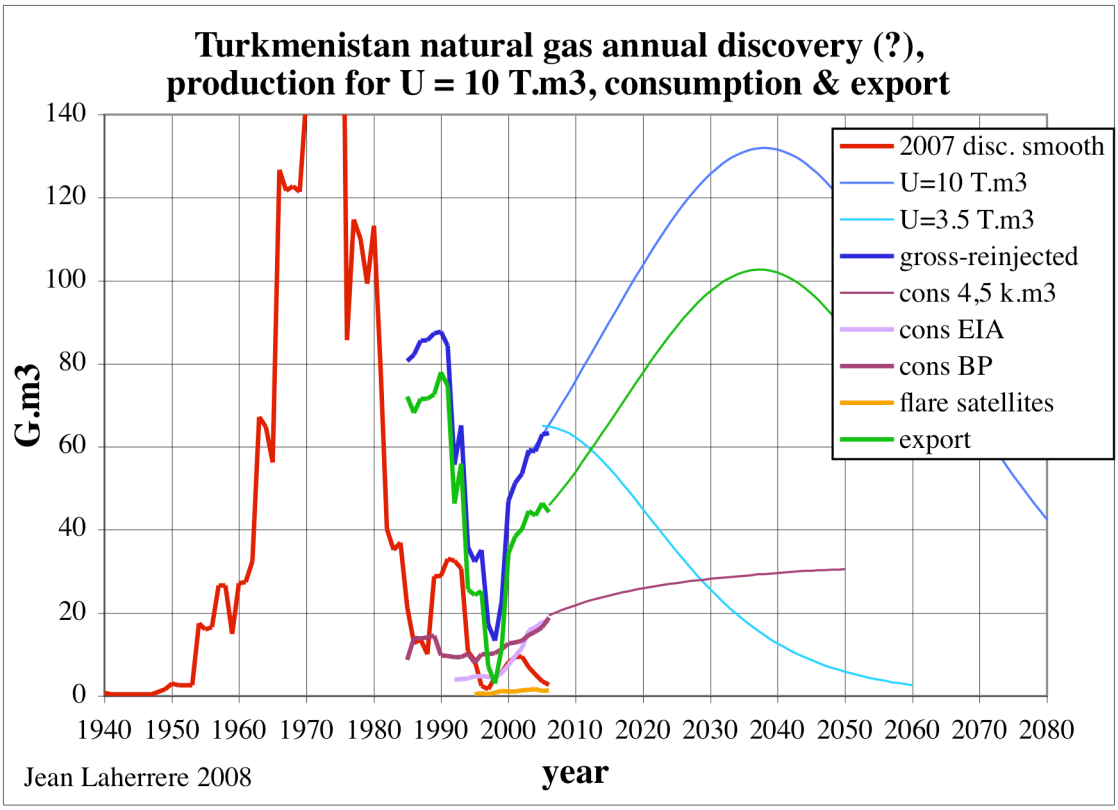
For the next decade production and consumption seems to run in parallel, leaving no much room for export increase.

Up to know Turkmen gas reserves were a State secret and the largest gasfield of Dovletabad has no reliable decline to check the reported ABC1 reserves of 50 Tcf

Figure 19: Turkmen Dovletabad gas decline 1983-2004

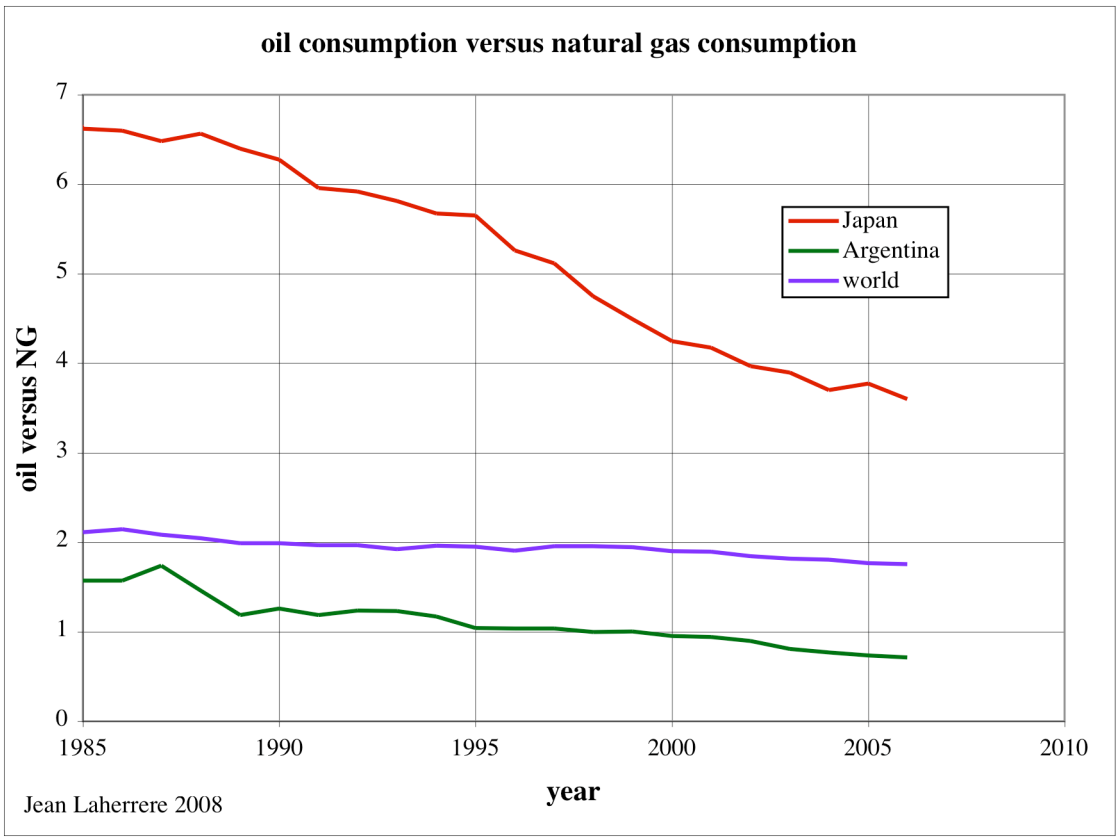


A recent audit by Gaffney, Cline & Associates on Turkmenistan (indirect release) has increased greatly the reserves of a huge gasfield now named South Yoloten-Osman (1800 km2; 600 m pay) estimated at 250 Tcf (bigger than Shtokman, Urengoy? and 5 times bigger than the previous largest field Dovletabad), when last year Yoloten Gunorta (found in 1970) (now South Yoloten) was estimated at 1,3 Tcf and Osman (2007) 25 km apart about 1 Tcf, being separate.
Yoloten was appraised under a 3 yr 2006 contract with China National Petroleum Corp (CNPC) to drill 12 wells, finding deeper pay and surface extension.
Turkmenistan which presently produced annually 70 G.m3/a is committed to supplying up to 40 G.m3/a to China through a pipeline currently under construction that will be put into service in 2009 (if everything goes as planned), in addition to 50 G.m3/a to Russia and 8 G.m3/a to Iran
In a presentation in Prague (April 2008) I displayed Turkmen NG production for an ultimate of 3,5 T.m3. With the new audit the ultimate has to be increased to 10 T.m3, making the gas peak around 2040 (instead of 2008)
Figure 20: Turkmen natural gas annual discovery, production, consumption & export



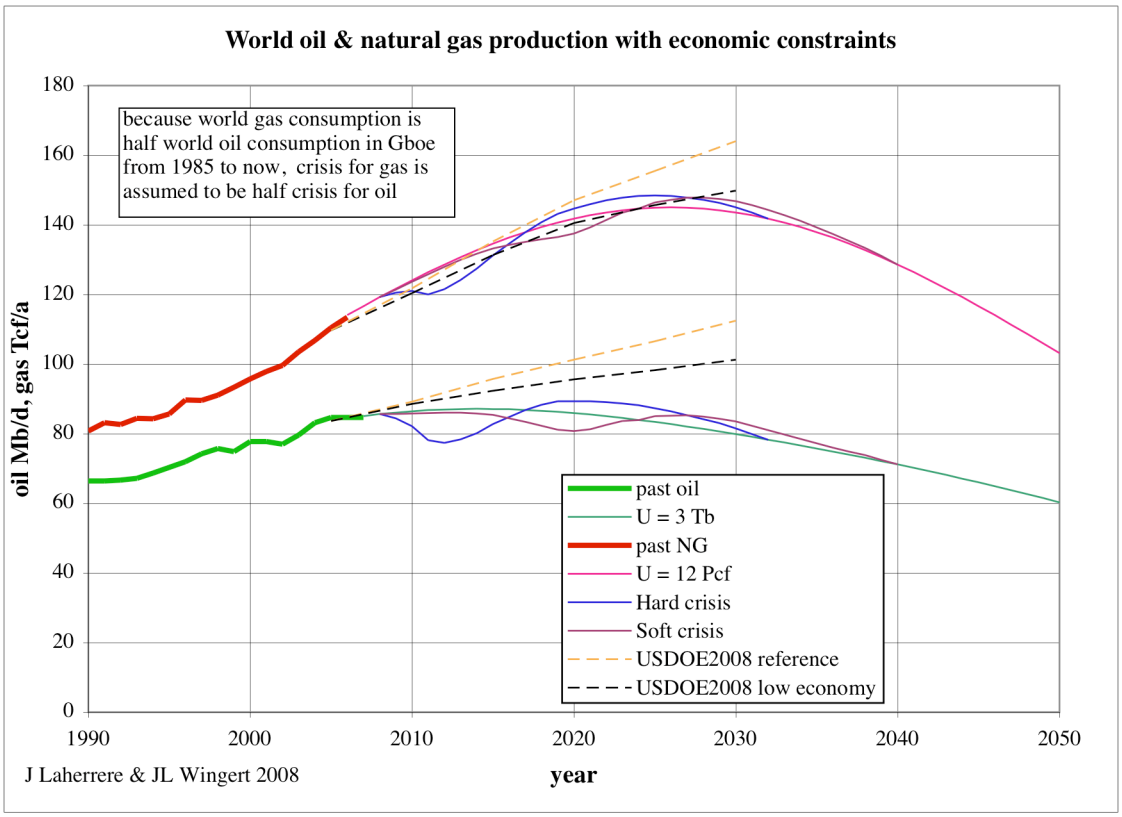
This Turkmen gas reserves increase is good news for China but maybe not for Europe.

-Above-ground constraints
In ASPO VII in Barcelona (20 October 2008) with JL Wingert we have estimated a hard and soft scenarios from the study of economic crisis of oil consumption in Argentina, Japan and the world. In order to apply a economic scenario for world gas, the plot of gas consumption in Gboe was compared to oil consumption.
Figure 21: oil consumption versus natural gas consumption (in Gboe) in Japan, Argentina and world 1985-2006



The world gas consumption being about half of the world oil consumption, we assume that the scenario to apply to gas should be half of the scenario applied to oil consumption.

Figure 22: world oil and gas production (consumption) forecasts with economic constraints for the likely ultimates 3 Tb & 12 Pcf



The oil plateau could extend up to 2030 being between 80 and 90 Mb/d.

The gas plateau could extend from 2020 to 2030
The USDOE/EIA WEO 2008 reference and low economy scenarios are plotted. The low economy is close to my forecast for gas and for oil on the way to come to mine next year ?

-Conclusions
Drastic increase in Turkmen gas reserves lately is due to lack of transparency.
Oil and gas data are still unreliable when the world does not know where it is going and needs good information.
The world needs to agree on good definitions for production & reserves and open release of field data (like it is done in UK & Norway).
Confidentiality profits only politicians.
The financial crisis will be followed by a major world economic crisis.
Oil production will be a bumpy plateau for decades below 90 Mb/d with chaotic prices.
Gas production will peak around 2025 at less than 150 Tcf/a
Official agencies are trending towards more pessimistic scenarios close to ASPO .