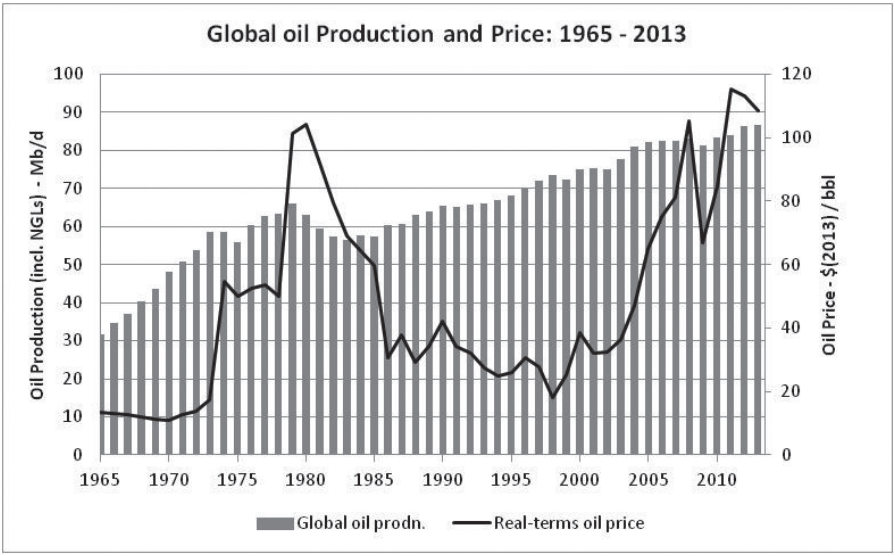
Charts

As mentioned in the Editorial, it is the intention to include in each issue of this journal a small number of charts - usually from already-published sources - chosen as being particularly informative. In this issue five charts are included. These depict:

- Recent global oil production, and real-terms price;
- Global oil potentially available, by category and production cost;
- Global oil discovery and production;
- Hence reserves; comparing 1P to 2P data;
- Use of a 'creaming' curve to estimate a region's URR.

Chart 1. Global Oil Production and Real-terms Price, 1965 – 2013.



Notes:

- Global 'all-oils' production: vertical bars, left scale.
- Real-terms oil price ($2013): line, right scale.
- Production data include all fossil oils plus NGLs; but exclude GTLs, CTLs and biofuels.

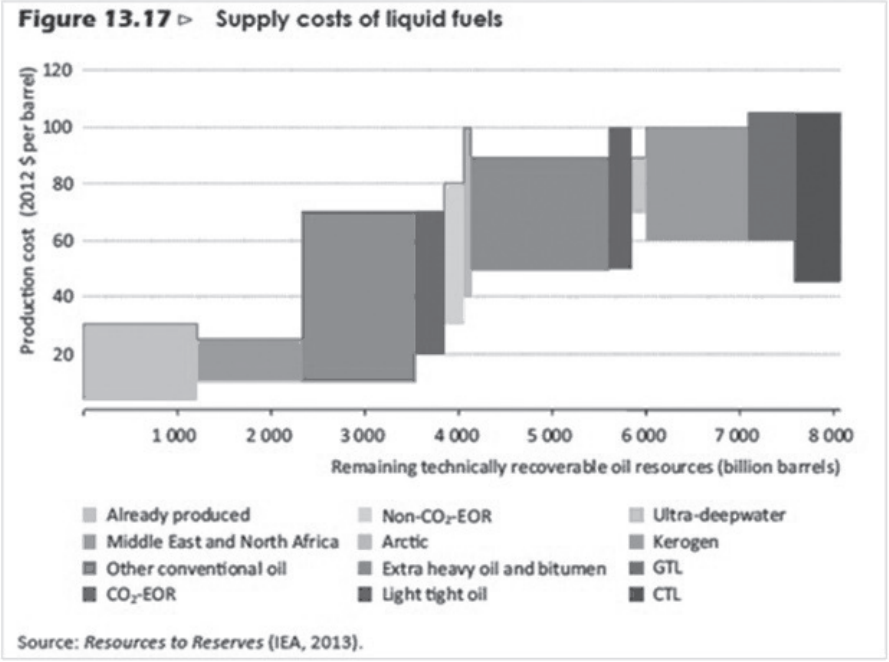
Comments:

- Production has shown weak growth since 2005.
- Over the last six years the average real-terms price of oil has been roughly that of the 1978 'oil shock', and approximately twice that of the 1973 shock.
- BP *Statistical Review* data show that for over four decades *prior* to 1973, the real-terms oil price averaged about $15/bbl; and global production grew rapidly, at up to ~8% a year.

- Once the shocks of the 1970s were passed, the oil price collapsed, but only down to about twice the pre-1973 level; averaging a real-terms ~$30/bbl over the following 15 years or so (1985 to 2000). This was because now the marginal barrels to meet demand were the more expensive oils from the North Sea, Alaska, offshore Africa, etc. As a result of this doubling in real-terms price, growth in oil production was considerably less, averaging somewhat under 2% a year.
- More recently, with the oil price between $50/bbl and $100/bbl, production growth (of all-liquids) has been lower still, below 1% a year, and where now the marginal barrels are the additional conventional oil itself brought on by the high price, plus increasing production of the generally expensive non-conventional oils.
- Note that the current high price cannot be driven *fundamentally* by growth in demand alone as is often claimed (citing e.g., rapidly rising demand in China & India). This is because in the over a century from 1861 to 1973, the average price of oil *fell* while global oil demand for oil grew rapidly. Today's high price thus needs an explanatory factor in addition to demand. This factor is the declining availability of conventional oil, as the papers in this issue have explained.

Source: BP *Statistical Review of World Energy,* 2014 edn.; graph based on an original by E. Mearns.

Chart 2. Quantities of Oil available by Category vs. Production cost:



International Energy Agency (IEA) plot of Global remaining technically recoverable volumes of oil available, by category (in Gb) vs. Production cost ($2012/bbl).

Notes:

- EOR: Enhanced oil recovery. MENA: Middle East and North Africa. GTL: Gas to liquids. CTL: Coal to liquids.
- Volumes of oil potentially available are shown along the x-axis, *not by the area* indicated.
- The first six categories of oil (up to 'Arctic'), plus also 'Ultra-deepwater', refer to mainly conventional oil.
- The other five categories are usually classed as either non-conventional oils (Extra heavy, Light tight and Kerogen) or as 'other liquids' (GTLs & CTLs). The plot does not include biofuels.

Comments:

- In terms of the current 'peak oil is dead' debate, note that the IEA's assessed global quantity of recoverable shale ('light-tight') oil is rather small, at ~250 Gb; i.e. about 8 years' of global supply, giving - *very roughly*, and if only this oil were used - about 4 years' to its peak.
- The wrong way to read a chart like this was that of the UK's Dept. of Trade and Industry which said, based on an earlier version of the chart, that "There is more than enough oil available to meet foreseeable demand". And this view might seem natural enough: after all there *is* ~ 7 000 Gb of recoverable oil of all types remaining, with a century-and-a-half of global production only having produced ~1 250 Gb.
- But this view is naïve. The correct way to read the chart is as follows:

  (a). Understand the 'mid-point' peak of *conventional* oil production, so on these data expect the global peak of conventional oil when ~1 875 Gb has been produced (i.e., half of the ~3 750 Gb URR resulting from summing 'already produced,' MENA, other conventional, Arctic, plus ultra deepwater; and excluding EOR, as this usually comes on only late in a region's life). At the current production rate of ~30 Gb/yr., and with 1 250 Gb already produced, the global conventional oil 'mid-point' peak is then expected roughly 20 years from now, depending on the rate of demand growth.

  (b). But then recognise that production of much of the MENA oil will not increase significantly due to resource-national reasons.

  (c) So look instead for the 'mid-point' of *total non-MENA* conventional oil. On these data this occurs at 1 325 Gb produced (half of ~2 650 Gb), i.e. in about 5 years' time.

  (d). Recall also, from the papers in this issue of the journal (and data elsewhere), that a global URR of 3 750 Gb for conventional oil (incl. NGLs) is judged by some analysts as being on the high side, at least as far as derived from extrapolated discovery, and hence in terms of driving the date of peak. These analysts estimate the total production of conventional oil (inc. NGLs) to 2100 (roughly equivalent to the URR) as being between 500 Gb and 1 000 Gb lower than the IEA 3 750 Gb number.

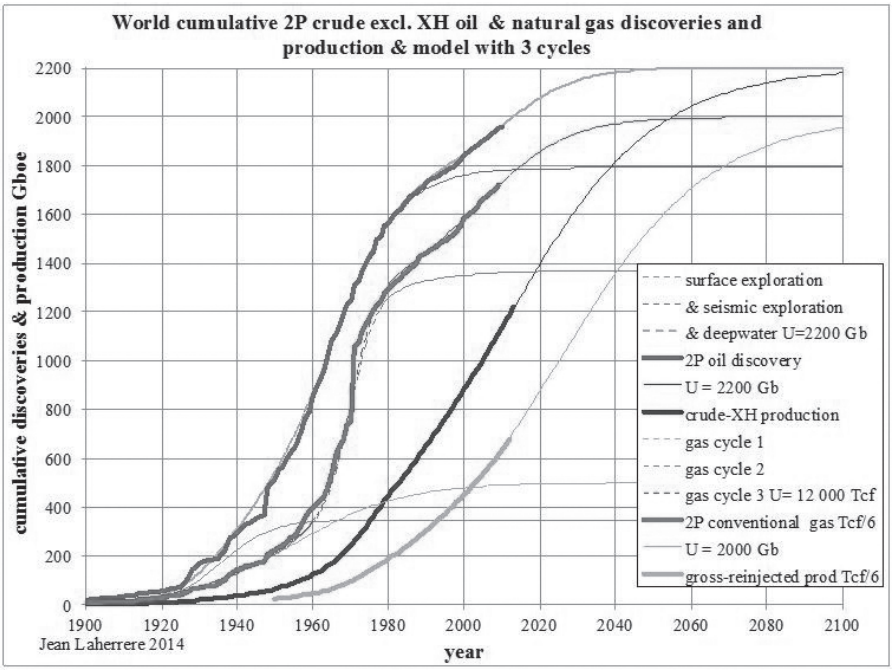
  (e). Hence conclude, correctly, that the steep rise in the oil price over

recent years has been because of the restricted increase in global conventional oil production resulting from proximity to this peak, which in turn has forced the world to obtain its marginal barrels of oil, to meet the growing demand, from the expensive oils shown to the right of the chart.

(f). And recognise that these 'other oils' tend to have poor energy-return-on-energy-invested ('EROEI') ratios (indeed, a major factor in why they are costly to produce); and face other constraints on their production, such as permitting, water requirement, CO_2 emissions, and volume of waste if produced by mining.

Source: IEA *Resources into Reserves*, 2013.

Chart 3. Plot by J. Laherrère: Global Oil & Gas 2P Discovery and Production, historical data & forecast, 1900 - 2100.



Notes:

- Leftmost line: Laherrère's judgement of 'most probable' *backdated 2P cumulative global discovery* data for crude oil less extra heavy oil (the latter mainly Athabasca tar sands and Orinoco oil), and does not include NGPLs.
- Next left line: Corresponding data for gas, calculated as Tcf/6.
- Next left line: Cumulative global production of crude oil less extra heavy oil. (EIA data includes condensate).
- Rightmost line: Cumulative global production of gas, Tcf/6.

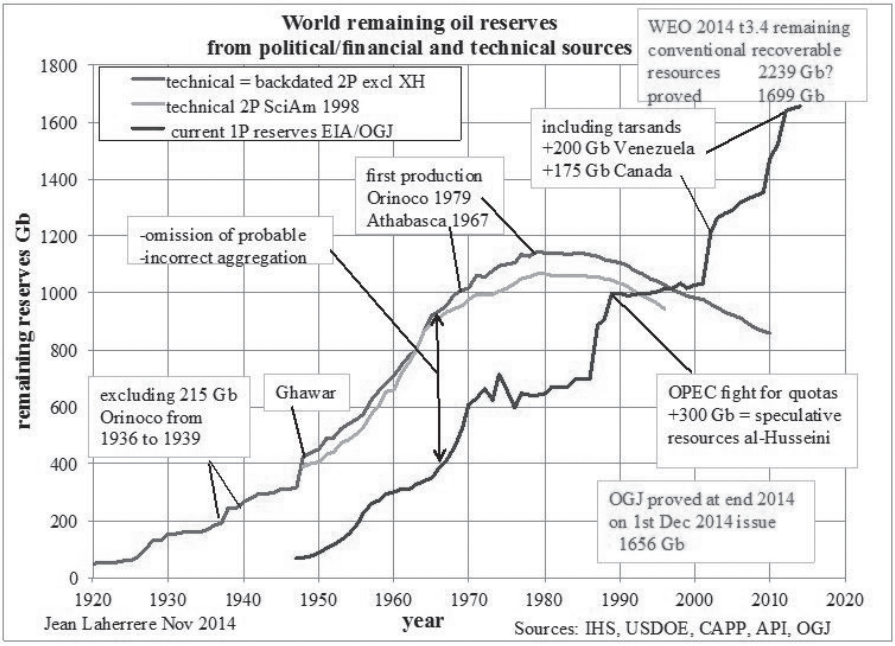
Comments:

- The 2P discovery data reflect data from industry scout sources, but reduced by: 300 Gb to allow for Laherrère's view of overstatement of

the OPEC Middle East original reserves data (as confirmed by Sadad Al-Husseini, former VP Aramco, at the 2007 'Oil & Money conference', London); by 30% of the FSU data (~100 Gb) to allow for the datasets ABC1 holding probably closer to 3P than 2P data (as indicated by field decline plots and by Gazprom audits in annual reports); and by 200 Gb to allow for Orinoco 2P discovery data reflecting non-conventional oil.

- As the chart indicates, Laherrère's view of the likely extrapolation of the backdated cumulative 2P discovery curve indicates a 'medium-term' global URR for 'conventional' crude oil (including condensate) less extra heavy of 2 200 Gb. On this basis, and using the 'peak at ~mid-point' rule, the 'expected' date of peak would be about the year 2010, having a cumulative production of 1 100 Gb; in reasonable agreement with the apparent actual date of this peak.
- Alternatively, one can use the 'PFC Energy '60%' rule, and estimate the global peak date, for conventional oil ex NGLs. On the basis of the data shown here, 60% of current 2P discovery (at 2,000 Gb) is 1,200 Gb, which estimates the date of this peak slightly later, but still in the past, at about the year 2012.

Chart 4. Plot by Jean Laherrère: World Remaining Oil Reserves: Comparison of 2P with 1P data, 1920 – 2014.



Notes:

- Laherrère's view, from sources listed, of the difference between *global backdated proved-plus-probable* ('2P') oil reserves, estimated from oil industry scout data, and *current-basis proved* ('1P') global oil reserves as given by public-domain data.
- Leftmost line (exhibiting a peak in 1980 at ~1,150 Gb): Laherrère's estimate of global 2P backdated oil reserves, 1920 to 2010, excluding extra-heavy oils (tar sands and Orinoco oil). Data are from industry scout databases as listed, but adjusted by removing 300 Gb from Middle East reserves, and 30% of FSU reserves, for the reasons given in Chart 3, above.
- Next leftmost line: The same data, but as reported in the article: *The End of Cheap Oil* by Campbell & Laherrère, *Scientific American*,

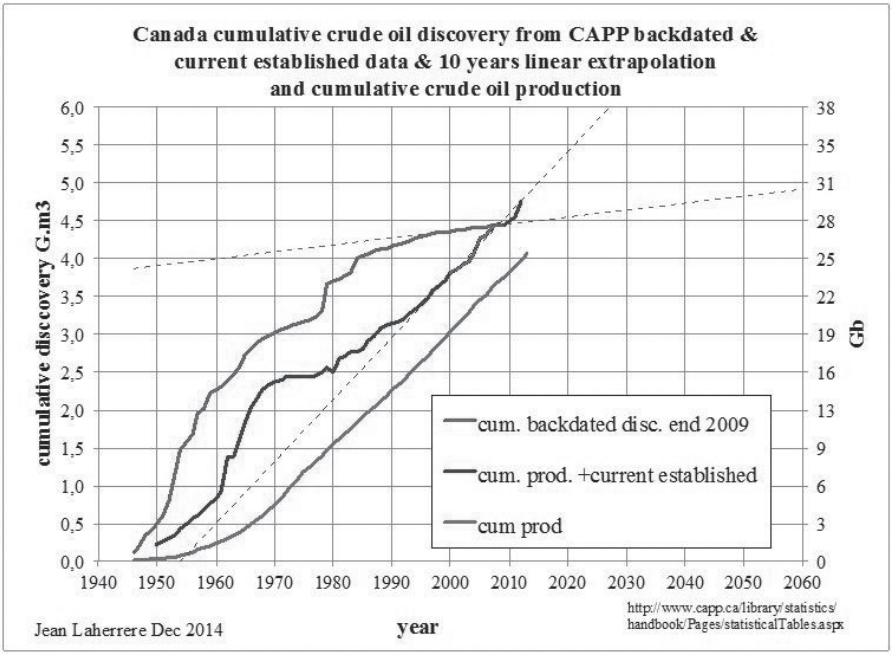
March 1998.

- Rightmost line: Data from US EIA and *Oil and Gas Journal* (OGJ) of public-domain current-basis global 1P oil reserves, 1947 to 2014, *including* extra-heavy oil.

Comments:

- The estimated backdated 2P global oil reserves, excluding extra-heavy oil, peaked in 1980.
- The global 1P oil reserves, also excluding extra-heavy oil, rose consistently to ~1997, to roughly match the 2P data (implying OPEC 1P overstatements roughly matched the industry global probable reserves); and increased subsequently, in part due to adding in Canada and Venezuela extra-heavies.
- On the public-domain 1P reserves data Laherrère notes that: 'The most recent figure available is that of 1 656 Gb, posted on internet on Nov 24 2014, of the OGJ issue dated 1st December 2014, and relating to reserves as the 1st of January 2015. These data are not measurements but guesses, and in fact political statements, because technical estimates cannot be delivered before March 2015. The OGJ data report 106 countries, of which 66 countries showed no change in their proved reserves from the previous year. (Within Eastern Europe and FSU, this was 19 countries out of 20). Hence only 40 countries showed any change in their 1P data. The countries that showed no change include those where assembly of technical estimates of proved reserves had not yet been carried out, as the year 2014 was not then completed. Note that in countries like Iran, Iraq, Qatar, Saudi Arabia & UAE the proved reserves data are used as a basis in quotas negotiations.'
- [For comparison of the 2P reserves data shown here with IHS Energy's 'all-oil' 2P reserves data, go to Miller and Sorrell (*The future of oil supply*. Phil. Trans. R. Soc. A **372**: 20130179, 2014) and subtract the graphed data for cumulative production from the corresponding graphed data for cumulative 2P discovery.]

Chart 5. Plot by Jean Laherrère: Creaming curve for Canadian conventional oil; Extrapolation to an estimated URR; and Comparison of backdated discovery vs. non-backdated discovery data.



Notes:

- Leftmost line: Backdated industry proved-plus-probable data for conventional oil discovery in Canada, to end-2009.
- Next leftmost line: The corresponding public-domain non-backdated discovery data to end 2013, generated by adding 'current established' (remaining) reserves to cumulative production.
- Rightmost line: Cumulative production.
- Data sources: As listed on the chart.

Comments:

- Estimating the total amount recoverable of conventional oil or gas that

will have been produced by the end of production for a region, known as the region's ultimately recoverable resource ('URR'), can be done in a number of ways. One of these is the 'creaming' curve method, which plots cumulative discovery against the cumulative number of New Field Wildcats (NFWs). The latter are exploration boreholes which are looking for new fields, contrary to exploration appraisal wells. The trend-line produced is known as the *Creaming Curve* for that region, and this can be extrapolated, sometimes using several cycles to reflect distinct phases of discovery, to give an estimate of the region's URR.

- A similar curve (often also called the creaming curve) can be produced by plotting cumulative discovery vs. date. This is usually less useful than vs. NFWs, as discovery effort may change with time, for example when the oil price is low, or political restrictions are imposed on exploration, and the discovery trend is less clear. Nevertheless, where discovery data vs. NFW drilling are not available, a 'creaming curve' vs. date can still give a good indication of URR (subject always to geological information being included of the chance of new plays in a region and their likely prospectivity).
- Here the creaming curve vs. date for Canada is shown. As this indicates, in the case of Canada's conventional oil, there have been two main cycles of discovery, reflecting discovery in the Western Canadian Basin and in the Eastern Offshore. As also shown, the trend of the line for backdated industry proved-and-probable ('2P') discovery data points to a total URR for Canadian conventional oil of around 32 Gb (billion barrels).
- By contrast, if public-domain non-backdated ('current') data are used, a picture of ever-advancing discovery emerges. Not only is this very misleading, but also no useful estimate of the region's URR can be derived.
- Laherrère notes: 'It is impossible to update this graph because CAPP has stopped reporting backdated reserves beyond 2009, and the same for New Field Wildcats. This is a shame: [perhaps] they do not want to show disappointing real data. Note that the graph of discovery versus date has a crooked section since 2010 because of tight oil.'

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