A Review of some Estimates for the Global Ultimately Recoverable Resource (‘URR’) of Conventional Oil, as an Explanation for the Differences between Oil Forecasts – Part 3

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Abstract

This paper is the final part of a three-part paper examining the link between estimates for the size of the global ultimately recoverable resource (‘URR’) of *conventional* oil and the differences between forecasts for global ‘all-oil’ production from different organisations.

Firstly in this paper the historical estimates of global URR by category of oil contained in Hubbert’s 1949 *Science* article are presented, and are compared to later estimates he used. Then an approximate current minimum value is given for the URR of global *conventional* oil based on three recent ‘mainstream’ oil forecasts, those from ExxonMobil, BP, and the IEA. A table is then presented that summarises the global URR estimates, by category of oil, covered in all three parts of this paper.

Finally, the difference between current URR estimates for global conventional oil is examined in terms of those estimates which are broadly in line with global proved-plus-probable (‘2P’) oil *discovery* data (in some cases, with adjustment for assumed data quality), and those estimates which differ significantly from this discovery trend. The paper concludes by suggesting that oil forecasts which use (or generate) global conventional oil URR estimates roughly in agreement with global 2P conventional oil discovery data are the more likely to be correct.

1. Introduction

This is the final part of a three-part paper examining the link between the estimated size of the global ultimately recoverable resource ('URR') of *conventional* oil and the results of forecasts of 'all-oil' production which have used these values. (Apologies are due, in that initially it was indicated that this paper would comprise only two parts, rather than three.)

The first part, Bentley (2015a), looked at the difference between oil forecasts from different organisations; firstly those forecasts covered by the UKERC *Global Oil Depletion Study* (Sorrell et al., 2009), and then in summary form a range of more recent forecasts. In order to understand the large difference between these forecasts, it was suggested that the primary factor is the difference between the values assumed for the global URR of *conventional* oil.

To examine this view, that part of the paper then presented historical URR estimates made between 1956 and 2005 for different categories of oil, and also the range of global URR estimates for *conventional* oil generated by the US Geological Survey (USGS) for the years from 1991 to 2012. It was shown that for many years the estimates for the global URR of conventional oil (less NGLs) were mostly in the range 1800 – 2500 Gb; and that the USGS mean estimates (also less NGLs) over the period examined were of a similar order, provided they did not include allowance for reserves growth.

However, if reserves growth were included in these USGS estimates (which was the case from the year 2000 onwards) the corresponding mean global URR values for conventional oil (and here, plus NGLs) was 3345 Gb in the 2000; and 3850 Gb (approximately) in 2012.

It was then shown that most 'mainstream' oil forecasts after the year 2000 used estimates of URRs, sometimes for conventional oil and sometimes for 'all-oil', that were either actually, or very probably, based on these USGS estimates of the global conventional oil URR.

The second part of the paper (Bentley 2015b) presented a number of more recent estimates of global URR, here by category of oil. These were estimates from the US EIA (2013 and 2015), the IEA's '*Resources into Reserves*' study (2013), IEA 2014 data, and URR estimates from IHS CERA (2014), Campbell (2015), Globalshift Ltd. (Smith, 2015), Laherrère (2015), and Miller (2015). Table 13 in that part of the paper summarised these URR values; where, for conventional oil plus NGLs *plus* reserves growth, they ranged from ~2500 Gb up to 4350 Gb. Not surprisingly, those forecasts which saw no production peak for 'all-oil' within their time horizons assumed higher URR values, while those that saw a near or medium-term 'all-oil' peak assumed lower ones.

In this third part of the paper we first return to history, and present Hubbert's 1949 global URR estimates, by category of oil, that were published in *Science* (Hubbert, 1949). Then we give an approximate current *minimum* value for the global URR for conventional oil as implied by extrapolation of three fairly recent 'mainstream' oil forecasts; those from the IEA (2011), BP (2015) and ExxonMobil (2015). Then a summary table is given of URR oil estimates covered in all three parts of this paper. This leads to the question: Which URR estimate is the most reliable, in terms of predicting future global oil production? This is discussed in the final section in this paper.

2. Difference between Forecasts

The reason for examining this topic of URR estimates is because oil forecasts from different sources give significantly different predictions.

This was particularly the case only a few years' back, see the report from the US National Research Council's *Trends in Oil Supply* workshop (Zucchetto, 2006), or that from the UK Energy Research Centre's *Global Oil Depletion* study (Sorrell *et al.*, 2009).

But the problem still exists today, with, for example, current forecasts for the global production of 'all-liquids' varying as follows:

- Forecasts which see the global production of 'all-liquids' as reaching a maximum within less than a decade, and then declining; e.g., the forecasts of Campbell (2015), or Laherrère (2015).

- Those forecasts which see production of this class of oil as reaching a maximum, but not until perhaps 2025 to 2035, and then declining; e.g., Smith (2015), Miller (2015).

- Those forecasts which see no maximum in the global production of all-liquids out to the end of their forecast horizons, typically out to 2035 to 2040. This group tends to be forecasts from the more 'mainstream' oil forecasting organisations; see for example the charts of forecasts by the IEA, BP and ExxonMobil in *The Oil Age*, Vol. 1, No. 2.

There are a number of reasons for these wide differences between forecasts, but one of the main ones, already identified by the UKERC 2009 *Global Oil Depletion* study, is the size assumed by these forecasts for the global ultimately recoverable resource ('URR') of *conventional oil*. (To a lesser extent the difference between forecasts also depends on the rates-on-stream assumed for the non-conventional oils, and for other liquids.)

It is important therefore to understand what URR numbers the various forecasts have used (or their forecasts imply). For this it is necessary to be clear about the definitions used for conventional and non-conventional oil, and for 'other liquids', and this was covered in Part 1 of this paper.

It is also important to understand what forecasters mean by 'URR'. This was also covered in Part 1, but here we recapitulate two key ideas:

- For most forecasters, 'ultimately recoverable' does not signify some truly 'ultimate' value, as who knows what future demand there may be for oil, nor what oil recovery techniques might be developed in the very long term. Instead, for most forecasters, URR signifies the quantity of a particular class of oil that will have been produced from a specified region by some distant future date, such as by 2070 or 2100.
- Secondly, in some modelling methodologies (such as those of Campbell and Laherrère) a URR value is first estimated from other determinants (such as a region's discovery history), and then this URR determines the forecast that is made for the region's production. In other methodologies the forecast is first generated (for example by forecasting production from known individual fields and from fields assumed to be found in future), and then a resulting URR can be calculated by summing past and future production as given by the forecast.

Note that some URR estimates (such as those from the USGS) are not used by the organisation generating them, but are used in forecasts by other organisations, such as the IEA and EIA. In other cases, URR estimates are both generated by, and used by, the organisations or individuals making the forecasts.

Finally, note that a more extensive list of past estimates of global URR values, plus an excellent commentary, is given in the paper by Andrews and Udall (2015) in a previous issue of this journal.

3. URR Estimates Published by Hubbert in 1949

In this first section of this paper we return to the topic of early estimates of the global URR for oil, and give here the data quoted by Hubbert in an article in *Science* (Hubbert, 1949). These data were overlooked in the first part of this paper, and are important as they underline how surprisingly consistent over time have been global URR estimates, both for conventional oil, as well as for some of the non-conventional oils.

Hubbert's paper gives a plot of world production of coal from 1870 (and estimated back to 1800) to 1947, and likewise for petroleum from 1860 to 1947. Note that by 'petroleum' Hubbert was referring to *conventional* oil (oil in fields), and this would have excluded NGLs as these only came to be produced in significant quantities relative recently.

For the global cumulative production of coal to end-1947 Hubbert gives ~81 Gt, and for petroleum to the same date, ~8 Gt. For gas he says: "*Because of lack of world production statistics, the energy from natural gas has not been included.*" (But based on US data says the that annual global production in 1939 "*may be assumed to be at least 40% of that of petroleum*".)

Hubbert then discusses the global population trend, writing: "*One of the most disturbing ecological influences of recent millennia is the human species' proclivity for the capture of energy, resulting in a progressive increase in human population.*" He gives data on human population growth since 1650, and notes: "*That the present rate of growth cannot long continue is also evident when we consider that at this rate only 200 more years would be required to reach a population of nearly 9 billion – about the maximum number of people the earth can support.*"

The global population in 1940 was just over 2 billion, and the 9 billion figure Hubbert mentions arises from his simply extrapolating forward the 0.7%/yr. growth rate that had prevailed "*over the last half-century*". By contrast, in the population graph Hubbert that includes in the paper, an inflection point in global population growth is indicated (at about 1950), where the asymptote of the resulting trend results in a significantly lower predicted global population, of only about 4 billion people. In reality of course, population did continue to grow strongly, where now the current asymptote is expected to reach ~9 billion, Hubbert's '*maximum number of people the earth can support.*'

However, in terms of the challenge we currently face, we now know in Hans Rosing's phrase that the world has reached 'peak child', and the problem is no longer the risk of unchecked population growth, but on how to navigate the energy/population difficulties from now into the medium-term.

Hubbert's paper then looked at the question of whether the world contains enough energy to support such population growth. He looked at both fossil fuels as well as solar energy, and it is the data on the former that we cover here. (In the following, the text is edited slightly, and some units converted to Gb.) Hubbert wrote:

"PHYSICAL LIMITS TO EXPANSION

… One cannot refrain from asking, "Where is [this trend of energy use and population growth] *taking us? How long can we keep it up?"*

This leads us to consider what physical limitations there may be upon the various types of energy whose expansion we have noted. In the case of the fossil fuels the answer is simple. As remarked before, these fuels represent an accumulation over 500 million years of geologic time, and any additional accumulation that may be expected within the next 10,000 years is negligible. When these fuels are burned, their material content remains upon the earth in a relatively useless form, but the precious energy, after undergoing a sequence of degradations, finally leaves the earth as spent, long-wavelength, low-temperature radiation. Hence, we deal with an essentially fixed storehouse of energy which we are drawing upon at a phenomenal rate. The amount which remains at any given time equals the amount initially present less that which has been consumed already.

The amount consumed up to any given time is proportional to the area under the curve of annual production plotted against time. This area may approach but can never quite equal the amount initially present. Thus we may announce with certainty that the production curve of any given species of fossil fuel will rise, pass through one or *several maxima, and then decline asymptotically to zero. Hence, while there is an infinity of different shapes that such a curve may have, they all have this in common: that the area under each must be equal to or less than the amount initially present.*

AMOUNTS OF FOSSIL FUELS

While the quantities of fuels upon the earth are not known precisely, their order of magnitude is pretty definitely circumscribed. The most accurately known is coal. At the Twelfth International Geological Congress at Ottawa in 1913 a world review of coal was made and the amount capable of being mined was estimated to be about 8000 Gt. Since that time some adjustments in the estimates have been made, giving us a present figure of about 6300 Gt of coal initially present.

Within the last few years this figure has been criticized by mining engineers (Ref. 2, Ref. 5) on the grounds that while the estimated amount of coal may in fact be present, the amount recoverable by practical mining operations is but a fraction - possibly as small as one tenth – of the foregoing estimate. The degree of validity of this criticism still remains to be determined.

For petroleum the estimation is considerably less accurate than that for coal but still it is probably reliable as to the order of magnitude. The method of estimation in this case is that of sampling. In the better-known areas the amount of petroleum produced per unit volume of certain classes of rocks has been determined. The areas and volumes (within drillable depths) of similar rocks over the earth are fairly well known. By application of the same factor for the undrilled areas as for those now well known, an order of magnitude of the petroleum that may exist may be obtained.

The most comprehensives studies so far made public appear to be those of Weeks, which are cited by Wallace E. Pratt (Ref. 7 to Ref. 9). According to these studies, in a volume of 10-12.5 million cubic kilometres (2.5-3.0 million cubic miles) of sediments in the United States there have already been discovered 8.4 x 10^9 *cubic meters (53 Gb) of oil. This represents about 10 percent of the total volume of such sediments of the land areas throughout the world. Hence, it is estimated that for the world there should have been present initially about ten times as much oil as for the United States. A similar volume of sediments occurs on the continental shelves, which may contain* *about as much oil as the land sediments.*

Assuming that the land areas of the United States will produce 16 x 10^9 cubic meters (100 Gb), then a reasonable estimate for the world would be:

Land:	*1000 Gb*
Continental Shelves:	*1000 Gb*
Total:	*2000 Gb*

These figures are regarded as being somewhat liberal and the quantity of oil may actually be considerably less. Not included in the figures are the Athabaska Tar Sands (Ref. 8), estimated to contain about ~200 Gb of oil.

The amount of natural gas may be estimated at 400 cubic meters of gas for one of oil, or at an energy content of 40 percent that of oil.

The oil shales of the world are less well known. Those of the United States, especially the Green River shales, are estimated to contain at least 350 Gb of oil. Assuming that the rest of the world has about three times the amount of oil shales in the United States, we would obtain, for an order of magnitude, 1,000 billion barrels of oil from this source.

The results of these estimates are given in Table 1 … It will be noted that 92% of the estimated total [energy] *is represented by coal - a figure which will not be greatly altered by any reasonable adjustments of the estimates of the* [other] *fuels, but may be considerably altered if the minable amount of coal is less than usually assumed.*

Table 1: *Energy in Fossil Fuels*[1]

	Quantity	**[Gt coal equiv.[2]]**
Coal[3]	6300 Gtonne	4600
Petroleum[4]	1000 Gb	135
Canadian Tar Sands[5]	200 Gb	25
Natural Gas[6]	420 Gboe	60
Oil Shale[7]	1000 Gb	135
Total		**~5000**

1. [Table truncated from the original, edited, and data rounded.]

2. [Hubbert used a conversion factor of 1 Gt of coal = 7.3 x 10^6 kcal, presumably assuming a mix of hard and soft coal. Conversion using BP *Stats. Rev.* data for hard coal gives Gt (hard) coal equiv., as used here.]

3. Revised from estimate. Twelfth International Geological Congress (1913).

4. Based on estimate of Wallace E. Pratt: "Petroleum on Continental Shelves" (Bull. A.A.P.G. 31, 1947, 657-672). [Based on Hubbert's earlier text, this probably refers only to the conventional oil on land.]

5. Wallace E. Pratt. Oil in the earth. *Lawrence: Univ. of Kansas Press, 1942, p. 44.*

6. Based on gas/oil ratio of 400 m3/m3, or energy of gas = 0.4 energy of oil.

7. Carl Belser: "Oil Shale Resources of Colorado. Utah and Wyoming" (A.I.M.E Tech. Publ. No. 2358, May, 1948). [Where Hubbert refers to 'oil shales' he is referring to oil retorted from kerogen (and not to today's 'light-tight' shale oil).]

[Hubbert's references are:

Ref. 2. Carlow, C. A. A.I.M.E., October 1946.

Ref. 5. Parsons, A. B. Mining and Metallurgy, 1948, 29, 63-64.

Ref. 7. Pratt, W. E. A.A.P.G. Bull. 28, 1944, 1506-1509.

Ref. 8. Pratt W. E. Oil in the earth. *Lawrence: Univ. of Kansas Press, 1942.*

Ref. 9. Pratt W. E. A.A.P.G. Bull. 31, 1947, 657-672.]

Hubbert then looked at the implication of the data given above in terms of the future production curve for fossil fuels, and thus in turn at the 'time perspective' of human affairs. His Figure 8 plots, against a time-scale running from effectively 10,000 years ago to over 10,000 years in the future, the following parameters:

- production of energy from fossil fuels;
- production of energy from water power and solar radiation;
- energy per capita per unit time;
- population;

and from which he draws the following conclusions:

"These sharp breaks in all the foregoing curves can be ascribed quite definitely, directly or indirectly, to the tapping of the large supplies of energy stored up in the fossil fuels. The release of this energy is a unidirectional and irreversible process. It can only happen once, and the historical events associated with this release are necessarily without precedent, and are intrinsically incapable of repetition. … it will still be physically possible to stabilize the human population at some reasonable figure, and by means of the energy from sunshine alone to utilize low-grade concentrations of materials and still maintain a high-energy industrial civilization indefinitely. Whether this possibility shall be realized, or whether we shall continue as at present until a succession of crises develop - overpopulation, exhaustion of resources and eventual decline - depends largely upon whether a serious cultural lag can be overcome. … it is upon our ability to eliminate this lag and to evolve a culture more nearly in conformity with the limitations imposed upon us by the basic properties of matter and energy that the future of our civilization largely depends."

Is not intended here that a detailed analysis of Hubbert's 1949 paper be given in light of today's knowledge, but the main things to note are:

- The estimate he gives of the conventional oil expected from US land areas, of ~100 Gb, was not unreasonable for that date, but certainly on the low side; his 1956 paper used US Lower-48 estimates of 150 Gb and 200 Gb (including continental shelves).

- For global oil, the data that Hubbert was using predated the discovery of Ghawar, so would be expected to be on the low side. Nevertheless, the estimate of global conventional oil URR, less NGLs, of 2000 Gb is surprisingly accurate, and well within 'an order of magnitude'.

- On shale oil (oil from kerogen), Hubbert wrote: "*A third source* *of fossil energy, oil shale, although exploited on a small scale for almost a century, is only now approaching its phase of rapid development.*" He probably expected use of this class of oil to increase faster than turned out to be the case, primarily because Middle East oil, and later that from other overseas provinces, came on-stream rapidly to compensate for the declining production of US conventional oil.

- On coal, Hubbert warns of mining engineers' doubts over the URR value then generally assumed. We will return to this topic in a future issue of this journal.

Next we summarise the global conventional oil URR data that Hubbert used over a sequence of publications, Table 2.

Table 2. Global Oil URR estimates quoted by Hubbert, 1949 – 1981.

Date of Paper	Global conv. oil URR (ex-NGLs) (Gb)	NGLs (Gb)	Tar sands (Gb)	Shale (kerogen) oil (Gb)
1949	1000 (a) 2000 (b)	n/a	200 (c)	1000
1956	1250 (d)	~225 (e)	400 – 800 (f)	1300 – 3000 (f)
1962	1250 (g)			
1969	1350 & 2100 (h)			
1977	2000 (j)			
1982	2000 (k)			

Notes:

(a). From Table 1 above (Hubbert, 1949); probably onshore only.

(b). From text above (Hubbert, 1949); onshore & offshore.

(c). Athabasca only.

(d). Hubbert (1956). Data from ESSO's L.G. Weeks, but increased based on new data from the Middle East, plus USGS information.

(e). Estimate derived here (i.e., not Hubbert's), based on the global crude oil URR ex-NGLs of 1250 Gb, and applying the US ratio of all-liquids to crude oil that Hubbert quotes.

(f). Ranges for global tar sands and shale oil URRs quoted by in the text of Hubbert (1956). Note that single-point estimates are used in Figure 16 of that paper.

(g). Hubbert (1962). Assumed same global conv. oil URR as in 1956.

(h). Hubbert (1969).

(j). Hubbert (1977). 'Best estimate' from Nehring's range 1700 - 2300 Gb

(k). Source: Andrews & Udall (2015). Says: "Hubbert and Root; reviewed [URR] estimates by others."

Note. In assembling these data, except for Hubbert (1949 and 1956), Hubbert's original papers have not been re-read, so this table may contain simplifications or errors.

Sources: Hubbert (1949); Hubbert (1956); Bentley (2016; which reviewed Hubbert 1962; Hubbert 1969; and Hubbert 1977); and Andrews & Udall (2015).

Note also that global URR estimates by Weeks increased from 650 Gb in 1942 up to 3600 Gb by 1978 (Andrews and Udall, 2015), but one would need to look at Weeks' papers in detail to be sure what categories of oil were included. For detail on Hubbert's life and views, see Mason Inman's forthcoming book: *The Oracle of Oil – A maverick geologist's quest for a sustainable future.* W. W. Norton.

4. Some Current Minimum Estimates of the Global URR of Conventional oil, deduced from 'mainstream' forecasts

We now move from history to relatively current data, and look not at global conventional oil URR estimates as such, but at a minimum URR value that is implicit in forecasts from a number of the ‘mainstream’ oil forecasting organisations.

We can do this because - relatively recently - such organisations have become much more circumspect on the amount of conventional oil production they foresee; and now explicitly forecast that such production will not increase in any significant way going forward; instead holding it flat out to the end of their forecast time horizons. This then lets us make a minimum estimate of the URR estimates for conventional oil that they must be using (or implicitly assuming), by allowing production of this oil to decline at a reasonable rate beyond the forecast horizon.

The three forecasts we examine are those of IEA (2011), BP (2015), and ExxonMobil (2015), the charts for which are on the web, and also in Volume 1 No. 2 of this journal.

As these forecasts are very similar we will only analyse that of ExxonMobil. As this shows (Chart 6 of Vol. 1 No. 2), here global production of conventional oil is forecast as staying essentially flat from 2005 out to 2040. If we then assume that production of this oil declines away exponentially from 2040, we get the following approximate data:

	Gb
Cumulative production to end-2014	~1250
Produced 2015 to 2040 (at 73 Mb/d)	670
Exponential decline down to ~7M/d (80 years)	800
Total conventional oil (~URR)	~2700

Note that there is no reason to think that this estimate, of 2700 Gb, is the URR for conventional oil that these organisations are assuming. But this calculation does give a likely *minimum* URR value. In future issues of this journal we will look at the actual data used by these organisations.

5. Summary of URR data presented in this paper

Now, with these extra historical and current data to hand, we are in a position to summarise the global conventional oil URR estimates that have been presented in all three parts of this paper. This is done in Table 3.

Table 3. Summary of URR estimates by category of oil. Data in Gb (rounded).

Author	Date of study	Conv. oil RG	Conv. oil (incl. RG)	NGLs	Total Conv. oil (incl. RG & NGLs)	'Light-tight' oil	Very heavy Oils	Total All-oil (excl. kerogen)
Hubbert	1949		2000				200 (a)	
"	1956		1250	225 (b)			400-800	
"	1969		1350 & 2100					
"	1977		2000					
"	1982		2000					
Others: 1972 - 2015								
ESSO	1972		2100					
Ward & Dubois	1972		2500					
SPRU, UK	1974		1800 - 2480					
Ehrlich et al.	1977		1900					
WEC / IFP	1978		1803					
World Bank	1981		1900					
Meadows et al.	1992		1800 - 2500					
Petro consultants	1995		1800					
Ivanhoe	1996		~2000					
Laherrère	1997							2700
BGR	2002		2670					
Shell	2002							4000
Bauquis	2003							3000
Laherrère	2003							3000
EU WETO study	2003							4500
Energyfiles Ltd.	2003		2338					
IHS CERA	2014	760			4000	485	470	5000

Author	Date of study	Conv. oil RG	Conv. oil (incl. RG)	NGLs	Total Conv. oil (incl. RG & NGLs)	‘Light-tight’ oil	Very heavy Oils	Total All-oil (excl. kerogen)
Campbell	2015		2250	220	2470		260 (c)	2730
Globalshift	2015		2500	370	2900	150	150	3200
Laherrère	2015		2200	300	2500	In conv.	500	3000
Miller	2015		~~2400 (d)	~~300	~2700	In conv.	225	~2900
ExxonMobil (min. value from forecast)	2015		>2700					
USGS (mean)	1991		~2300					
“	1994		2400					
“	2000	700	3000	400	3345			
“	2012	720	~~3400 (e)		~3850			
IEA								
(ref. case)	1998		2300					
(ref. case)	2000				3345			
	2013	500			4350	215	1,470	6000
See ExxonMobil(from forecast)								
US EIA	2001		3303					
“	2013				4250	345		
“	2015					420		

Notes:

- RG: Reserves growth. NGLs: Natural gas liquids.

- A number of assumptions have been made in assembling these data. These assumptions are believed to be correct, or at least reasonable, but the author would be very pleased to receive corrections. It is fairly certain that all authors would accept that the data here are more uncertain than the degree of rounding shown above would indicate. For additional information, and caveats, on these data see the discussion in the relevant parts of this paper.

- Definitions by category of oil are not consistent between authors, such that exact comparisons between these data are not possible.

(a). Athabasca tar sands only.

(b). Estimate derived here (i.e., not Hubbert's); see Table 2.

(c). For Campbell, this figure combines 'light-tight' oil plus very heavy oils (tar sands & Orinoco oil).

(d). For Miller, the NGLs data of ~300 Gb is imputed, based on other sources; where hence the ~~2,400 Gb value for 'Conv. oil + reserves growth' is derived.

(e). Approximate reconstruction of value implied in USGS 2012 data if NGLs at ~400 Gb are assumed.

Table 3 may seem a little complex, but it is fairly easy to draw out the main conclusions. Concentrating on the URR data for conventional oil plus reserves growth (but ex-NGLs), as this is the focus of this paper, we can see that:

(a). URR estimates in the table, in the thirty or so years from about 1970, when the full scale of the Middle East finds were appreciated, up to the year 2000 varied over a surprisingly small range, from 1800 – 2500 Gb. (Note that while Hubbert's 1949 estimate of 2000 Gb meets this range, as explained earlier, it was based on analogy with the US, rather than on global discovery data.)

(b). Subsequent to the year 2000, when the USGS included a global allowance for reserves growth for the first time, higher URR estimates were generated, from 3400 Gb up to ~4000 Gb (after deducting as assumed ~400 Gb for NGLs), and where these estimates are mostly from the 'mainstream' forecasters.

(c). By contrast, the recent URR estimates from the 'independent' forecasters (Energyfiles, Campbell, Globalshift, Laherrère, Miller) still sit at relatively low values, from 2200 to 2500 Gb. (Note that on inclusion of reserves growth in these estimates, some of these authors may recognise that quite large quantities of such growth are technically possible over time, but do not reflect this in the data shown here. This is almost certainly the case for both Campbell and Laherrère; where, since they predict peak production of this class of oil as soon, the URR values given are those that help calculate their dates of peak.)

In summary, from Table 3, we really have two distinct sets of URR estimates: The first is the mainstream estimates from about 1970 up to the year 2000, plus the recent estimates from the 'independents', where these all sit in a 1800 – 2500 Gb range. The second set is the 'mainstream forecasters' estimates since the year 2000, where these now sit between about 3400 - ~4000 Gb (if the 2013 data given here for the IEA and EIA are correct); and where also today (2015) 'mainstream' URR estimates must be at least greater than 2700 Gb, if the 'extrapolation calculation' given above based on recent forecasts is correct.

The next section looks at which of these two sets of URR estimates would seem to be the more likely. However, before we do so, here is an aside on how the URR estimates of the 1970s and 1980s given above were collected. All simply came from textbooks on the bookshelf of this author's then supervisor, George Whitfield. As the period post-1973 was characterised by a widespread acceptance that global oil would soon 'run out' - based almost certainly simply on the size of global proved reserves at that date - most textbooks on energy in the 1980s contained at least some reference to oil. As a result, and not surprisingly, the list of URR estimates given here for these dates is not complete; at least one notable absence being the WAES study. It would be useful to assemble and analyse a more comprehensive list, where the paper by Andrews and Udall (2015) would provide a good starting point.

6. Comparing URR Estimates with the Global Volume of Oil Discovered To-date

So now we turn to the question of which URR estimate for conventional oil (including reserves growth, but excluding NGLs) is likely to be the most accurate, at least in terms of forecasting global 'all-oil' production over the near and medium term? Is it a value lying in the range 2200 - 2500 Gb; or one well over 1000 Gb higher, lying between ~3400 - 4000 Gb?

This is an important question. If the lower range is correct, with ~1250 Gb of conventional oil produced to-date, and if the approximate 'peak at mid-point' rule is used, then the global production of conventional oil is about at mid-point, or passed. If the higher URR range is correct, then with ~25 Gb of conventional oil being produced per year, the mid-point is some 25 years into the future.

To answer this question, we turn to recent industry data on global oil discovery. Figure 1 gives IHS Energy global proved-plus-probable ('2P') backdated oil discovery data, drawn from Miller and Sorrell (2014). The data are for IHS Energy's 'Liquids' category, which includes NGLs, light-tight oil, extra-heavy oil (the latter mainly tar sands and Orinoco oil), and oil from kerogen, but excludes GTLs, CTLs and biofuels.

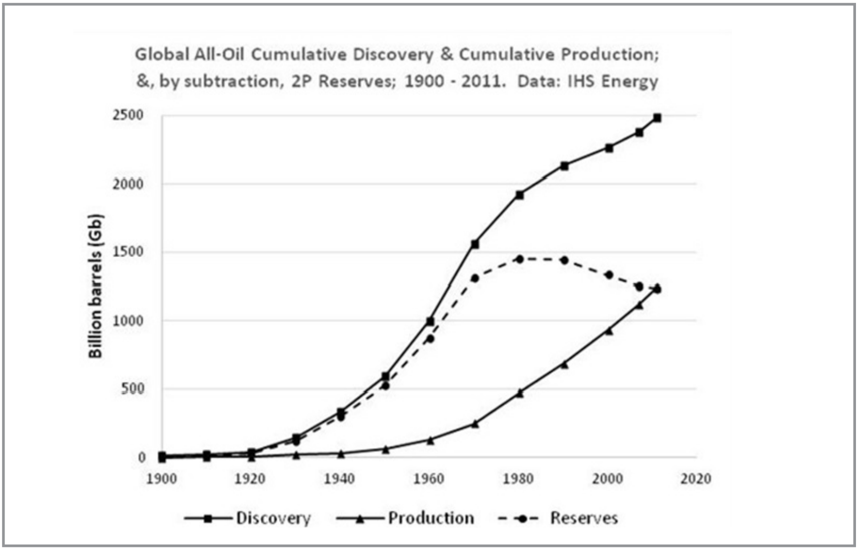

Figure 1. IHS Energy data on World cumulative 2P backdated oil Discovery, and Cumulative oil Production; and hence 2P Reserves by subtraction: 1900 – 2011.

Source: Miller and Sorrell (2014).

Notes:

- The plot shows IHS Energy 'Liquids' data, stated to include: "crude oil, condensate, NGLs, liquefied petroleum gas, heavy oil and syncrude". The data thus include light-tight oil, and oil from tar sands and Orinoco oil, but exclude GTLs, CTLs, biomass, and refinery gain.
- The plot is generated by reading data at 10-year intervals from Figure 7 of Miller and Sorrell (2014) for cumulative discovery from 1900 to 2007, and from the corresponding Figure 3 for cumulative production over the same period.

Included in this plot are the data for end-2011 as given in the text of the Miller and Sorrell paper.

- Data are 2P, except for the US and Canada non-frontier areas, where the data are proved ('1P') data. The 2P data are backdated, in that they reflect information available to the IHS Energy as of 2007 (for the discovery curve), and to 2011 (for the final discovery data point). Reserves are calculated here (as done also by IHS Energy) by subtracting cumulative production from cumulative discovery.
- IHS Energy data are for oil in fields for conventional oil; and as announced in projects for non-conventional oils. The 'up-tick' in global discovery of this 'all-oil' visible from about the year 2000 (and hence the slowing in the fall-off of 2P reserves) is due to increasing inclusion of data for tar sands projects, and subsequently for US shale (light-tight) oil projects. Data are hence largely for conventional oil plus NGLs up until about the year 2000, after which significant amounts of tar sands and Orinoco projects were included, and most recently also data for 'light-tight' oil projects.
- As the plot shows, the global proved-plus-probable (2P) all-oil reserves at end-2011 were ~1,250 Gb. This contrasts with the corresponding end-2011 value for global proved only (1P) all-oil reserves (from BP Stats.) of 1,652 Gb. The difference is partly in the amount of non-conventional oil include in the two sets of reserves figures, and partly in the likely overstatement of Middle East OPEC proved reserves.

We can see from Figure 1 that the global discovery of *conventional* oil (incl. NGLs) might be judged (based on the pre year-2000 trend) to be heading for an asymptote URR around 2500 Gb, thus supporting the lower URR range outlined above, and where the corresponding production 'mid-point' is around 2011. (Note, incidentally, that this Figure shows that the rate of global *discovery* of conventional oil peaked around the mid-1960s; and the volume of oil in global 2P *reserves* peaked about 1980, at about 1450 Gb.)

A more conservative view of global oil discovery is that produced by Jean Laherrère, again using oil industry 2P data, and is given in Figure 2. Like Figure 1, this shows proved-plus-probable backdated global oil discovery, but here the data exclude NGLs and extra-heavy oil (the latter mainly tar sands and Orinoco oil). Also from the industry discovery data Laherrère here has subtracted 300 Gb to allow for Middle East 'quota wars' overstatement; 100 Gb to allow for FSU field data being closer to 3P than 2P; and 200 Gb to allow for inclusion of early Orinoco heavy oil fields. In this view, a reasonable asymptote of global conventional oil discovery (ex-NGLs) is thus about 2200 Gb;

and hence the corresponding 'mid-point' production date is somewhat earlier than for Figure 1, at around 2005.

(Also shown are the corresponding discovery and production data for gas.)

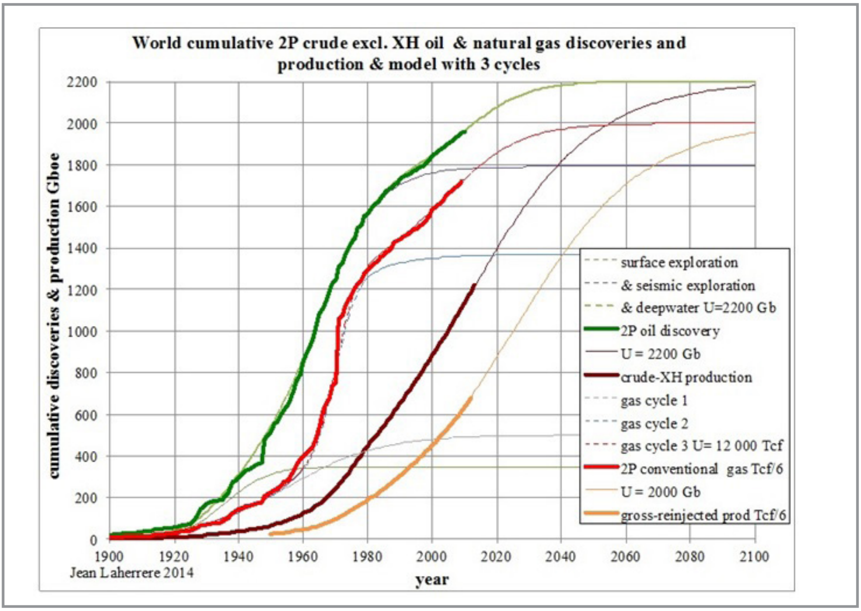

Figure 2. World: Cumulative 2P Backdated Oil Discovery 1900 - 2010, and forecast to 2100; Cumulative Oil Production, 1900 – 2013, and forecast to 2100.

- Leftmost line: Laherrère's judgement of 'most probable' backdated 2P cumulative global discovery data for crude oil plus condensate, less extra heavy oil (the latter mainly Athabasca tar sands and Orinoco oil), and not including NGLs.
- Next left line: Corresponding data for gas, calculated as Tcf/6.
- Next leftmost line: Cumulative global production of crude oil less extra heavy oil and NGLs.
- Rightmost line: Cumulative global production of gas, Tcf/6.
- Laherrère writes: 'The 2P discovery data reflect data from industry 'scout' sources, but reduced by: 300 Gb to allow for overstatement of the OPEC Middle East original reserves data (as confirmed by Sadad Al-Husseini, former VP Aramco, 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.'

Source: J. Laherrère.

The data in Figures 1 and 2 are hard to fully reconcile, perhaps partly due to differences in data definitions, but both show that an estimate for the global URR of conventional oil (ex-NGLs) probably at the lower end of the lower range given above (2200 - 2500 Gb) looks realistic if based on the discovery trend to-date.

Thus the higher URR range, of 3400 - 4000 Gb, looks unrealistic on solely the discovery trend. It is certainly true that a high URR value is theoretically possible over a longer term, resulting from a combination of above-trend discovery plus significant technologically-driven reserves growth, both brought on by a long period of high oil price. But in terms of near and medium term forecasts for 'all-oil' production, forecasts which use (or imply) global URRs for *conventional* oil (ex-NGLs) significantly above the 2200 - 2500 Gb range seem unrealistic.

7. Conclusions

From the above, we conclude as follows:

Global URR estimates for *conventional* oil (ex-NGLs) have been remarkably consistent over many years. Once the big Middle East finds were solidly in, though there have been higher values, many such URR estimates have ranged between 1800 Gb to 2500 Gb.

This in turn has allowed the date for the global peak in production of *conventional* oil, as occurring around the year 2000, to be predicted with reasonable confidence for many years. (This is contrary to the view, still held by many analysts, that all such 'fixed resource' oil forecasts have no merit; see, e.g., Aguilera and Radetzki, 2016.)

If oil industry backdated proved-plus-probable discovery trend data are used, a global URR value for *conventional* oil (ex-NGLs) at the lower end of a 2200 - 2500 Gb range looks most likely, at least in the near or medium term.

As a consequence, those global forecasts which use (or imply) URR values for this class of oil significantly above this range, mostly the forecasts from the 'mainstream' oil forecasting organisations, need to justify their assumptions on use of a URR value that is out-of-line with the discovery trend.

These findings in turn support the view that the major rise in oil price since 2004 was caused primarily by the world approaching its peak production of conventional oil, and hence needing to meet demand increasingly from production of the significantly more expensive non-conventional oils (see, e.g., Bentley & Bentley, 2015).

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