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 2.

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Abstract:

This paper is the continuation of a previous one looking at the link between estimates for the size of the global ultimately recoverable resource ('URR') of conventional oil and the differences between forecasts for global oil production from different organisations.

In this paper the estimates of URR examined are those from: the US EIA (2013), the IEA's '*Resources into Reserves*' study (2013), IHS CERA (2014), Campbell (2015), Globalshift Ltd. (2015), Laherrère (2015) and Miller (2015).

Full conclusions will be drawn in a follow-up part (Part 3) of this paper. Here, the reader's attention is drawn to the difference between estimates for the global URR of conventional oil generated primarily from discovery data (and sometimes with adjustments for data quality), and the more 'mainstream' URR estimates generated by what may be called 'assessment procedures'.

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1. Introduction

This is the second part of a three-part article looking at the link between the estimated size of the global ultimately recoverable resource ('URR') of conventional oil and the results of oil forecasts which have used these values.

The first part of this paper was published in the previous issue of this journal, as Bentley (2015). That looked at relatively early URR estimates (those from 1956 up to 2005), and also at the estimates for the global URR of conventional oil generated by the US Geological Survey (USGS) between the years 1991 to 2012.

This part of the paper, and also Part 3, looks at current estimates of URR. As mentioned in Part 1, a person studying the future of global oil supply has the problem that oil forecasts from different sources give significantly different predictions. This was particularly the case only a few years' back, see for example the report of the US National Research Council's *Trends in Oil Supply* workshop, Zucchetto, 2006; or the UK Energy Research Centre's *Global Oil Depletion* study, Sorrell *et al.*, 2009.

But still today there exists an uncomfortably large gap between the oil forecasts from different individuals and organisations; where for example current forecasts for the global production of 'all-liquids' can be classified as:

- Those that see this production as reaching a maximum within less than a decade, and then declining (e.g., the forecasts of Campbell, 2015; or Laherrère, 2015).
- Those that see this production as reaching a maximum, but not until perhaps 2025 to 2035, before then declining (e.g., Smith 2015; or Miller 2015).
- Those which see no maximum in the global production of all-liquids out to the end of their forecast horizons, typically to 2035 to 2040. This latter group of forecasts tend to be those 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 the wide differences between forecasts, but one of the main ones, already identified by the UKERC 2009 *Global Oil Depletion* study, is the size assumed for the ultimately recoverable resource ('URR') of global *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; and in particular why they were used, and how they were arrived at.

In reaching this understanding, it is necessary to be clear about the definitions used by the various forecasts for conventional and non-conventional oil, and for 'other liquids'. 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 of these 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. In other cases, the URR estimates are both generated by, and used by, the organisations or individuals making the forecasts.

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

As mentioned, in this second part of this paper we examine a number of more recent estimates for the global URR of conventional oil, as well as URR estimates for other categories of oil and liquids. These estimates are from:

- The US EIA, 2013
- IEA *Resources to Reserves* report, 2013
- IHS CERA, 2014
- And from number of the oil forecast models described in this journal to-date; specifically those of Colin Campbell, Globalshift Ltd., Jean Laherrère and Richard Miller.

It is intended that the information on URR values will be updated in future issues of this journal, and also subjected to more detailed analysis. In this sense, this paper is preliminary in terms of examining this key topic relating to future oil production.

2. Some Current Estimates of the Global URR of Conventional oil, and of Other Categories of Oil, and Liquids

2.1 US Energy Information Administration, 2013

The first URR estimate we examine is from the US Energy Information Administration. Table 1, taken from EIA (2013, p3), gives estimates of the global volumes of 'technically recoverable oil & gas assessed to be remaining' as of the date of the report, split between 'conventional' and 'shale', where the latter refers to tight oil or gas that is extracted by hydraulic fracturing.

	Conventional	Shale ('tight')	Total
Oil (Gb)	3012	345	3357
Gas (Tcf)	15583	7299	22882

Table 1. EIA data (2013) for "Global technically recoverable oil & gas remaining".

Notes:

Here 'shale' refers to 'light-tight' oil or gas produced by fracking, and excludes some regions & categories of tight oil. It excludes oil produced from 'oil shale', i.e. by retorting kerogen from source rocks.

This study quotes Oil and Gas Journal data as of 2012 as the source for the size of global conventional oil "proved reserves", and USGS data as of the same date as the source for global conventional oil "unproved resources".

More recent EIA data give somewhat different estimates for tight oil and gas: the EIA's "World Shale Resource Assessments, Last updated Sept 24 2015" gives 420 Gb (rounded) for "Unproved technically recoverable tight oil", and 7580 Tcf (rounded) as the equivalent for "wet shale gas".

If we take the estimate above of 3012 Gb for the global conventional oil recoverable resource *remaining* as of 2013, and add the approximately 1250 Gb of conventional oil consumed to end-2012, we get a URR for global conventional oil (assumed here to include both reserves growth and NGLs) of ~4250 Gb.

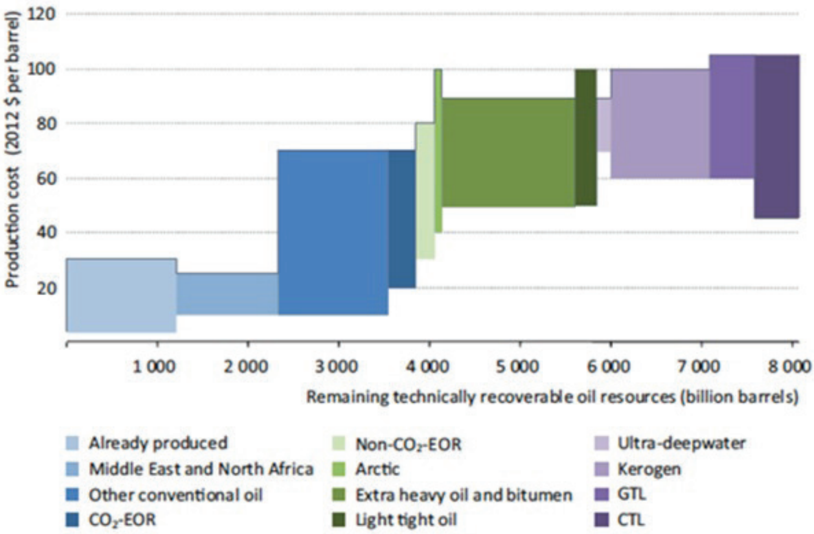
Summarising the above data, we have (Table 2):

		URR estimates, Gb	
Source	**Date**	**Conv. oil**	**Light-tight oil**
US EIA	2013	4250	345
US EIA	2015		420

Table 2. US EIA estimated global URR values (rounded). Because of the size of this estimate, it is assumed that here that 'conventional oil' includes both reserves growth and NGLs.

2.2 International Energy Agency data, 2013

Now we turn to data from the International Energy Agency. Figure 1 gives the IEA's view of recoverable volumes available of different classes of oil, as a function of cost range, as given in their *Resources to Reserves* report, 2013.



Source: *Resources to Reserves* (IEA, 2013).

Figure 1: Estimated global remaining technically recoverable volumes of oil available, by category (in Gb), vs. Production cost range (in $2012/bbl).

Notes:

- EOR: Enhanced oil recovery; MENA: Middle East and North Africa; GTL: Gas to liquids; CTL: Coal to liquids.
- The plot includes only fossil resources, so does not include biofuels.
- Volumes of oil potentially available are shown by length along the x-axis, not by the area indicated.

Source: IEA Resources into Reserves, 2013.

As the Figure shows, and as would be expected, conventional oil, non-conventional oil, and other liquids come at different ranges of production costs. And as we define conventional oil here, this IEA report's view of the quantities remaining by category comprise (reading from the chart, and rounding):

Middle East and North Africa (MENA)	1115 Gb
Other conventional	1215
Arctic	80
Ultra-deepwater	185
Total (rounded)	**2600 Gb**

Using the figure given above of global cumulative production of conventional oil to end-2012 of ~1250 Gb, we get the estimated global URR for conventional oil, without allowance for reserves growth, as ~3850 Gb. (Note that here we assume these data *include* NGLs.)

Reserves growth can be driven by a wide variety of factors, including technology gain, better knowledge of the reservoirs, and an increase in oil price. But approximating with the data given here, we can say, roughly, that reserves growth is the sum of CO_2-EOR (at 300 Gb) plus non-CO_2-EOR (at 200 Gb), giving a total of 500 Gb. This puts the total global URR for conventional oil, including reserves growth, (and again assuming that NGLs are included) at ~ 4350 Gb.

The non-conventional URR data (here the 'Extra heavy oil and bitumen', probably mainly tar sands plus Orinoco oil, but some other extra-heavy oil also at 1470 Gb; plus 'Light tight' oil, at 215 Gb), totals 1685 Gb.

And the 'other liquids' are, respectively:

Kerogen oil	1100 Gb
Gas-to-liquids	500
Coal-to-liquids	480 Gb

This gives a total URR, for all categories of oil plus other liquids (but excluding biofuels) as ~8000 Gb, as the Figure indicates.

Note that in terms of understanding the future production of oil, and in particular the date at which the global production of conventional oil is expected to peak, this chart is included in *The Oil Age* (vol. 1, no. 1, p78), with an explanation of both the right and wrong ways it can be read. Specifically, it is wrong to think, as many authorities state in effect: 'Well, there are plenty of resources remaining'. Instead it is necessary to recognise the approximate mid-point production peak of conventional oil, and hence see in the chart the explanation for the step-change in oil price that occurred around 2005; and see also Bentley & Bentley (2015a).

Finally, it is worth noting that while the future production of oil from 'fracking' is usually discussed - at least within Europe - in terms of public acceptability (relating to noise and disturbance, potential water pollution, seismic shocks and CO_2 emissions), generally overlooked is the fact that the total amount globally of light-tight oil (as opposed to tight gas) assessed as recoverable is not so very large. As shown above, back in 2013 the IEA assessed ~215 Gb recoverable; and even if the higher US EIA estimates are used, see above, of 345 Gb (as of 2013) or 420 Gb (as of 2015), though these are very useful amounts of oil (climate change aside), compared to the global annual usage of oil of ~30 Gb per year, no-one should see 'light-tight' oil from fracking as an endless cornucopia.

Re-stating the data above we get Table 3a:

Source	Conv. oil (ex-RG)	RG Conv. oil	Total Conv. oil	Extra-heavy	'Light-tight'	Total All-oil	Other Liquids	Total All-liquids
IEA, 2013	3850	500	4350	1470	215	6035	2080	8115

Table 3a. IEA 2013 estimated global URR values. (Gb). Note: RG: Reserves growth.

With a global URR value for conventional oil (including reserves growth) of 4350 Gb, this IEA estimate is close to the 4250 Gb value estimated by the US EIA.

Slightly more recent data come from the IEA's *World Energy Outlook*, 2014. This gives 'Remaining recoverable oil resources … end-2013' as (in Gb):

Crude oil	2239
NGLs	476
Extra heavy oils	1879
Kerogen oil	1073
Tight oil	344
Total oil resources remaining	**6010 Gb**

If we assume the above figure for crude oil includes reserves growth, and take cumulative production of conventional oil to end-2013 as ~1275 Gb, we can create Table 3b.

Source	Conv. oil (incl.RG)	NGLs	Conv. oil + NGLs	Extra-heavy	'Light-tight'	Total All-oil	Kerogen oil	All-oil + kerogen
IEA WEO 2014	3515	475	3990	1880	345	6215	1075	7290

Table 3b. IEA imputed end-2013 global URR values (rounded). (Gb).
Note: RG: Reserves growth.

With a global URR here value for conventional oil (including NGLs, and also assumed to include reserves growth) of ~4000 Gb, this end-2013 IEA estimate is reasonably close to the close to the 4350 Gb value estimated given by the IEA's 2013 report *Resources to Reserves*.

2.3 IHS CERA data

Now we turn to recent URR data from the consultancy IHS CERA, Table 4. These data are given in the paper by Jackson and Smith (2014) in the theme issue: *The future of oil supply*, edited by Miller and Sorrell, of *Phil. Trans. R. Soc. A*.

		Remaining Technically Recoverable										
	Cum. Prodn. (a)	OPEC Middle East	Other Onshore and shallow water Conv.	Deep-water (>1000 ft)	Arctic	Reserve growth (b)	Extra Heavy Oil (c)	Kerogen Oil Extract (d)	Tight Oil	Exploration potential Conv. Oil	Total Global Endow-ment	Total Remain-ing
Rest of the World	968	696	385	111	83	681	303	116	442	565	**4350**	**3382**
United States	243	—	10	15	35	76	—	371	40	83	**873**	**630**
Canada	36	—	4	0.6	3		169	2	3	15	**233**	**197**
Total	**1247**	**696**	**399**	**127**	**121**	**757**	**472**	**489**	**485**	**663**	**5,456**	**4209**
For reference, CERA 2005 data:												
Total	**1000**	**662**	**404**	**61**	**118**	**592**	**444**	**704**	**-**	**758**	**4743**	**3743**

Table 4. Global Resources, Conventional and Unconventional, IHS CERA Compilation (billions of barrels, Gb.)

Notes:

Stated sources: IHS Energy, USGS (2000), US EIA (2012), Canadian Assocn. of Petroleum Producers (2011), Ahlbrandt (2002).

(a). End-2010 numbers. [Note that here the ‘cumulative production to end-2010’ value given of 1247 Gb refers to IHS CERA's definition of ‘liquids’, which includes crude oil, condensates, NGLs, very heavy oils (including tar sands and Orinoco oil), light-tight oil and oil from kerogen.]

(b). Reserve growth (or reserves upgrade) is a common process by which the reserves estimates of existing fields and discoveries increase over time as a consequence of a range of factors including additional technical data, analysis and application of new technologies.

(c). Extra heavy crude oil is any type of crude oil which does not flow easily. It is referred to as ‘heavy’ because its density or specific gravity is higher than that of light crude oil. Physical properties that differ between heavy crudes and lighter grades include higher viscosity and specific gravity, as well as heavier molecular composition. Extra heavy oil is defined as having a gravity of less than 15° API and is typically found and produced in Canada and Venezuela.

(d). Kerogen oil, or shale oil, is an unconventional oil produced from oil shale by pyrolysis, hydrogenation, or thermal dissolution of the rock. These processes convert the organic matter within the rock (kerogen) into synthetic oil and gas.

For reference, earlier CERA data from 2005 are also shown, taken from CERA Press release 60907-9, Nov. 2006, quoted in Sperling and Gordon (2009)

Note, there is a small degree of ambiguity in this table as to whether or not it includes NGLs. But looking at the paper's Section 6 on definitions, and cross-referencing the data here to comparable IHS Energy data elsewhere, it seems fairly certain that NGLs are included.

Then on this basis, and as the table shows, if we take cumulative production of conventional oil only to end-2010 (incl. NGLs) as being ~1200 Gb, (i.e., allowing ~50 Gb for cumulative production to this date for the non-conventional oils), then the IHS CERA estimate of the global URR for conventional oil (incl. NGLs) is ~3200 Gb excluding reserves growth (where this total is derived by summing: cum. prodn. + OPEC M.E. + other conv. + deepwater + Arctic + conv. exploration potential); and is ~4000 Gb if reserves growth is included. This leads to Table 5 (in which, 'Total All-oil' includes the assumed notional production to-date of non-conventional oils, of ~47 Gb):

Source	Conv. oil (ex-RG)	RG Conv. oil	Total Conv. oil	Extra-heavy	'Light-tight'	Total All-oil	Oil from kerogen	All-oil plus kerogen
IEA, 2013	3200	760	4000	470	485	5000	500	5500

Table 5. IHS CERA estimated global URR values (rounded). (Gb).

With a global URR value for conventional oil (including reserves growth) of 4000 Gb, this IHS CERA estimate is essentially in agreement (given the large underlying uncertainties of such estimates) with the US EIA and IEA URR values for conventional oil, of 4250 Gb and 4350 Gb respectively, given above.

Now we turn to global URR estimates for conventional oil associated with some of the oil forecasting models covered in *The Oil Age* to-date. These URR estimates are those by Colin Campbell, Globalshift Ltd., Jean Laherrère, and Richard Miller. As we shall see, these estimates tend to be significantly below those of the 'mainstream' organisations considered above. We start with the URR estimate from Campbell.

2.4 Colin Campbell

Table 6 shows the current URR values as estimated by Colin Campbell for various categories of oil and gas. Note that Campbell points out that these are not necessarily true 'ultimates', but reflect total production to 2100 as forecast by Campbell's model, see Campbell (2015).

	OIL AND NGLs						GAS			TOTAL OIL & GAS
	Regular Conv.	Non-Conventional			NGLs	TOTAL OIL	Regular Conv.	Non-Conv.	TOTAL GAS	
All data in Gboe		Heavy & Tight	Deep-water >500m	Polar	(Plant; at cal. equiv.)	(to 2100)				
PAST	1187	61	22	22	79	1371	737	50	**787**	**2158**
FUTURE	913	199	78	28	141	1359	1013	330	**1343**	**2702**
Known	794		60	15			810			
Y-t-f	119		18	13			203			
TOTAL	**2100**	**260**	**100**	**50**	**220**	**2730**	**1750**	**380**	**2130**	**4860**

Table 6. Campbell values for total production to 2100 (~URR data) by category of oil and gas as forecast by his current model. (Data in Gboe.)

Notes:

- NGLs: Natural gas liquids, produced from gas plants.
- Conv.: Conventional.
- Regular Conv.: 'Regular conventional', as defined by Campbell: For oil this includes condensate and conventional oil generally, but excluding heavy oil (<17 °API) and tight oil, deepwater (>500m), and Polar oil which are broken out and modelled separately. Also excluded are NGLs. 'Regular conventional' gas excludes gas from 'tight' reservoirs, from coal or shale, and from methane hydrates.
- PAST: Total produced to-date.
- FUTURE: Quantity expected to be produced in future (up to 2100); composed of:
- Known: Quantity to be produced in future (to 2100), for which the location is known (equivalent to proved-plus-probable, '2P', reserves); plus:
- Y-t-f: Quantity to be produced in future (to 2100), for which the location is not known (i.e., the 'yet-to-find').
- Data are mostly to mid-2015 (approx.). Totals here have been rounded, and as a consequence 'Future' values are adjusted slightly to agree with the 'Past' and 'Total' values shown.

Note that these 'URR' values are generated by Campbell by a variety of methods including discovery 'creaming curves' (see Campbell, 2015), and are then used as inputs to the forecasting component of his model.

To convert Campbell's 'Regular conventional' oil to the definition of conventional oil used in this paper, we need to add in the deepwater and Polar oil. This gives Table 7.

Source	Conv. oil (incl. RG)	NGLs	Conv. + NGLs	Heavy + Light-tight	Total All-oil
Campbell	2250	220	2470	260	2730

Table 7. Campbell estimated global production to 2100 (~URR) values. (Gb).

With an estimated URR for conventional oil (including NGLs) of 2470 Gb, this is over 1,500 Gb less than the 'mainstream' estimates given above.

2.5 Globalshift Ltd.

Michael Smith of Globalshift described the company's bottom-up by-field oil and gas forecasting model in Smith (2015). That paper contained the following table, Table 8, showing the model's forecast total production of 'all-oils' out to the year 2100, split by region. (For the definition here of 'all-oils', see the notes to the Table.)

GLOBAL REGION	Cumulative Production (bn bbls to 2013)	Remaining Production (bn bbls to 2100)	Ultimate Production (bn bbls to 2100)
North America	286	356	642
Latin America	165	213	378
Europe	242	227	469
Africa	123	187	310
Middle East	372	629	1001
Asia-Pacific	140	217	357
GLOBAL	1328	1829	3157

Table 8: Globalshift Ltd. data on production volumes of 'all-oils' to 2100.

Notes:

- All-oils' here includes conventional oil (termed 'field oils' in the Globalshift model), drilled shale / tight oils (elsewhere sometimes called 'light-tight' oil or shale oil), oils from oil sands, and NGLs. Not included in 'all-oils' are what Globalshift terms 'manufactured oils', where these include GTLs, CTLs, oil produced by retorting kerogen, oils from biomass, and refinery gain.
- The category 'Ultimate production' can be taken as approximating the forecast's URRs.

In terms of the analysis being attempted here, what we would like is the breakdown of the volumes in Table 4 by category of oil. Following a request, Smith kindly provided these, as follows (Table 9):

Oil category	**Cumulative Production to 2100 (~URR), Gb**
Onshore conventional oil	1783
Offshore conventional oil	718
Total conventional oil	2500
Onshore tight reservoirs (including shale)	150
Onshore oil sands (including Canada and Venezuela)	151
Total non-conventional oil	300
Onshore NGLs	274
Offshore NGLs	95
Total NGLs	370
Total 'All-oils'	**3170**
Biofuels	222
Oil from converting kerogen	11
Gas-to-liquids	23
Coal-to-liquids	113
Refinery gain	76
Total 'Other liquids'	**445**
TOTAL 'All-liquids' **Note: Totals rounded*	**3615 Gb**

Table 9. Globalshift Ltd. values for total production to 2100 (~URR data) by category of liquid.

On these estimates, Smith notes: "Obviously the second set [the 'All-liquids' components, from biofuels to refinery gain] are mere speculation as the numbers are heavily dependent on global economic circumstances, population growth/decline, climate pressures and technological developments in fuel substitution. Of course the first set [the 'All-oils' components] is dependent on these too." Smith also notes: "These volumes are not precisely ultimately recoverable resource (URR) numbers as they only model production forecasts to the year 2100. There will be a considerable volume of URR remaining in the ground after 2100 that may or may not be eventually produced. This will depend on the economic and social circumstances of the world's population during the 22nd Century. For this reason I am sceptical of the value of URR numbers for assessing any relevant future of oil and gas production."

With these caveats in mind, Table 10 provides a summary of Globalshift's ~URR data:

Source	Conv. oil (incl-RG)	NGLs	Conv. + NGLs	Extra-heavy	'Light-tight'	Total All-oil	Other Liquids	Total All-liquids
Globalshift	2500	370	2870	150	150	3200	450	3600

Table 10. Globalshift Ltd. est'd. global production to 2100 (~URR) values (rounded). (Gb).

As shown, Globalshift Ltd.'s approximate URR value for conventional oil (including NGLs) is ~2870 Gb; about 400 Gb higher than Campbell's 2470 Gb; but still over a 1,000 Gb less than the 'mainstream' values given earlier.

2.6 Jean Laherrère

Jean Laherrère described his top-down oil and gas forecasting model, and its background, in Laherrère (2015).

His model assumes an ultimate for each category of oil; and plots logistic-derivative curves for these where the 'upside' parts of the curves are constrained to match historical production of each of these oils to a reasonably good approximation. His methods for estimating the URR values for the various categories of oil depend on the liquid in question, and are described in his paper.

In particular, like Campbell, for the quantities of conventional oil in certain Middle East OPEC countries, and also in former Soviet Union countries, he significantly reduces the 'proved-plus-probable' ('2P') values given in industry datasets for some countries to reflect his judgment of the more likely values, and where his paper gives the rationale for these adjustments.

The resulting URR values that Laherrère generates, and then uses in his model, are:

- **Conventional oil.** This includes condensates, but excludes extra heavy oil and natural gas plant liquids (NGPLs). URR= 2200 Gb. (Note, in his forecast given as Figure 8 of his paper, production of conventional oil is indicated in the legend as: 'crude oil plus condensates, less extra-heavies and NGPLs.')
- **Fallow fields.** These data are included in 'conventional oil' Laherrère's judgment is that: "while the number of such fallow fields is important, the volume of their reserves is not, being less than the uncertainty of the current value of the North Sea's total remaining reserves."
- **EOR, and scope for 'reserves growth'.** Laherrère discounts large contributions from EOR, at least in the sense of affecting the (near-term) peak in all-oil production his model predicts; see the detailed argument in his paper.
- **Natural gas plant liquids (NGPLs):** URR = 300 Gb.
- **Heavy & Extra-heavy oils.** In Laherrère's model these include: heavy oil needing thermal stimulation to produce, tar sands, and Orinoco oil. His 'rounded guess' for the total URR of Heavy & Extra-heavy oils is 500 Gb, but where he states: " … note that the shape of the production profile of this oil , and hence the date of [its] peak, and peak volume, is something of a wild guess".
- **'Light-tight' oil, and oil from kerogen.** For 'light-tight' oil he recognises the production of this, and note that some of the corresponding reserves of this are already in industry data. On oil from kerogen, he notes the potential for production, but at a low EROI ratio. On balance, he judges the contributions from these two classes of oil as "small compared to the corrections needed for 2P conventional oil reserves; and hence does not model explicitly the contributions from these two classes of oil."

- **Other liquids:** These include GTLs, CTLs & synthetic fuels, for which Laherrère states: " … I assume that for reasons of production cost, production will be too small, at least over the near and medium term, to be included in the model." The category also includes biofuels, where he models this as reaching a production asymptote of 3 Mb/d. In his forecast (Figure 8 of his paper) biofuels are the main component of his 'other-liquids' production curve.
- **Refinery gain.** This is modelled as 3% of the total crude oil production less the extra-heavies.

Summarising the above URR values, we have (and see also Table 11):

Oil category	**URR (Gb)**
Conventional oil (including condensate)	2200
Natural gas plant liquids (NGPLs)	300
Extra heavies (heavy oil needing thermal stimulation, tar sands & Orinoco oil)	500
Total: All-oils	**3000**
Other Liquids	
Refinery gain (3% crude – extra-heavy)	75
Other liquids (mainly biofuels, but also GTLs, CTLs & synthetic fuels)	Production rising to an asymptote of 3 Mb/d.

Source	Conv. oil (incl-RG)	NGLs	Conv. + NGLs	Extra-heavy	'Light-tight'	Total All-oil	Ref'y. gain	Other Liquids	Total All-liquids
Laherrère	2200	300	2500	500	Incl. in Conv.	3000	75	Rising to 3 Mb/d	n/a

Table 11. Laherrère estimated URR values (rounded). (Gboe).

Notes:

Laherrère cautions that:

- He does not use the term 'conventional oil'; using instead 'crude oil less extra-heavy', where 'crude oil' itself includes condensates, as his data correspond to US EIA definitions.
- Refinery gain should not be quoted with a URR, as it reflects a change in volume but not in weight.
- The data for NGLs here have been corrected for energy content. (This is not likely to be the case with some of the other NGLs data in this paper.)
- Subtracting only 50 Gb from the IHS CERA data for cumulative production to end-2010 of 'liquids' (as defined by IHS), in order to generate a figure for the cumulative production to end-2010 of conventional oil alone, is probably an underestimate of the size of the adjustment needed. IHS Energy data record Orinoco (i.e. heavy oil) discoveries in four fields from 1936 to 1939 totalling 215 Gb.

As shown, Laherrère's resulting URR value for conventional oil (including NGLs), and keeping the above caveats in mind, is 2500 Gb. This is essentially the same as Campbell's estimate of 2470 Gb. This is not surprising because, as mentioned above, both analysts judge that some of the industry dataset '2P' discovery data need significant reductions.

2.7 Richard Miller

Finally in this section, we turn to the oil forecast model of Richard Miller. This model is bottom-up by field, and is a follow-on to one originally developed and run within BP. It is described in Miller (2015).

In terms of generating URR estimates by summing the model's output to a distant future date, the model has the problem that individual field production data are only held in the model's database from 1992. Thus to generate global URR estimates by oil category, some other source of cumulative production to-date is needed.

In the estimates kindly provided below by Miller, he takes as this value that given in the paper by Jackson and Smith (2014) in the Roy. Soc. *Phil. Trans. A* theme issue: *The future of oil supply*. This gives (and see the graph of the same data in Figure 2 of Bentley & Bentley (2015b) the global liquids cumulative production to end-2010 as 1247 Gb.

Miller's model forecasts production to 2100, but even at this date still shows small amounts of production by oil category, so in the data below he adds on a small extra quantity to account for production post-2100. His URR estimates then are:

Oil category	URR (Gb)
Conventional oil (excludes most condensate and excludes NGLs; includes 'light-tight' oil)	2580
Canadian tar sands	136
Venezuela extra heavy	88
Total: All-oils (rounded)	**2800**

Note that these URR data exclude most of the condensate, the NGLs, oil from kerogen, refinery gain, and any of the 'other liquids' (GTLs, CTLs and biofuels).

We can make three adjustments to the above data:

- As mentioned, the cumulative production data refer to the IHS CERA 'liquids' category, which includes the very heavy oils, tar sands and Orinoco oil, and NGLs. For this reason, and as indicated earlier in this paper, it is probably fair to subtract perhaps up to 50 Gb from the conventional oil URR given above; bringing the latter to 2530 Gb.
- Secondly, Miller does not include NGLs in his estimate of the conventional oil URR, nor provide estimates for these NGLs. If we take, rather arbitrarily, a URR for NGLs of ~300 Gb, this puts the conventional oil URR (incl. NGLs) as ~2800 Gb
- Finally, Millers model is explicit in bringing on-stream fairly rapidly oil currently in fallow fields (see Miller, 2015), where this generates the noticeable 'Miller bump' in production in the relatively near future (see his paper, and the UKER *Global Oil Depletion* report, Sorrel *et al.*, 2009). If all of this 'bump' is discounted as unlikely to be produced (probably overstating the case), then this reduces the above URR estimates by 140 Gb. Removing a part of the 'Miller bump' gives an estimated resulting value for Miller's URR for conventional oil (excluding NGLs) as ~2450 Gb; and a corresponding value of ~ 2700 Gb if imputed NGLs are included.

The above considerations lead to the summary data given in Table 12.

Source	Conv. oil (incl-RG; ex-NGLs)	NGLs	Conv. + NGLs	Extra-heavy	'Light-tight'	Total All-oil	Other Liquids	Total All-liquids
Miller	2530	[300] est'd.	~2800	225	Incl. in Conv.	n/a	n/a	n/a
If 'Miller -bump' removed	2390	"	~2650					
If part of 'bump' removed	~2450	"	~2700					

Table 12. Summary table: Miller's estimated URR values; conventional oil production to-date adjusted down by 50 Gb. (Gb.) NGLs data from other sources.

Miller's approximate value URR imputed here of conventional oil plus NGLs of ~2700 Gb is part-way between the corresponding URR estimates of Campbell and Laherrère, and that of Globalshift Ltd; and again well below the 'mainstream' estimates.

3. Interim Summary

The third part of this article will look at additional URR estimates, including those implicit in forecasts by the more 'mainstream' oil forecasting organisations, such as the IEA, BP & ExxonMobil. Having done this, the aim is to then to draw conclusions based on the data presented in the whole paper (Parts 1 to 3), with a view of making a judgement on the likelihood of the associated forecasts.

Here, however, we restrict ourselves to summarising the some of the data presented above, particularly those that relate to the global URR for conventional oil. This is done in Table 13.

Author	Date of study	Conv. oil reserves growth	Conv. oil + reserves growth	NGLs	Total Conv. oil (incl. RG & NGLs)	'Light-tight' oil	Very heavy oils	Total All-oil
US EIA	2013				4250	345		
"	2015					420		
IEA	2013	500			4350	215	1470	6000
"	2014		3515	475	4000	345	1880	6220
IHS CERA	2014	760			4000	485	470	5000
Campbell	2015		2250	220	2470	In heavy	260*	2730
Globalshift	"		2500	370	2900	150	150	3200
Laherrère	"		2200	300	2500	In conv.	500	3000
Miller	"		~2450**	~300	~2700	In conv.	225	~2900

Table 13. Summary of URR estimates by category of oil. Data in Gb (rounded).

Notes:

- *For Campbell, this figure combines 'light-tight' oil plus very heavy oils (tar sands & Orinoco oil).
- **For Miller, the NGLs data of ~300 Gb is imputed, based on other sources; from which the imputed ~2700 Gb value for 'Conv. oil + reserves growth + NGLs' is derived.
- RG: Reserves growth.
- Definitions by category of oil are not consistent between authors, such that exact comparisons from these data are not possible.
- 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 in this Table are far more uncertain than the degree of rounding shown above would indicate.

4. Conclusions

The data in Table 13 are very approximate in themselves, and too approximate to afford exact comparisons.

Nevertheless, the divergence in URR estimates for conventional oil, and also for 'all-oil', between the more 'mainstream' organisations (US EIA, the IEA, and the consultancy IHS CERA), and the 'independent forecasters' of Campbell, Globalshift Ltd., Laherrère and Miller is far too large to ignore, and needs a solid explanation. Part 3 of this paper will examine this difference in URR estimates in greater detail.

Moreover, it is worth recalling that the historical URR estimates for global conventional oil given in Part 1 of this paper (there excluding NGLs) mostly fell in the range 1800 to 2500 Gb. If one takes the view of the 'independent forecasters', then - and perhaps surprisingly - the estimated size of the global URR for conventional oil (ex NGLs) does not seem to have changed much over the years (see the column 'Conv. oil + reserves growth' in Table 13); where this lack of change has been despite increasing knowledge and technological progress. The consistency of government estimates for the UK's oil URR over the years (see successive UK 'Brown books' since 1974) lends weight to this apparent stability of URR estimates.

References

Ahlbrandt, T. S. (2002). *Future petroleum energy resources of the world*. Int. Geol. Rev. vol. 44, pp 1092 – 1104 (doi:10.2747/0020-6814.44.12.1092).

Andrews, S. and Udall, R. (2015). *Oil Prophets: Looking at World Oil Studies Over Time.* The Oil Age, Vol. 1 No. 3, pp 41 - 61.

Bentley, R.W. (2015). *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 1*. The Oil Age, Vol. 1 No. 3, pp 63 - 90.

Bentley, R.W. and Bentley Y. (2015a). *Explaining the Price of Oil, 1971 to 2014: The need to use reliable data on oil discovery and to account for 'mid-point' peak.* Energy Policy, Special issue on '*The Enigma of Economic Growth*', Vol. 86, pp 880-890.

Bentley, R.W. and Bentley Y. (2015b). *Explaining the Price of Oil, 1861 to 1970: The need to use reliable data on oil discovery and to account for 'mid-point' peak.* The Oil Age, Vol. 1 No. 2, pp 57 – 83.

Canadian Association of Petroleum Producers (2011). *Statistical handbook for Canada's upstream petroleum industry*. Calgary, Alberta.

Campbell, C.J., (2015). *Modelling Oil and Gas Depletion*. The Oil Age, Vol. 1 No. 1, pp 9-33.

EIA (2012). United States Energy Information Administration. *Annual Energy Outlook 2012 with projections to 2035*. DOE/EIA-03832012. Washington, DC.

EIA (2013). US Energy Information Administration report: *Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries outside the US*. Update June 13 2013

IEA (2012). *World Energy Outlook 2012*. International Energy Agency, Paris.

IEA (2013). *Resources to Reserves*. International Energy Agency, Paris.

Jackson, P.M. and Smith, L.K. (2014). *Exploring the undulating Plateau: the future of global oil supply*. Phil. Trans. R. Soc. A vol. 372 20120491.

Laherrère, J. H. (2015). *A Global Oil Forecasting Model based on Multiple 'Hubbert' curves and Adjusted Oil-industry '2P' Discovery data: Background, Description & Results*. The Oil Age, Vol. 1 No. 2, pp 13 - 37.

Miller, R.G. (2015). *A Bottom-up Model of Future Global Oil Supply*. The Oil Age, Vol. 1 No. 2, pp 39 - 55.

Smith, M. R. (2015). *Forecasting Oil and Gas Supply Activity*. The Oil Age, Vol. 1 No.1, pp 35-58.

Sorrell, S., Speirs, J., Bentley, R., Brandt, A., Miller, R. (2009). *Global Oil Depletion - An assessment of the evidence for a near-term peak in global oil production*. Technology and Policy Assessment report: UK Energy Research Centre, August 2009. ISBN 1-903144-0-35 (Go to: www.ukerc.ac.uk & search 'TPA reports').

Sperling, D. and Gordon, D. (2009). *Two Billion Cars: Driving Toward Sustainability*. Oxford University Press.

USGS (2000). US Geological Survey World Energy Assessment Team. 2000. *USGS World Petroleum Assessment*, Denver Co.

Zucchetto, J. (2006). *Trends in Oil Supply and Demand, the Potential for Peaking of Conventional Oil Production, and Possible Mitigations Options. A Summary Report of the Workshop*. October 20 & 21 2005, US National Research Council. Available from: www.nap.edu.catalog/11585.html

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