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

R.W. BENTLEY

1. Introduction

This is the first part of a two-part article looking at the link between the estimated size of the global ultimately recoverable resource (‘URR’) of conventional oil and forecasts which have used this value. The second part will be published in the next issue of this journal.

Those studying the future of global oil supply have the problem that current oil forecasts from different individuals and organisations give significantly different predictions. Only a few years’ back the difference between such forecasts was very large: one set of forecasts saw global production of ‘all-oil’ as reaching a resource-limited peak in the near or medium-term, followed by a steady decline, while other forecasts predicted that production of this oil would be able to keep rising in a normal ‘business-as-usual’ manner out to the end of the forecast time horizons.

This first set of forecasts included those by Campbell, Laherrère, Miller, Deffeyes, Energyfiles, Germany’s BGR, LBST and the University of Uppsala, while the latter were mainly those from the ‘mainstream’ oil forecasting organisations, such as the IEA, US' EIA, OPEC, an EU study, some of the oil consultancies, and most of the oil majors. It was clearly very unsatisfactory to have such a wide divergence of forecasts, given the importance of the topic to the global economy and to society as whole.

To understand the differences between forecasts at that time, and hence see which was most likely, the UK Energy Research Centre (UKERC) undertook a major study, summarised in the *Global Oil Depletion* report (Sorrell *et al.,* 2009). This included a detailed comparison of a range of then-current forecasts, with the results being given in the study's Technical Report 7 (Bentley et al., 2009). The study as a whole looked primarily at the future global production of only conventional oil, and concluded:

> "*On the basis of the current evidence we suggest that a peak of conventional oil production before 2030 appears likely and there is a significant risk of a peak before 2020*."

However, the study did also report on a number of forecasts that covered the global production of 'all-liquids'.

More recently there have been two significant developments in global oil forecasting. Firstly, most of the 'mainstream' forecasting organisations listed above have now begun to recognise the likely existence of a near-term peak (or at least a plateau) in the global production of *conventional* oil, see the charts in *The Oil Age* Vol. 1 No. 2. Secondly, partly in response to the 'light-tight' oil now being produced by hydraulic fracturing in the US, there is greater attention on forecasts of 'all-liquids' production, and on the components of this (again, see the charts mentioned).

Even so, despite these recent developments, there still exists today an uncomfortably large gap between the forecasts which see a near or medium-term peak in global 'all-liquids' production, and those which see this supply, though admittedly now somewhat constrained, as still able to increase to meet expected demand out to the end of the forecast horizons (typically now to 2035 or 2040). So there is still a need to understand why such significant differences in oil forecasts can exist, and to judge which set of forecasts is the more likely.

1.1 Differences between Forecasts in the Size of Global Conventional Oil URR

There are of course a number of reasons for such differences. But one of the main reasons, already identified at the time of the UKERC study, is the difference between the sizes assumed for the ultimately recoverable resource ('URR') of global *conventional oil*. This subject is the main focus of this paper. To discuss it, we need to be clear on the various categories of oil considered, and also on what is generally meant by 'ultimately recoverable resource'. This is covered in the next two sections.

1.2 Definitions

There are many types of hydrocarbon liquids, and there is no fully standard way to classify them. Here we define:

Conventional oil: Taken as referring to *flowable oil in fields*, i.e., oil that has migrated to a trap, and from which, under a 'standard' drive mechanism such as own-pressure, mechanical lift, or gas- or water-drive, it is able to flow to a production well. The bulk of all oil produced currently, and by far the largest part of that historically, has been of conventional oil.

Non-conventional oils: These tend to be found in geographically extensive regions (within which there may be 'sweet spots'), and where flow to a production well is not possible without significantly changing the nature of the oil (for example, by heating, or treating with a solvent), or that of the surrounding material (for example, by hydraulic fracturing ('fracking') of the rock, or by mining the sand, in which the oil resides). These non-conventional oils include:

- Light-tight ('shale') oil: light oil trapped in very low permeability rock, and which requires fracking of the rock, and these fractures to be kept open by proppants, for its production.
- Very heavy oils that require thermal stimulation to be produced (though these are sometimes classed within conventional oil).
- Oil produced from tar sands, either by mining the sand and then separating and upgrading, or produced thermally *in-situ*.
- Heavy oil from the Orinoco basin.

Liquids from gas, either in the same field as oil, or from a separate condensate or gas field. Sometimes these liquids are included in oil production data: They are:

- Condensate, liquids which condense out of the gas at surface temperature and pressure.
- Other natural gas liquids (NGLs), including those produced in a processing plant (NGPLs).

'Other liquids'. These do not come from either oil or gas fields. They include:

- Oil produced from the oil pre-cursor kerogen (giving 'oil-shale' oil), either by mining the rock and retorting, or by retorting in situ.
- Liquids produced by chemically altering natural gas ('gas to liquids', GTLs).
- Liquids produced by chemically altering coal ('coal to liquids', CTLs).
- Oil from biomass (including directly from oil seeds; or from alcohol produced from corn, sugar-cane or other biomass; or produced from biomass by some other process).

In addition, in forecasting total liquids production, account must be taken of refinery gain.

Thus we get the three main categories of oil liquids:

- **Conventional oil:** Crude oil plus condensate, but excluding the non-conventional oils ('light-tight' oil, extra-heavy oil, oil from tar sands, and Orinoco oil), and also excluding oil from kerogen. Some sources, such as the UKERC report, include NGLs in their definition of 'conventional oil', but here - in order to be able to compare to URR estimates made back in the 1960s to 1980s - we do not. (NGLs are therefore in 'all-oil', see the next category.)
- **All-oil:** Conventional oil, plus: non-conventional oils, NGLs, and oil from kerogen.
- **All-liquids:** All-oil, plus: CTLs, GTLs and biofuels.

The reason for differentiating conventional oil from the non-conventional oils (and other liquids) is that conventional oil is generally *intrinsically* cheaper, and has a better energy return ratio, than these other liquids; see the discussion in Bentley & Bentley (2015).

1.3 Meaning of ultimately recoverable resource (URR)

Now we consider what is meant by a field's, a region's, or the global 'ultimately recoverable resource' (URR) of a class of liquids.

The *reserves* of an oil field give the amount of recoverable oil remaining in the field at a given point of time. The *resource* of the field, by contrast, refers to the total amount of oil in-place, and thus includes the oil that is recoverable and unrecoverable. (Note that for reserves there is a strong need to distinguish proved ('1P') reserves from proved-plus-probable ('2P') reserves, see Bentley & Bentley, 2015.)

For a region comprising a number of fields, there are also fields yet to find. Here the term 'reserves' refers only to oil that has been discovered. The resource for a region, by contrast, includes the oil yet to be discovered. Thus at a given point in time, a region's ultimately recoverable resource (URR) is given by:

URR = cumulative production to-date + proved-plus-probable reserves + recoverable oil yet-to-find

Note that this estimate of URR can be expected to change with the recovery technology used, and the price of oil.

So if the URR can change with technology or oil price, what is meant by 'ultimately' in this context? Most modellers today do not think in terms of a true ultimate 'ultimate' (who knows what oil extraction technology might be economic in 100 years?), but in more pragmatic terms of how much their models expect to see produced of a given class of oil out to some rather distant date, for example to 2070 or 2100.

In addition, some forecasters take optimistic views of how much extra *conventional* oil new technology or a higher price can bring on-stream. With the current global volume-weighted average recovery factor of oil in fields at perhaps only 40%, there is a great deal of *theoretically* potential oil that can be gotten from these fields. But other forecasters point to calculations by reservoir engineers, and to the fact that two near-decade-long periods of high oil prices (above $60/bbl in current real terms) did not bring on much extra oil. Because of this difference of views, this 'scope for true 2P reserves growth' question remains an important research topic.

2. The UKERC Study, 2009

Now we return to the UKERC *Global Oil Depletion* study mentioned above, as this developed a useful approach for examining the differences between oil forecasts. This approach was developed by Dr. Richard Miller (one of the report's authors), and looked explicitly at the link between the assumed (or imputed) global URR for conventional oil used in the forecast, the date of peak production of this oil (if peak occurred within the forecast horizon), and the predicted or imputed rate of post-peak decline in the production of this oil.

Figure 1 shows the predictions for global oil production out to 2030 made by the different forecasts examined in the UKERC report.

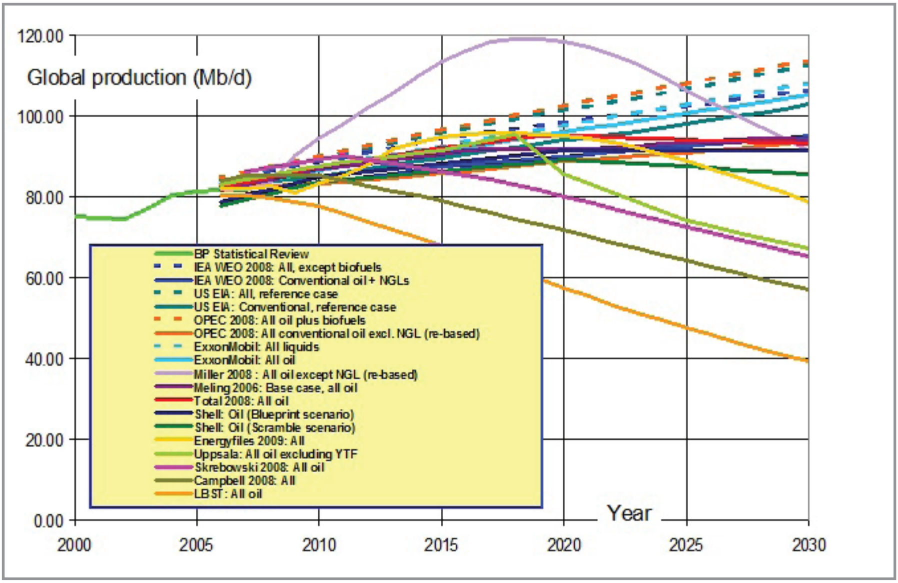

Figure 1: Forecast global oil production (covering various categories of oil) vs. date.

Legend (from top) is:
BP Statistical Review (historical data)
IEA WEO 2008: All oil, except biofuels
Ditto: Conventional oil + NGLs
US EIA: All-oil, reference case
Ditto: Conventional oil, reference case
OPEC 2008: All-oil plus biofuels
Ditto: All conventional oil excl.
NGL (re-based)
ExxonMobil: All liquids; All-oil
Miller 2008: All-oil except NGL (re-based)
Meling 2006: Base case, all-oil
Total 2008: All oil
Shell: Oil (Blueprint scenario)
Ditto: (Scramble scenario)
Energyfiles 2009: All-oil
Uppsala University: All oil except yet-to-find
Skrebowski 2008: All-oil
Campbell 2008: All-oil
Ludwig-Bölkow-Systemtechnik GmbH (LBST): All-oil

Source: UKERC Global Oil Depletion report (2009).

As figure 1 shows, at that date there were three distinct classes of forecast:

- Forecasts that showed global oil production peaking before 2030. These were mainly from the 'independent' forecasters: Energyfiles, LBST, University of Uppsala, Miller, Campbell and Skrebowski.
- Forecasts that saw production increasing out to 2030, but flattening out. These were either from the 'mainstream' forecasters but for conventional oil, or were for 'all-oil' from the other oil companies reviewed: Shell, Total and StatoilHydro (where the latter was a private forecast from a senior employee).
- Forecasts for a roughly linear increasing trajectory for global oil production out to 2030 (the end of the forecast period). These forecasts were mainly for all-oil from the 'mainstream' forecasters: the IEA, US EIA, OPEC, and ExxonMobil.

The difference between these forecasts was not explained simply by the categories of oil they covered. For example, the US EIA forecast had a roughly linear plot for global conventional oil production, with this reaching ~103 Mb/d by 2030, whereas at the other end of the spectrum LBST forecast 'all-oil' production to fall to only 40 Mb/d by the same date. The main difference between the forecasts was that between the 'mainstream' oil forecasters and the others. (And note that only a few years earlier these 'mainstream' forecasts had been for global supply to grow much faster still, to reach around 120 Mb/d by 2020.)

To examine the assumptions - not always explicit - in the above forecasts for conventional oil, and to see how likely were these assumptions, Miller's analysis is given in Figure 2.

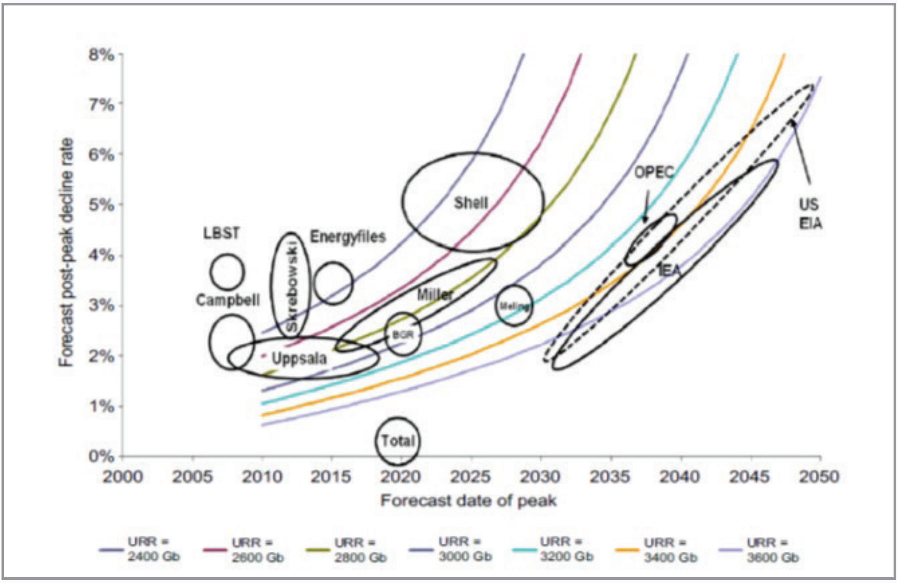

Figure 2: Date of peak vs. post-peak decline rate and size and ultimately recoverable resource (URR) for conventional oil.

Graph developed by Dr. Richard Miller to examine the differences between the forecasts for (primarily) conventional oil. Iso-lines represent the assumed or implied global URR of conventional oil. Rate of production increase prior to the peak was set to 1.3%/year. Mapping of individual forecasts onto the graph involved some judgment. Conventional oil here includes crude oil, condensate and NGLs, but in some cases also included production from currently operating and planned oil sands production as this was difficult to separate out. Excluded was oil from oil sands plants not yet planned, oil from kerogen shale, and other liquids (GTLs, CTLs and biofuels). Note that the forecast from Total included extra-heavy oil in its model.

Source: UKERC Global Oil Depletion report (2009).

On such a plot, forecasts that showed global production of conventional oil as peaking before 2030 are to the left, while the 'quasi-linear' forecasts are to the right. As the plot shows, most forecasts which had the date of peak as 2020 or before (LBST, Campbell, Skrebowski, Energyfiles, Uppsala University, BGR and Miller) typically had fairly low URR's for conventional oil, and also 'medium' post-peak decline rates (from 2 to 4% p.a.); while the 'mainstream' forecasts of OPEC, US EIA and the IEA were constrained to have high URRs for conventional oil (from ~3,250 to ~3,800 Gb); and also post-peak decline rates that were quite high (~ >5% p.a.) if the date for peak was assumed to be after 2040.

Thus - in broad terms - the large difference between the forecasts in Figure 1 for global 'all-oil' oil production could be explained mainly by differences in the URRs assumed or implied for conventional oil; and in the post-peak decline rates assumed or implied.

Next we look at more current forecasts.

3. Current Forecasts

As mentioned earlier, current oil forecasts still give very different predictions, now generally for 'all-liquids' production. In broad terms, the current forecasts can be classified as:

- Forecasts that see the global production of all-liquids as probably peaking within less than a decade from the date of assessment; see e.g., Campbell (2015), Laherrère (2015).
- Forecasts that have global all-liquids as peaking, but not until perhaps 2025 to 2035; see e.g., Smith (2015), Miller (2015).
- Forecast that see no-peak in all-liquids production out to the end of their forecast horizons of 2035 to 2040. (See e.g., the charts mentioned earlier for IEA, BP and ExxonMobil given in *The Oil Age*, Vol. 1, No. 2).

As in the explanation given above for the UKERC study, it would seem that a significant part of the differences between current forecasts still lies in the URR values they assume for conventional oil, though now also – and to a lesser extent - in the rates of production assumed for the non-conventional oils and other liquids.

It is for this reason that this paper presents data on some of the estimates for the size of the global conventional oil URR made at different dates, and by different sources. These data illustrate two things:

- Firstly - and perhaps surprisingly - that in the view of the 'near-peak' oil forecasters, the size of this URR has not changed by much over the years, despite increasing knowledge and technological progress.
- Secondly, the large current disagreement between the 'near-peak' and the 'far-peak' (or, indeed, 'no-peak') forecasters over what is realistic to assume for this URR, and hence difference in their resulting forecasts.

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

In terms of the information provided here, see also the excellent broader summary of, and commentary on, global URR values given by Andrews and Udall in this issue.

4. URR Data: Conventional oil; and Also for other categories of oil and liquids

This section gives a selection of estimates of global URR values for conventional oil, and for other categories of oil and liquids, from a variety of sources and over a range of dates. The URR values are selected as having a bearing on the various oil forecasts discussed here, and also on the general problem of the disagreement between forecasts mentioned above. The selection starts with some early estimates for the global URR of conventional oil used, or listed, between 1956 and 1981.

4.1 Relatively early estimates for the global URR of conventional oil, from 1956 - 1981

Table 1 shows some relatively early estimates for the global URR of conventional oil and (in most cases) the corresponding predicted dates of the production peak of this category of oil. (As mentioned, for a more exhaustive list of URR estimates, see Andrews and Udall in this issue.)

Table 1. Estimates from 1956 - 1981 of Global URR for conventional oil (almost certainly ex-NGLs), and Corresponding predicted dates for peak or plateau of global production of this category of oil.

Date	Author	Hydrocarbon	Ultimate Gb	Date of global peak
1956	Hubbert	Cv. Oil	1250	"about the year 2000" [at 35 Mb/d]
1969	Hubbert	Cv. Oil	1350 2100	1990 [at 65 Mb/d] 2000 [at 100 Mb/d]
1972	ESSO	Pr. Cv. Oil	2100	"oil increasingly scarce from ~2000."
1972	Report: UN Confr.	Ditto.	2500	"likely peak by 2000."
1974	SPRU, UK	Ditto.	1800-2480	no prediction
1976	UK DoE	Ditto.	n/a	"about 2000"
1977	Hubbert	Cv. Oil	2000	1996 if unconstrained logistic; plateau to 2035 if production flat.
1977	Ehrlich et al.	Ditto.	1900	2000
1978	WEC / IFP	Pr. Cv. Oil	1803	no prediction
1979	Shell	Ditto.	n/a	"plateau within the next 25 years."
1979	BP	Ditto.	n/a	Peak (non-communist world): 1985
1981	World Bank	Ditto	1900	"plateau at ~ turn of the century."

Notes: Cv.: Conventional. Pr.: Probably. Gb: billion barrels.

'Ultimate': Ultimately recoverable resource (URR); this is equal to the recoverable portion of the original total in-place oil resource.

This table is not complete; one notable omission is the WAES study from the late 70s / early 80s; there are probably other forecasts omitted also.

Methodologies:

- 1956 Hubbert: Used a global ultimate from Weeks (but modified); and predicted production via a hand-drawn curve constrained to fit this URR, past production, and judged realistic future production.
- 1969 Hubbert: Used symmetric logistic curves.
- 1972 Ward & Dubois, a report to the UN.
- 1977 Hubbert: Used a global ultimate from Nehring; and assumed two cases: an unconstrained logistic curve, this generated a 1996 peak; and flat demand flat from 1974, which generated a production plateau lasting to 2035. (Actual global oil demand post-1974 was between these two cases.)
- 1979 BP: Ultimate for conventional oil for the non-communist world, ex NGLs. With unconstrained demand this gave a peak at 1985. This prediction was later used (e.g., variously by Odell, Mitchell and Smil) to dismiss all such 'fixed-resource' predictions. In fact the size of the URR assumed was about right for the oil covered (non-communist conventional oil, ex-NGLs), but global demand fell sharply post the 1978 price shock, rather than rising as assumed in the BP forecast.

Source: Bentley & Boyle (2008); Detail on sources is given in the Annex.

At these dates, it is almost certain that the URR estimates in Table 1 referred only to conventional oil (i.e., essentially, oil in fields), and did not include NGLs. Also at these dates the existence of light oil trapped in rock (but not its extraction process), of the extensive quantities of oil in tar sands, and very large quantities of oil potentially producible from kerogen were well known, see for example the estimates quoted by Hubbert (1949) for tar sands and kerogen oil, but these are not included in the URR estimates given above, which relate to conventional oil only.

The conclusion to be drawn from Table 1 is that at that time the URR estimates for global conventional oil (ex-NGLs) ranged typically from 1,800 to 2,500 Gb, with the resulting dates for the corresponding global peak or plateau in production (predicted prior to the large global fall in oil demand triggered by the 1978 price shock) mostly lying around the year 2000.

The next section examines some somewhat later URR estimates, up to the year 2005; where these cover a range of categories of liquids.

4.2 Somewhat later estimates of the global URR for conventional oil, and also non-conventional oil and other liquids, 1992 to 2005.

These later data are given in Tables 2 and 3. Table 2 gives URR estimates mostly associated with a prediction for date of peak, and are data mostly from non-'mainstream' forecasts, except for the significant 1998 IEA forecast (that has been written about by several authors in Campbell, Ed., 2011); and the 2002 BGR forecast. Table 3 gives forecasts from a range of the 'mainstream' forecasters, none of which saw oil production as reaching peak or plateau within their forecast horizons; and where for some of these URR estimates were given.

Table 2. Later estimates for the global URR of conventional oil, and also non-conventional oil and other liquids, 1992 to 2005.

Date	Author	Hydrocarbon	Ultimate Gb	Date of global peak
1992	D. Meadows *et al.*	Pr. Cv. Oil	1800-2500	no prediction
1995	Petroconsultants, '95.	Cv. oil (xN)	1800	About 2005
1996	Ivanhoe	Cv. Oil	~2000	About 2010 [Prodn. mirrors Disc.]
1997	Edwards	Pr. Cv. Oil	2836	2020.
1997	Laherrère	All liquids	2700	no prediction
1998	IEA: *WEO 1998*	Cv. Oil	2300 ref.case	2014
1999	Magoon of the USGS	Pr. Cv. Oil	~2000	Peak ~ 2010.
2000	Bartlett	Ditto.	2000 & 3000	2004 & 2019, respectively.
2002	BGR (Germany)	Cv.&Ncv. Oil	Cv.: 2670	Combined peak in 2017.
2003	Deffeyes	Cv. oil*		~2005 [Hubbert linearisation.]
2003	P-R Bauquis	All liquids.	3000	Combined peak in 2020.
2003	Campbell-Uppsala	All h'carbons		Combined peak ~2015 [Includes gas infrastructure constraints.]
2003	Laherrère	All liquids	3000	See notes.
2003	Energyfiles Ltd.	All liquids	Cv: 2338	2016 (if 1% demand growth).
2003	Energyfiles Ltd.	All h'carbons		Combined peak ~ 2020 [Includes gas infrastructure constraints.].

Date	Author	Hydrocarbon	Ultimate Gb	Date of global peak
2003	Bahktiari model.	Pr. Cv. Oil		2006 - 7
2004	Miller, BP- own model	Cv.&Ncv. Oil		2025: All poss. OPEC prodn. used.
2004	PFC Energy	Cv.&Ncv. Oil		2018 - Base case.
2005	Deffeyes	Cv. oil*		2005 [Hubbert linearisation.]

Notes: Cv.: Conventional. Pr.: Probably. xN: ex-NGLs. +N: incl. NGLs. All liquids: Conv. and Non-conv. oil plus NGLs. All h'drocabons: Conv. and Non-conv. oil and gas. Gb: billion barrels.

* = and probably all-oil.

'Ultimate': ultimately recoverable resource (URR); equal to the recoverable portion of the original total in-place resource.

Laherrère: Laherrère, probably as much as anyone, knows how uncertain are the oil data, particularly as far as which of the possible non-conventional oils, and oil substitutes, are likely to yield useful volumes on a world scale. At this date (2003) he was reluctant therefore to break this 3 Tb estimate into components; but a reasonable guess (personal communication) was: 2.0 Tb for conventional oil, 0.3 Tb for NGLs, 0.3 Tb for tar sands, 0.3 Tb for Orinoco and other very heavy oils, and 0.1 Tb for refinery gains and GTLs etc.

Source: Bentley & Boyle (2008); Detail on sources is given in the Annex.

The conclusions from Table 2 are:

- This later range of URR estimates and production forecasts explicitly sometimes included allowance for the production of non-conventional oils, and other liquids,
- As these forecasts were made well after the 1970s price shocks, allowance was now included for the fall in demand that had resulted from the period of oil high prices.
- Within this period, two 'mainstream' forecasts did predict a peak in oil production; that of the IEA 1998 forecast, and the Germany BGR forecast in 2002.
- URR estimates for *conventional* oil were mostly still in the range 1,800 to 2,500 Gb; (Bartlett's 2,000 and 3,000 Gb data were more of a 'let's see when peak is, if the URR has these values').
- URR estimates including non-conventional oil, or all-liquids, increased the URR up to ~3,000 Gb.

Within this period, we can also examine a number of the more typical 'mainstream' forecasts; these are given in Table 3.

Table 3. Data on a number of 'mainstream', mostly non-peak forecasts, 1998 - 2005.

Date	Author	Hydrocarbon	Ultimate (Gb)	F'cast date of peak (by study end-date)	World prod. Mb/d 2020 2030
1998	WEC/IIASA-A2	Cv. Oil		No peak	90 100
2000	IEA: *WEO 2000*	Cv. oil (+N)	3345	No peak	103 -
2001	US DoE EIA	Cv. Oil	3303	2016 / 2037***	Various
2002	US DoE	Ditto		No peak	109 -
2002	Shell Scenario	Cv.& Ncv. Oil	~4000*	Plateau: 2025 – 2040	100 105
2003	'WETO' study	Ditto	4500**	No peak	102 120
2004	ExxonMobil	Ditto		No peak	114 118
2005	IEA: *WEO 2005*				
	Reference Sc.	Ditto		No peak	105 115
	Deferred Invest.	Ditto		No peak	100 105

Notes: Mb/d: Million barrels per day. Cv.: Conventional. Ncv: Non-conventional. (+N): Plus NGLs.

*Shell's ultimate of 4,000 Gb was composed of: ~2,300 Gb of conventional oil (incl. NGLs); plus ~600 Gb of 'scope for further recovery' ('SFR') oil; plus 1,000 Gb of non-conventional oil.

**WETO's ultimate of 4,500 Gb is for conventional oil only; it started with a USGS figure of 2,800 Gb, then grew this by assuming large and rapid recovery factor gains to 2030.

***These are results from an EIA paper that assumed a global URR of 3,303 Gb and then applied various R/P ratios (and hence post-peak decline rates). An R/P ratio of 10, giving the peak at 2037, matched US experience (for 100 years!), but based on 1P reserves data. This gave a very sharp post-peak rate of production decline. Only the post-peak decline rate corresponding to the peak date of 2016 (for this URR of 3,303 Gb) was realistic in terms of typical regional oil production behaviour; the EIA paper did not seem to recognise this.

The conclusions from Table 3 are;

- Over this period, the bulk of 'mainstream' forecasts predicted no peak in oil production out to 2020, or 2030.
- Use was now being made of the USGS year-2000 Assessment data (the 3,303 and 3,345 Gb estimates), see the next section on USGS estimates.
- Shell's values for the size of the components of the 'all-oil' URR were sensible, as is the plateau for 'all-oil' from 2025. But there was possibly no recognition that the earlier peak of conventional

oil production would lead to historically high oil prices (and hence global recession, and subsequent reduced economic activity) that the world has experienced since 2008.

- The WETO study URR of 4,500 Gb for conventional oil only was an outlier. (A technically polite way of saying ‘very unlikely’, in terms of ability of this oil to impact medium-term oil production, given the quantity of oil discovered to-date, and the declining long-term trend in oil discovery in new fields.)

Next we look at estimates for global URR generated by the United States Geological Survey (USGS) from 1991 to 2012.

4.3 USGS Assessments, 1991 to 2012

Over many years now the USGS has been unique in the world as a public institution in carrying out high quality detailed basin-based assessments of global undiscovered oil, for which they are much to be thanked. (Other institutions also carry out various important fossil fuel assessments, including Germany’s BGR, France’s IFP, the British Geological Survey and the World Energy Council, but the USGS assessments of undiscovered oil and gas are by far the most extensive.)

In assessments carried out prior to the year-2000, the USGS had formally decided to exclude reserves growth in these calculations, recognising that while such growth appeared large in the US, this was fundamentally an issue with US data, and it would be inappropriate to apply reserves growth factors to 2P data for regions outside the US (see comments at the time by C. Masters).

This changed with the Year-2000 Assessment, where a reserves growth factor was applied by globally (and possibly also by region, though not by country). Reserves growth refers to the change over time (usually growth, though sometimes reduction, especially for smaller later fields) in the estimated size of the total recoverable oil that will be produced by a field over its lifetime (and hence also in a region, if field data are aggregated). Reserves growth is a wonderfully complex topic, see for example the discussion in Bentley (accepted for publication).

Some earlier, and the Year-2000, USGS global assessments are tabulated in Table 4.

Table 4. Summary of USGS Global Oil Assessment Data, 1991 to 2000.

Date of Assessmt.	(Date of data used)	Category of oil included	URR			
			F95%	Mode	Mean	F5%
1991	(1990)	Cv., no RG, ex-NGLs		2200		
1994	(1993)	Cv., no RG, ex-NGLs	2100	2300	2400	2800
2000	(1996)	Cv., no RG, ex-NGLs	2000	2300	2300	2800
		RG	200	700	700	1100
		Cv. + RG; ex-NGLs	2200	2900	3000	3900
		NGLs + own RG	*200*	*300*	*400*	*500*
		Cv.+RG+NGLs+RG	**2400**	**3200**	**3300**	**4500**

Notes: Data have been rounded to make comparisons easier.

All data need re-checking; they are probably correct but please do not quote these data without checking back to the original sources; and please bring any errors to my attention.

Data in Gb (billion barrels). Cv. Conventional oil. RG: Reserves growth. NGLs: Natural gas liquids. F95%, mode, Mean, F5%: Probabilities.

URR: Ultimately recoverable oil resource. Here given by:

URR = Cumulative produced + ['2P'] Reserves + Yet-to-find

and, where stated, includes allowance for 'reserves growth', and NGLs, including the latter's own allowance for reserves growth.

USGS Assessments primarily look only at the question of the quantities of undiscovered oil, and only in specific basins outside of the US. Hence some basins, generally assumed less productive, are not included in these data. Moreover, the US data included in the above global totals come from other assessments, or from non-USGS sources (but are included in USGS' own summary tables). Likewise, the cumulative production and '2P' reserves data used to generate the above URR totals are not USGS data, but are drawn from other sources; in the case of the Year-2000 Assessment, from Petroconsultants' data.

Sources: USGS Assessments, as of dates specified.

The conclusions from Table 4 are:

- If we look at the 'mode' values for global URR (which in turn, are close to the 'mean' values), we can see that if only conventional oil is considered (i.e., excluding allowance for reserves growth or NGLs), then these changed little between assessments. They also sat comfortably within the URR range of 1,800 to 2,500 Gb that had been common for a long time (Tables 1 and 2).
- If reserves growth and NGLs (and the latter's own scope for reserves growth) are added, then the potential global URR can be

quite a bit larger, up to the mean value of 3,345 Gb generated by the Year-2000 Assessment.

[Perhaps the readers will excuse an anecdote here; to use a term first heard from my PhD supervisor Professor Peter Dunn, I have reached my anecdotage:

At the time the Year-2000 USGS Assessment was being prepared, I was working as the employee of the Oil Depletion Analysis Centre (ODAC) in London. I knew that the USGS was working on the Assessment, and would regularly 'phone their competent and amiable Ron Charpentier, who was in charge of pulling the final data together, to ask what the new global URR number was likely to be.

When told it was to be a big jump from previous assessments, as it now included reserves growth, I said that there was a danger that this new number would become 'carved in stone', and mislead the mainstream analysts. Ron saw this point of view, but pointed out that the Assessment methodology, including how reserves growth was calculated and why it was applied, would all be clearly stated, and it was up to analysts who used the data to make their own judgement on the issues. Both of us were right: the data, methods and reasoning were there for all to see; but also the new URR number of 3,345 Gb did indeed get 'carved in stone', and used without caveat in subsequent IEA and other 'mainstream' forecasts; see Table 3.]

The caveat that needed to be applied was to compare such a relatively high URR estimate with the amount of conventional oil that had been discovered to-date. No-one suggested that 3,345 Gb was too high *in principle*, but the questions centred on how fast the yet-to-find contained in this quantity would be found, given the much lower amount that had been found at that date, and the declining discovery rate of oil in new fields; and under what technical conditions and oil price, and how quickly, could the reserves growth also assumed in the URR estimate come on-stream. To some analysts the 3,345 Gb URR (incl. NGLs) seemed to require rather heroic assumptions, compared to lower range for the global URR for conventional oil that had seemed reasonable since about 1970, of 1,800 - 2,500 Gb (ex-NGLs).

We now turn to the updated more recent 2012 USGS assessment data. First we re-present the USGS Year-2000 data of Table 4 in a way to facilitate comparison with the 2012 data; this is done in Table 5.

Table 5. USGS Year-2000 Assessment: World conventional oil, including NGLs.

Report Date	Date of data (1 Jan)								
2000	1996	Cum. Prod	Reserves	--------Y-t-F--------			-----Ultimate-----		
				F95	Mean	F5	F95	Mean	F5
Total ex-RG		717	959	495	939	1589	2171	2615	3265
RG							265	730	1197
Total+RG							**2436**	**3345**	**4462**

Notes: All data in Gb. Cum. Prod.: Cumulative production. Reserves: 2P reserves; data from Petroconsultants S.A. Y-t-F: Yet to find (i.e., 'undiscovered') Ultimate: Ultimately recoverable resource ('URR'). F95, Mean, F5: Probabilities. RG: Reserves growth in the 2P data.

Source: USGS (2000).

Unlike Table 4 which just shows the URR totals, this table shows the components of this, broken out as cumulative production, 2P reserves, and yet-to-find. As can be seen (and Table 4 showed, rounded), a mean global allowance of 730 Gb was made for reserves growth, resulting in the total mean global URR for conventional oil of 3,345 Gb, if both NGLs and reserves growth were included.

Now we turn to the 2012 data. The USGS team in 2000 had accepted that their methodology for reserves growth was in part preliminary, based largely on US experience, so in work leading up to the 2012 Assessment a new approach was adopted. For the 2012 report they write: "Unlike past assessments of reserve growth that relied on statistical extrapolations of growth trends, this [new] methodology includes detailed analysis of geology and engineering practices observed in developed fields." But they add: "Because of the paucity of data for many fields outside the United States, data acquired from U.S. fields undergoing reserve growth were used as analogs in this study." The resulting Year-2012 data, comparable to Table 5, are shown in Table 6.

Table 6. USGS Year-2012 Assessment: World conventional oil, including NGLs.

Report Date	Date of data				
2012	2009-11	Cum. Prod	Reserves	Y-t-F	Ultimate
				Mean	Mean
Total ex RG		1250 [1]	1110 [2]	780 [3]	~3150
RG					723
Total+RG					~3850

Notes: All data in Gb. RG: Reserves growth.

- Though Year 2012 data are given by probability, this time these values have not been summed statistically as was the case in year-2000, so the 2012 totals are given only for the mean values (shown here).
- As far as I am aware, the USGS year-2012 Assessment did not give data for global cumulative production or 2P reserves, nor for yet-to-find in the US. Hence the following approximations have been made in compiling this table, with data not from the USGS year-2012 reports shown in the Table in italics:

1 Cum. Prod.: Based on the 2011 IHS Energy 'Liquids' value given in the text of Miller and Sorrell (2014), of 1,248 Gb. Then a guessed 100 Gb subtracted to take off the non-conventional oil component in the IHS 'Liquids' category; and a further guessed 100 Gb added back on for production 2012 to 2015 inclusive.

2 Reserves: 2P reserves. Likewise, based on the 2011 IHS Energy 'Liquids' value given in the text of Miller and Sorrell (2014) for cumulative discovery of 2,486 Gb, and with 1,248 Gb subtracted off to give 2P reserves. Then reduced to a guessed 1,100 Gb to reflect only conventional oil.

3 Y-t-F: Yet to find. The USGS Year-2012 Assessment gives an estimate for the global mean undiscovered, excluding U.S. Including NGLs this is 732 Gb. Adding on a guessed 50 Gb for the U.S. (reduced from the specified 83 Gb for the U.S. Y-t-F in the Year-2000 Assessment) gives an approximate total for global yet-to-find, including the U.S. and NGLs, of ~780 Gb.

Note that all three of these estimates (Cum. Prod., Reserves, and Y-t-F), while certainly approximate, would probably agree with data the USGS would produce for these categories for conventional oil plus NGLs to perhaps +/- 50 Gb or so.

USGS Sources:

- An Estimate of Undiscovered Conventional Oil and Gas Resources of the World, 2012. USGS Fact Sheet: 2012-3028, March 2012.
- Assessment of Potential Additions to Conventional Oil and Gas Resources of the World (Outside the United States) from Reserve Growth, 2012. USGS Fact Sheet: 2012-3052, April 2012.
- Assessment of Potential Additions to Conventional Oil and Gas Resources in Discovered Fields of the United States from Reserve Growth, 2012. USGS Fact Sheet: 2012-3108, August 2012.

As can be seen from Table 6, the Year-2012 Assessment puts global reserves growth of conventional oil (plus NGLs) as ~ 720 Gb, i.e., essentially unchanged from the Year-2000 value.

By contrast, given the passage of time, and hence the amount of oil that has been produced from 1996 to about 2010 or so, and the revised view of the quantity of oil yet to be discovered, the Year-2012 Assessment puts the global conventional oil URR (including NGLs), if based on the approximations made here, at ~3,850 Gb; i.e., about 500 Gb higher than the figure estimated in the Year-2000 Assessment.

So the key question is: How does this new estimate for the global URR of conventional oil agree with the amount of conventional oil that has been discovered to-date? This will be addressed in the second part of this paper, which will cover information from:

- IHS Energy, 2011
- The US EIA, 2013
- IEA *Resources to Reserves* report, 2013
- The oil models described in this journal to-date (Campbell, Smith, Laherrère, Miller and McGlade).
- The 'mainstream' forecasts for which charts were given in Issue-2 of this journal (IEA, BP and ExxonMobil).

It is the intention that a summary table of 'all-liquids' URR estimates from different authorities will be generated, including the components of this, to allow useful comparisons to be made.

5. CONCLUSIONS

The main conclusions to be drawn from the first part of this paper are:

1. Only a few years back, the difference between oil forecasts was very large; some seeing the peak production of conventional oil as being soon, others seeing no peak of this oil out to the end of their forecast horizons. Recently this gap has closed somewhat, with most forecasts now recognising the importance of modelling the various components of 'all-liquids' production, and where the global production of conventional oil (essentially, oil in fields) is expected to reach a peak (or at least a plateau) in the near to medium term.

2. Perhaps surprisingly, in the view of the 'near-peak' group of oil forecasters, the estimated size of the global URR for conventional oil (ex-NGLs) has not changed by much over the years, despite increasing knowledge and technological progress, still taking a value in the range 1,800 - 2,500 Gb.
3. There is, however, still wide disagreement over what is the most realistic value to assume for this URR; a disagreement that feeds directly into how near or far forecasters see the peak of global conventional oil production. This topic will be examined in detail in the second part of this paper.

Annex: Data Sources for Tables 1 to 3

A. General background and early sources

In the 1970s and early 1980s a variety of groups forecast the date of global oil peak, probably in some (or even most) cases using either Hubbert's own findings, or his general methodology. These forecasts included:

- ESSO used an ultimate of 2,100 Gb to expect: "oil to become increasingly scarce from about the year 2000", (The Ecologist, 1972, pp 18 and 130).
- B. Ward and R. Dubois, in a landmark environmental report to the United Nations, said: "One of the most quoted estimates for usable reserves [of oil] is some 2,500 billion barrels. This sounds very large, but the increase in demand foreseen over the next three decades makes it likely that peak production will have been reached by the year 2000. Thereafter it will decline", (Ward and Dubois, 1972, p184).
- The UK Department of Energy, in commenting on the expected date of the UK peak, noted that the world peak would not be far behind, at: "about [the year] 2000." (UK Dept. of Energy, 1976, p12).
- P. Ehrlich et al. calculated the global oil peak date at the year 2000 based on their 'high-estimate' for conventional oil endowment of 10,900 trillion MJ (~ 1,900 Gb), (P. Ehrlich et al., 1977, pp 400-404).
- Shell in 1979 expected oil production to: "plateau within the next 25 years." However, they did not specify the data behind this forecast. (Shell, 1979, p 1)

- The World Bank, on the back of an ultimate of 1,900 Gb, expected oil to “plateau around the turn of the century.” (World Bank, 1981, p 37, 46).

A number of other authorities at about this time also gave estimates for size of the global oil ultimate but did not carry these through to predictions for the date of peak. These included:

- The Science Policy Research Unit (SPRU) at Sussex University, which gave a range for the world oil ultimate as 1,800 – 2,480 Gb, (Cole et al., Eds., 1974).
- The World Energy Conference (WEC, now the World Energy Council), whose Commission report included a Petroleum Resources and Production study by the Institut Français du Pétrol. This estimated the world oil ultimate as 1,803 Gb. In commenting on this WEC/IFP study, J. Keily noted presciently: “The world can have the energy it needs for the rest of the 20th century. But … with a false sense of security, many will not look over the horizon to the early part of the 21st century. … It is only by looking beyond the early 2000s that we can see how fast the change will come.” (J. Keily, 1980, pp 26 - 32.)
- D. Meadows et al. in Beyond the Limits (sequel to Limits to Growth) quoted the range for the world’s oil ultimate as 1,800 – 2,500 Gb (D. Meadows et al., 1992). No forecast for date of peak was given; the group perhaps not aware of the serious implications of combining these data with a ‘decline from the mid-point’ model.

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