Background & Objectives

This journal addresses all aspects of the evolving Oil Age, including its physical, economic, social, political, financial and environmental characteristics.

Oil and gas are natural resources formed in the geological past and are subject to depletion. Increasing production during the *First Half* of the Oil Age fuelled rapid economic expansion, with human population rising seven-fold in parallel, with far-reaching economic and social consequences. The Second Half of the Oil Age now dawns.

This is seeing significant change in the type of hydrocarbon sources tapped, and will be marked at some point by declining overall supply. A debate rages as to the precise dates of peak oil and gas production by type of source, but what is more significant is the decline of these various hydrocarbons as their production peaks are passed.

In addition, demand for these fuels will be impacted by their price, by consumption trends, by technologies and societal adaptations that reduce or avoid their use, and by government-imposed taxes and other constraints directed at avoiding significant near-term climate change. The transition to the second half of the Oil Age thus threatens to be a time of significant tension, as societies adjust to the changing circumstances.

This journal presents the work of analysts, scientists and institutions addressing these topics. Content includes opinion pieces, peer-reviewed articles, summaries of data and data sources, relevant graphs and charts, book reviews, letters to the Editor, and corrigenda and errata.

If you wish to submit a manuscript, charts or a book review, in the first instance please send a short e-mail outlining the content to the Editor. Letters to the Editor, comments on articles, and corrections are welcome at any time.

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J. Laherrère, R. Miller, C. Campbell,
J. Wang & R.W. Bentley.

Editorial

Welcome to the Spring 2017 issue of this journal. This contains the third and final part of the Laherrère et al. paper on the reliability of data used for oil forecasting. Part-1 was published in the Autumn 2016 issue, and Part-2 was published late, as the Winter 2016 issue. As before, we apologise for the delay in publishing, caused by the amount of work it took to produce this paper.

As mentioned previously, we recognise that some readers may find this paper unnecessarily detailed. But given the data problems it highlights, we judged it merited publication at length.

We look forward to criticism and feedback on this paper. This will allow us to judge whether its intended audience of oil forecasters (and those who rely on such forecasts) have thought the paper useful. And should we get sufficient useful feedback we intend to publish a corrected, updated, version of the paper at some future date; either in the journal itself, or online.

As with the previous parts of this paper, we recognise that a number of the charts here may be difficult to read in black and white. As a result, subscribers to this journal may receive free of charge a PDF version of the paper, giving the charts in colour, by contacting Noreen Dalton at: theoilage@gmail.com.

Finally we note that in future issues of this journal will return to papers of wider interest, covering the history, societal impact, and production of other energies, that recognition of the constraints on global oil production suggest.

- R.W. Bentley, May 20th 2017.

Oil Forecasting: Data Sources and Data Problems – Part-3

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Abstract

This is the third and final part of a three-part paper that looks at the data needed to make forecasts of oil production, and highlights some of the significant problems with these data. The paper is primarily intended for those that forecast oil production, but will be of interest also to those who use such forecasts, to judge the quality of the data employed and hence this aspect of a forecast's reliability.

The first part of the paper discussed the data by *type* (e.g., data on production, consumption, and reserves) and pointed out areas where these data are unreliable, in particular with regards to reserves data. This second part included annexes on oil gravity and energy content, oil net-energy, greenhouse gas emissions, and importantly, detailed comparison of proved ('1P') vs. proved-plus-probable ('2P') oil reserves data for a number of countries.

This third part of the paper discusses oil data by *source* (e.g., data from the IEA, IHS Energy, JODI and the BP *Statistical Review of World Energy*) and again points out areas where the data are unreliable or must be treated with caution.

Analyses are given of oil data from 47 organisations, but where some of these organisations are covered in considerably more detail than others. For the main data providers analysis is generally under four headings: background information, oil production data, oil reserves data, and oil forecasts. As indicated in Parts-1 and -2 of this paper, this part of the paper also shows that there are considerable problems with much of the generally available oil data, and that analysts need to exert considerable caution in their use.

This final part of the paper also discusses the use of oil data to forecast oil production; and the accuracy of past oil forecasts and projections, of both oil production and oil price.

1. Introduction to Part-3

This part of the paper continues with the presentation of annexes that support and elaborate the information given in Part-1.

Annex 1 on units and acronyms, and Annex 2 on the definition of terms and categories of oil, were included in Part-1. Part-2 included Annex 3 on oil gravity and energy content, and reporting of condensate production; Annex 4 on oil net-energy, and greenhouse gas emissions produced by the combustion of oil; and Annex 5 on oil reserves data, and in particular the comparison of proved ('1P') vs. proved-plus-probable ('2P') reserves.

This Part-3 of the paper starts with Annex 6 that looks at oil data by data *source* (e.g., data from the IEA, IHS Energy, JODI and the BP *Statistical Review of World Energy*), and points out areas where these data are unreliable or must be treated with caution. Analyses are given of data from 47 organisations in total, but where some of these are covered in considerably more detail than others. For the main data providers the analysis is generally under four headings: background information, oil production data, oil reserves data, and oil forecasts.

This Part-3 of the paper also includes Annex 7 on the use of oil data to forecast oil production, and Annex 8 on the accuracy of past forecasts and projections of oil production, and oil price.

As with Parts-1 and -2 of this paper, we note that this part also will undoubtedly have errors as well as significant omissions, and we welcome corrections and comments.

Annex 6: Oil Data by Data Source

This annex discusses oil data by the *sources* of these data.

Note that this survey simply reflects the experience of the authors, and as a result readers should make no judgement on the data from sources that are absent in the list below, or those which are only covered briefly. (And in some places we write simply 'no specific comment', to either indicate we have no direct information on the quality of data mentioned, or have not filled in the information in the interest of brevity.)

It is our intention to circulate this paper once published to all the data providers known to us to request that the errors here - of which there will certainly be many - be corrected, and for additional information on those sources for which we have provided insufficient information.

This annex is ordered as follows:

- data from international sources,
- national sources providing international data,
- government data on fields and projects within their territory,
- widely-used publications,
- other public-domain sources, and
- data from commercial providers.

We start by considering data provided by international sources.

A6.1: International Sources

A6.1.1 The International Energy Agency (IEA)

- https://www.iea.org

Background

On the origins of the IEA, its website notes:

> *"Founded in 1974, the IEA was initially designed to help countries co-ordinate a collective response to major disruptions in the supply of oil such as the crisis of 1973/4. … An autonomous organisation, the IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 member countries and beyond. … Before becoming a member country of the IEA, a candidate country must demonstrate that it has:*
>
> - *as a net oil importer, reserves of crude oil and/or product equivalent to 90 days of the prior year's average net oil imports to which the government (even if it does not own those stocks directly) has immediate access should there be activation of the Co-ordinated Emergency Response Measures (CERM) – which provide a rapid and flexible system of response to actual or imminent oil supply disruptions.*
> - *a demand-restraint programme for reducing national oil consumption by up to 10%.*
> - *legislation and organisation necessary to operate, on a national basis, the CERM.*
> - *legislation and measures in place to ensure that all oil companies operating under its jurisdiction report information as is necessary.*
>
> *Since the 1980s, the IEA has been building good working relationships with countries beyond its membership, in particular major energy consuming, producing and transit countries."*

Production data

The IEA provides a wide range of energy statistics (see http://www.iea.org/statistics); and also monthly data and analyses in its *Oil Market Report (OMR)*. Comparisons of the IEA's global oil production data with those from other sources were given in Figures 1, 2, 5, 18 and 19 in Part-1 of this paper.

Oil reserves data

For data on oil resources and reserves, the IEA relies mainly on external sources, but maintains internal databases also. For example in Table 3.4 of their *World Energy Outlook (WEO)* 2015, for remaining technically recoverable oil end-2014, they quote the use of: *"IEA databases; BGR (2014); BP (2015); OGJ (2014); US DOE/EIA/ARI (2013); USGS (2012a, 2012b)."*

In addition, the IEA has made use of commercial data from IHS Energy and more recently from Rystad Energy also. As a result the IEA is one of the very few 'public domain' sources (along with the BGR) that does report proved-plus-probable (2P) oil reserves, as opposed to only the wholly unreliable proved (1P) oil reserves reported by so many other institutions, including the EIA, OPEC, WEC, O&GJ, World Oil, and the BP Statistical Review. In terms of the evolution of the data reported by the IEA, Wang notes: *"I checked the IEA's WEO 1994 - 2015 and found that:*

1. The IEA starts to analyse the resources/reserves in 1998. Thereafter, resources and reserves have been parts of WEO.
2. In WEO 2004, the IEA discuss the 1P, 2P and 3P reserves, and state that they focus on proved reserves and ultimate recoverable resources.
3. In WEO 2006, unconventional resources are included in the IEA's report.
4. In WEO 2010, the IEA gives the definitions of resource and reserves, and from 2010, proved reserves, remaining technically recoverable resources and URR for both conventional and unconventional are reported by the IEA annually."

However - to our knowledge - the IEA does not provide detailed tabulations by country of these 2P reserves, or of total recoverable oil. Instead the data (often aggregated by region) are to be found in the IEA's generally excellent occasional publication: *Resources to Reserves* (see, for example Figure 53 given in Part-1 of this paper); and as mentioned, in tables in its annual *World Energy Outlooks* (for example, see Table 3 in Part-1 of this paper).

Oil forecasts

In terms of longer-range forecasting, the IEA's main vehicle is its *World Energy Outlook (WEO).* This looks at the production of oil (and all energies) up to 2040. The methodology used is well documented on the IEA website, at http://www.worldenergyoutlook.org/weomodel. Importantly, the IEA makes it clear that they do not make actual forecasts beyond the time horizon of their medium-term market reports. Instead the *World Energy Outlook* views on future production are projections, based on assumptions in various scenarios and cases; and where they write: " *… it is useful to compare previous projections to actual - and we routinely do so."*

In Annex 8 we look at the IEA's past projections on both oil production and price, and where - in common with nearly all past oil projections - these have not been particularly accurate. However, the IEA's methodology on the supply side has significantly improved over time; and its demand-side modelling has long been recognised as of a high standard. For a discussion of some of the problems associated with past and current supply-side methodologies used for IEA WEOs see Section 11.4 in Part-1 of this paper, Annex 8 below, and Bentley (2016) Section A5.12.

A6.1.2 Organisation of Petroleum Exporting Countries (OPEC)

- www.opec.org

Background

On OPEC's history, its website notes:

> *"The Organization of the Petroleum Exporting Countries (OPEC) was founded in Baghdad, Iraq, with the signing of an agreement in September 1960 by five countries namely Islamic Republic of Iran, Iraq, Kuwait, Saudi Arabia and*

Venezuela. They were to become the Founder Members of the Organization.

These countries were later joined by Qatar (1961), Indonesia (1962), Libya (1962), the United Arab Emirates (1967), Algeria (1969), Nigeria (1971), Ecuador (1973), Gabon (1975) and Angola (2007). From December 1992 until October 2007, Ecuador suspended its membership. Indonesia suspended its membership in January 2009, but this was reactivated in January 2016. Gabon terminated its membership in January 1995. However, it re-joined the Organization in July 2016.

This means that, currently, the Organization has a total of 14 Member countries."

Production data

OPEC reports world (and OPEC members') reserves and production crude oil data, in particular in its *Annual Statistical Bulletin*. On production, OPEC omits reporting condensate (because condensate is outside OPEC quotas), and NGLs are reported only for OPEC countries, so there is a difference between the EIA's crude oil+condensate production data and OPEC's crude oil data, see Figure A6.1.

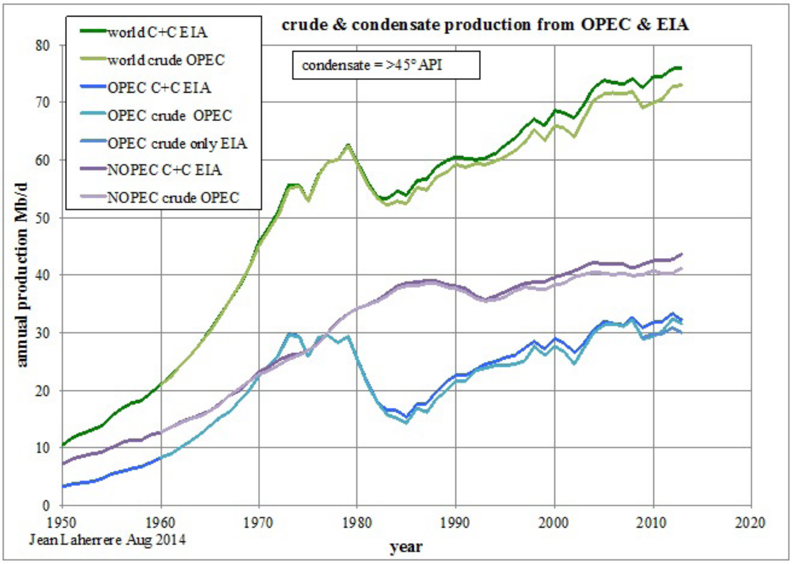

Figure A6.1 Comparison of Crude-plus-condensate Production data from OPEC and the EIA, for the World as a whole; and for OPEC and not-OPEC ('NOPEC') countries.
Source: J. Laherrère, from sources listed.

Oil reserves data

As mentioned above, for oil reserves, OPEC (like virtually all the other main 'public-domain' sources of global oil reserves except the BGR and IEA) reports only the very unreliable 1P data. (And, as mentioned in Section A5.1.4, a significant component of the poor quality of the 1P data relates to OPEC's own 1P data, which are unaudited and cannot be challenged by other countries without diplomatic repercussions.)

OPEC 1P reserves data differ quite significantly from, for example, BP *Stats. Review* data. In total, for end-2015 global 1P reserves, OPEC reports 1493 Gb, vs. BP *Stats.* reporting some 200 Gb higher, at 1698 Gb. Some of this difference is due to BP *Stats.*

including condensate and NGLs, which OPEC do not; but where the bulk of the difference is that BP *Stats*. for Canada include a high tars sands estimate, whereas OPEC reports these data far more conservatively: BP *Stats*. reporting Canada as having 172 Gb of total 1P oil reserves, vs. the OPEC figure of only 4 Gb.

On top of this there are apparent anomalies; for example the BP *Stats. Review* gives China 18.5 Gb of 1P reserves, while the OPEC number is significantly higher at 25.1 Gb; where the latter matches the data in the National Bureau of Statistics of China's *China Statistical Yearbook 2016*, which reports China's 'proved remaining technologically recoverable' oil reserves as 3.49 Gt (~ 25.5 Gb).

Oil forecasts

In terms of forecasting, for 10 years now OPEC has produced global oil forecasts in their *World Oil Outlook (WOO).* The *WOO* 2015 displays crude oil production and liquids supply (where the latter includes NGLs, processing gain, and other liquids), see Figure A6.2. For 2040 the global all-liquids 'Reference Case' demand is forecast to be 109 Mb/d, which is fairly close to the IEA and EIA 2015 projections.

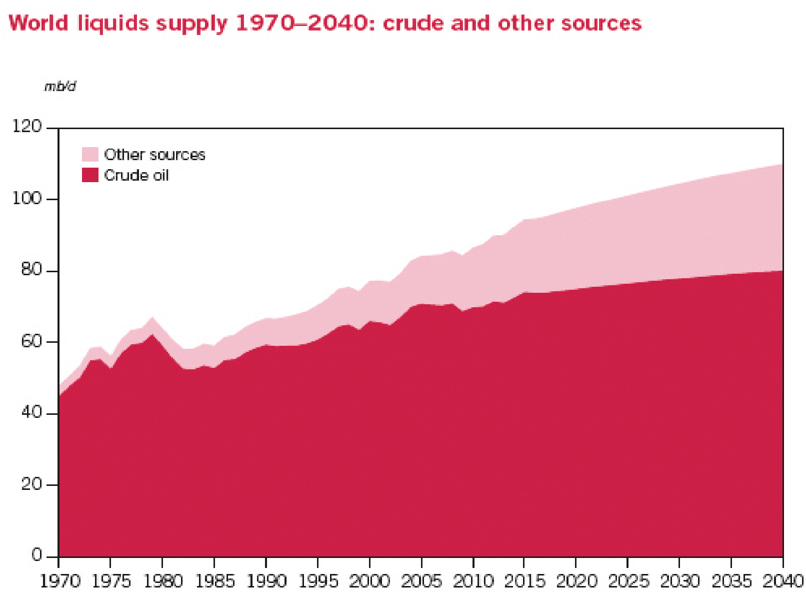

Figure A6.2 OPEC *World Oil Outlook* 2015: Historical data and Forecasts of 'All-oil' Production, 1970 – 2040.

Legend: 'Other sources' include includes NGLs, processing gain, and other liquids.

Source: OPEC *WOO 2015* page 94. (Note: *WOO 2016* does not provide such a comparable world liquids supply graph, but in Table 4.2 quotes global 'all-oil' production as 110 Mb/d in 2040, similar to *WOO 2015* forecast.)

A6.1.3 Joint Oil Data Initiative (JODI)

https://www.jodidata.org

Background

JODI is a data provider, and does not make oil forecasts. Importantly also, it does not provide data on oil reserves, saying in effect (private communication): *'We report data that change frequently, such as oil*

stocks and production, but not the reserves data'.
On its history, JODI reports:

> *"Back in the late 1990s, Energy Ministers identified the lack of transparent and reliable oil statistics as a key contributor to oil price volatility. Producers and consumers alike stepped up efforts to improve the availability and reliability of oil data, and Ministers at the 7th International Energy Forum in Riyadh urged a global response to the challenge of greater transparency. Six international organisations - APEC, Eurostat, IEA, OLADE, OPEC and the UNSD - took up the challenge, combined their efforts, involved their Member Countries and in April 2001 launched the Joint Oil Data Exercise. The primary goal was not to build a database, but to raise awareness among oil market players about the need for more transparency in oil market data. ... later there were over 70 participating countries, representing 90% of global oil supply and demand.*
>
> *In 2002, Ministers reaffirmed their political support, and with that mandate the six organisations obtained agreement from their Member Countries to make the Exercise a permanent reporting mechanism. The Joint Oil Data Initiative was born. [Later still] the JODI-Oil World Database was created … [and] made freely accessible to all.*
>
> *The IEF Secretariat, which took over the co-ordination of JODI in January 2005, and its partner organisations are fully aware of the limitations of the database, but already for many countries – especially for the top 30 producers and consumers – timeliness, coverage and reliability are at reasonable levels. The challenge for the organisations now is to increase the coverage to other countries, to reduce the delay in data submissions and to further enhance the data quality. [Since 2008] the data have been extended to cover gas."*

Its current partners are: the Asia Pacific Economic Cooperation (APEC), Statistical Office of the European Communities (EUROSTAT), Gas Exporting Countries Forum (GECF), the IEA, International Energy Forum (IEF), Latin American Energy

Organization (OLADE), OPEC, and the United Nations Statistics Division (UNSD).

Production data

On its Oil World Database, JODI writes:

> *"This database should in no way be seen as a final product. The database evolves continuously. The quality of the data is assessed on a continuous basis too. Other flows already collected through the JODI questionnaire, such as imports and exports, will be included at a later stage. Making the data available was only the first step towards more transparency.*
>
> *The database consists of:*
>
> - *Thirteen product categories: Crude oil, NGL, Other (refinery feedstocks + additives/oxygenates + other hydrocarbons), Total (primary products), LPG, Naptha, Motor/aviation gasoline, Kerosenes, of which: Kerosene type jet fuel, Gas/diesel oil, Fuel oil, Other oil products and Total oil products;*
> - *Fourteen flows: Production. From Other sources, Trade, Products transferred/Backflows, Direct use, Stock change, Statistical difference, Refinery intake, Closing stocks, Refinery output, Receipts, Products transferred, Interproduct transfers, Demand;*
> - *Data in three different units: barrels, tons and litres;*
> - *Data for more than 100 participating countries;*
> - *Data from January 2002 to one month-old."*

Laherrère notes that JODI production data are not especially reliable, in part because often when summing data they assume absent data are zero values. When compared with EIA data on production, JODI data can display unreliable steps, see Figure A6.3.

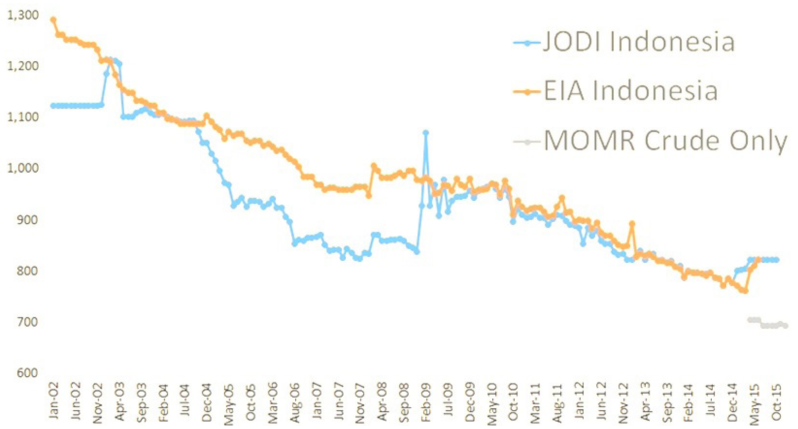

Figure A6.3 Comparison of JODI and EIA Production data for Indonesia.
Legend: - MOMR: IEA's Monthly Oil Market Report.
Source: J. Laherrère, http://peakoilbarrel.com/opec-except-iran-has-peaked/#more-11308

A6.1.4 The World Energy Council (WEC)

- http://www.worldenergy.org/

Background

The WEC website notes:

> *"The World Energy Council is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all.*
> *Formed in 1923, the Council is the UN-accredited global energy body, representing the entire energy spectrum, with more than 3000 member organisations located in over 90 countries and drawn from governments, private and state corporations, academia, NGOs and energy-related stakeholders.*

> *The World Energy Council informs global, regional and national energy strategies by hosting high-level events, publishing authoritative studies, and working through its extensive member network to facilitate the world's energy policy dialogue."*

In addition to holding triennial World Energy Congresses, WEC author a number of 'flagship' reports of which the main ones are: World Energy Scenario, World Energy Resources, a new Trilemma Index, and the Issue Monitor.

Production and oil reserves data

On oil data, the WEC website says:

> *"[Here we] present the key figures for reserves and production from the most recent World Energy Resources report with the option to search by resource, region or country … and underlying data can be downloaded in standard formats.*
>
> *Since 1933 the World Energy Council has published a report presenting statistics for reserves, and production of various resources at the global level. The World Energy Resources study group and its working groups collect and evaluate data on resources. It focuses on proven reserves, examines the evolving nature of the energy mix in countries worldwide and highlights emerging energy sources and technologies.*
>
> *The World Energy Resources report is a strategic publication of the World Energy Council prepared triennially and timed for release at each World Energy Congress. It offers a uniquely global perspective on twelve major resources. This highly regarded publication is an essential tool for governments, industry, investors, NGOs and academia."*

As the text above explains, on reserves the WEC *"focuses on proven reserves";* thus exhibiting the same problem of reporting the misleading 1P oil reserves data (see Annex 5 above) as do most organisations that provide public-domain reserves data.

Oil forecasts

The WEC forecasts oil production, and recently identify 'peak oil demand', rather than supply, as the focus. In a reflection on the organisation's key highlights of 2016, the WEC Secretary General Christoph Frei noted:

> *"[This year is the] the first time we have referred to 'peak demand' and stranded resources – and we have done so with OPEC seating at the table. After Congress, OPEC began to refer to the possibility of peak demand in oil in the next decade – which truly is the start into a new energy reality."*

WEC thus joins a growing list of organisations that see peak oil demand as arriving in the fairly near term, and certainly before any supply-limited peak. Other organisations, such as the IEA, are less sure of 'peak demand', where the latter admits demand for oil-based fuel for cars may decline, but demand from trucks, ships and planes, and for petrochemicals, is still expected to increase. This is a topic we will examine in greater detail in future issues of this journal.

A6.1.5 International Energy Forum (IEF)

- https://www.ief.org

Background

The IEF website notes:

"The IEF, as the neutral facilitator of open dialogue on energy with key global oil and gas actors, helps ensure energy security

> *and transparency." … Based in the Diplomatic Quarter of Riyadh, Saudi Arabia the Secretariat [of the IEF] has been headquartered there since its inception in December 2003. The duties of the Secretariat include:*
>
> - *provision of a neutral platform for dialogue and an exchange of views on issues relating to the objectives of the Forum among Members of the Forum and between Members of the Forum and energy-related industries;*
> - *exchange of energy data and information among energy producing, consuming and transit States, organisations and energy-related industries;*
> - *organisation of seminars, symposia, conferences, workshops, training programmes, exhibitions and roundtable discussions on energy-relevant global or regional issues;*
> - *establishment and conduct of dialogue and cooperation with other energy relevant entities in undertaking research and analyses;*
> - *outreach to energy entities in the public and private sectors, and to international organisations and non-governmental organisations, to promote the study and exchange of views on the interrelationship among energy, technology, environmental issues, and economic growth and development. ….*
>
> *The Secretariat also seeks to improve the relationship and depth of understanding between the energy industry and the governments of oil and gas producing and consuming countries through industry's participation in IEF events and symposia. This effort includes a permanent Industry Advisory Committee (IAC) that counsels the Secretariat, and frequent topical symposia that incorporate members of industry and government, as well as participants from international organisations, other experts and academia."*

In addition, Wikipedia notes:

> *"[The] IEF is the world's largest recurring gathering of energy ministers. It is unique in that participants not only include*

> *IEA and OPEC countries, but also key international actors such as Brazil, China, India, Mexico, Russia, and South Africa. The IEF countries account for more than 90 percent of global oil and gas supply and demand."*

Production and oil reserves data

The IEF does not provide oil data itself, though it is a key member of JODI, and provides the latter's Secretariat.

Oil Forecasts

In addition to its other tasks listed above, the IEF is much to be praised for its hard work on collating and comparing existing oil (and wider energy) forecasts. Currently the IEF's website holds forecasts and data, generally over a number of years, from the following: IEA, OPEC, UK DECC, EIA, the EU's *Energy 2020* report, IEE (Japan), the Chinese Academy of Social Sciences, IMF, WEC, BP, ENI, ExxonMobil, Shell and Statoil.

However, at least in the past, sometimes these comparisons, though well meant, have misled analysts. For example, a number of years' back the IEF reported good agreement between the oil production forecasts of the EIA, IEA and OPEC. But in the event all these forecasts - though in agreement - were considerably incorrect; primarily due to all relying on high estimates for the global URR of conventional oil (that of the USGS year-2000 Assessment), and to not correctly factoring-in the production declines resulting from 'mid-point' peaking of conventional oil in the countries modelled. As Annex 8 below indicates, the global oil production volumes predicted by the 'mainstream' oil forecasts over many years have had to be consistently scaled back as a result of the increasing difficulty of producing low-cost conventional oil, and hence the world's increasing need to turn to the generally more expensive non-conventional sources of oil in order to meet demand.

A6.2: National Sources of International Data

Now we turn to those national organisations which provide international oil data, and start with the US EIA.

A6.2.1 The US Energy Information Administration (EIA)

- https://www.eia.gov

Background

The EIA is perhaps the pre-eminent public-domain provider of hydrocarbon data, and though it is always possible to question some of what is reported, it is widely recognised that the organisation provides an invaluable service to mankind. In terms of oil data, the organisation's single main drawback is that it reports only proved reserves, as discussed below.

Production data

For oil production, the EIA lists on its website nearly 80 data sources that it draws on for the data it presents. In terms of methodology, for its monthly oil production data the EIA relies also on other data from the US states and from enquiries to some producers; for full details see the EIA 914 report: *Monthly Crude Oil, Lease Condensate, and Natural Gas Production Report Methodology June 2016* at https://www.eia.gov/petroleum/production/pdf/eia914methodology.pdf

- The petroleum production data themselves, which run from 1980, monthly or annual, are at: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=50&pid=53&aid=1

These tables report four categories of liquids:

- Crude including lease condensate (where crude oil data for Canada include oil processed from Alberta oil sands);
- Natural gas plant liquids (NGPLs);

- Other liquids (includes biodiesel, ethanol, liquids produced from coal, gas, and oil shale, Orimulsion, and other hydrocarbons);
- Refinery gain – volume expansion of liquids that occurs during refining.

The first three of these add to give: 'Crude oil, NGPLs and other liquids'; and this, added to refinery gain, gives: 'Total oil supply'. Data are by country by month; and typically run six months behind. See the EIA's 'Notes to Table' for more information on what is, and is not, included.

On these production data, Laherrère writes:

"The EIA provides user-friendly monthly and annual data since 1980, which are constantly revised, but where production is normally only in volume terms; though sometimes in energy terms of quads (where 1 quad = 10^{15} Btu = 1.055 EJ = 25.2 Mtoe).

The EIA data contrast, for example, with data from the BP Stats. Review, where the data are revised only yearly, though starting from 1965; and where production data are provided in volume, weight and energy terms (toe).

A problem is that EIA reports the information they get from the 'US states such as Texas, and these states allow (for confidential reasons) producers to delay their production data; for example in Texas, by 2 years.

One significant issue is that the EIA does not report actual data, but estimates, being based on an enquiry questioning only a relatively few producers out of the 12 000 in only 19 states (see EIA-914). In addition, the EIA also extrapolates past data to report recent months.

"(Incidentally, Ron Patterson runs a website, peakoilbarrel.com, which provides excellent graphs coming from the EIA, as well as from US states such as Texas and North Dakota, JODI and OPEC, and which also provides interesting comments. For example, Figure A6.4 gives the chart: 'Texas Oil and Gas Production Declining', posted by Patterson on 01/17/2016.)"

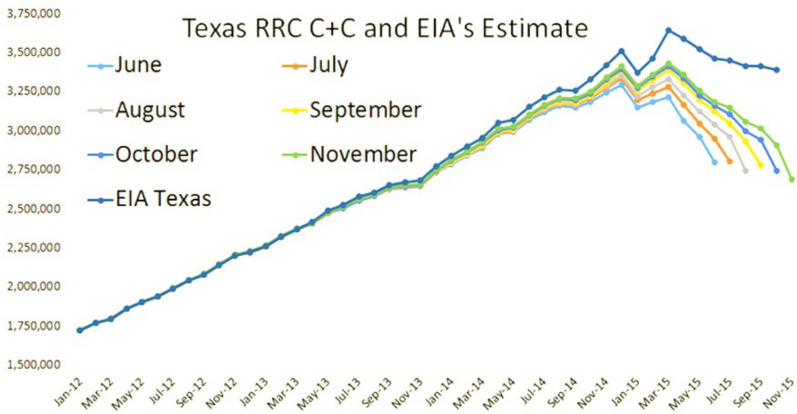

Figure A6.4 Comparison of Texas 'Crude-plus-condensate' ('C+C') production data with the corresponding estimate from the EIA.

Terminology: RRC: Railroad Commission; 'the main provider' of petroleum data for Texas.

Source: J. Laherrère.

In connection with Figure A6.4, see the discussion in Annex 3 above on how the EIA reports the production of condensate and NGPLs.

Oil reserves data

For oil reserves data, unfortunately the EIA only reports proved ('1P') reserves, which the EIA misleadingly defines (similar to the BP *Stats. Review*) as follows: *"Proved reserves of crude oil … are the estimated quantities of all liquids defined as crude oil, which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from reservoirs under existing economic and operating conditions."*

As explained in Annex 5 above, this is simply not the case; and where this definition of reserves is better estimated by the proved-plus-probable ('2P') reserves given by the operators themselves, or in commercial datasets. However, the EIA does recognise problems in this area, saying: *"Reserve estimates for crude oil are very difficult to develop"* [which is also usually not true; see elsewhere in this paper (for example, Figure A5.8) where, in general, and provided reasonable 2P discovery data are available, generation of reliable 2P reserves data is straightforward]; and goes on to say: *"As a convenience to the public, EIA makes available these crude oil reserve estimates from other sources, but it does not certify these data. Please carefully note the sources of the data when using and citing estimates of crude oil reserves."*

On the EIA reserves data, Laherrère writes: *"These primarily come from the Oil & Gas Journal (O&GJ)* for data outside the US." For problems with the latter data, of which there are quite a number, see the section on the O&GJ data, below.

Oil forecasts

The EIA produces three main forecasts:

- The *Short-Term Energy Outlook (STEO).* This relates to the domestic US market, is produced monthly, and looks (now) two years ahead.
- The *Annual Energy Outlook* (AEO). This also relates to the domestic US market, is produced annually at the beginning of the year, and carries projections to 2050.
- The *International Energy Outlook* (IEO). This relates to the global energy market, is produced annually (usually in the Summer), and carries projections to 2040.

On the 2017 AEO the EIA website notes:

> *"The Annual Energy Outlook provides modelled projections of domestic energy markets through 2050, and includes cases with different assumptions of macroeconomic growth, world oil prices, technological progress, and energy policies. With strong domestic production and relatively flat demand, the United States becomes a net energy exporter over the projection period in most cases. ….*
>
> *• Projections in the Annual Energy Outlook 2017 (AEO2017) are not predictions of what will happen, but rather modelled*

> *projections of what may happen given certain assumptions and methodologies.*
>
> *• The AEO is developed using the National Energy Modelling System (NEMS), an integrated model that aims to capture various interactions of economic changes and energy supply, demand, and prices.*
>
> *• Energy market projections are subject to much uncertainty, as many of the events that shape energy markets and future developments in technologies, demographics, and resources cannot be foreseen with certainty."*

On the 2016 IEO the EIA website notes:

> *"The International Energy Outlook 2016 (IEO2016) presents an assessment by the U.S. Energy Information Administration (EIA) of the outlook for international energy markets through 2040. U.S. projections appearing in IEO2016 are consistent with those published in EIA's Annual Energy Outlook 2015 (AEO2015). IEO2016 is provided as a service to energy managers and analysts, both in government and in the private sector. …*
>
> *The IEO2016 focuses exclusively on marketed energy. Non-marketed energy sources [2], which continue to play an important role in some developing countries, are not included in the estimates. … In general, IEO2016 reflects the effects of current policies - often stated through regulations - within the projections. EIA analysts attempt to interpret the likely effects of announced country targets when the implementation of those targets will require new policies that have not been formulated or announced.*
>
> *Objectives of the IEO2016 projections:*
>
> *The projections in IEO2016 are not statements of what will happen, but what might happen given the specific assumptions and methodologies used for any particular scenario. The Reference case projection is a business-as-usual trend estimate, given known technology and technological and demographic trends. EIA explores the effects of alternative*

> *assumptions in other scenarios with different macroeconomic growth rates and world oil prices. …*
>
> *Energy market projections are subject to much uncertainty. Many of the events that shape energy markets are random and cannot be anticipated. In addition, future developments in technologies, demographics, and resources cannot be foreseen with certainty. Key uncertainties in the IEO2016 projections are addressed through alternative cases.*
>
> *EIA has endeavoured to make these projections as objective, reliable, and useful as possible. They are intended to serve as an adjunct to, not a substitute for, a complete and focused analysis of public policy initiatives."*

Annex 8 presents data on past oil forecasts from the EIA, on both production and price. We note that in general, among the three main non-oil-company annual energy projections (the others being the IEA's *WEO* and OPEC's *WOO*), the EIA's *IEO* oil forecasts are usually seen as being at the more optimistic end of the spectrum in terms projections of global oil supply. We note also that all three forecasts have been - and still are - significantly at variance with that presented by Laherrère in this paper; and where, in part, this difference is driven by different assumptions on the size of the global conventional oil URR (see Section 11 in Part-1 of this paper, and Bentley, 2015). We aim to look at these differences in oil projections in more detail in future issues of this journal.

A6.2.2 United States Geological Survey (USGS)

- https://www.usgs.gov

Background

The USGS website notes:

> *"Created by an act of Congress in 1879, USGS has evolved over the ensuing 125 years, matching its talent and knowledge to the progress of science and technology. USGS is the sole*

> *science agency for the Department of the Interior. It is sought out by thousands of partners and customers for its natural science expertise and its vast earth and biological data holdings.*
> *Mission: The USGS serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life."*

Though it has a US focus, in fact the USGS provides the whole world with many invaluable services, including seismic monitoring and similar. One of these services is analysis of mineral availability, including for many years now where the USGS has evaluated the world's likely volumes of *undiscovered* conventional oil; and also made estimates of recoverable volumes of certain non-conventional oils. Note however that USGS does not provide data on oil production, nor make forecasts of production.

Oil reserves data

Many oil forecasting organisations, including the IEA, Enerdata and some of the oil majors use the USGS estimates of oil resource availability within their modelling; and in particular the estimates of the quantities of conventional oil yet to be discovered. But these data are not without some potential problems, particular over the quantities of conventional oil assigned to 'reserves growth'.

The last full-scale USGS assessment of global undiscovered oil was in the year 2000 (though there have been updates since). For this the USGS used the 1996 Petroconsultants (now IHS) database holding data to end-1995 (perhaps because this was cheaper to buy than more recent data). Nevertheless, the study was an excellent inventory of all the main petroleum basins of the world, and took a proper 'petroleum systems' view, analysing source rocks, migration, and traps.

There was one major question mark over this study, raised by a number of analysts at the time, and which still remains to be fully answered. The year-2000 Assessment changed from previous assessments in how the totals of undiscovered conventional oil were calculated, for the first time assigning significant quantities of oil to the category of 'reserves growth' for countries other than the US; see the discussion of this in Bentley (2015 & 2016). As a result, a number of analysts judged the USGS estimate on global undiscovered oil to be too high by perhaps ~500 Gb or more; and where this view was supported by comparing the resulting USGS global URR conventional oil estimate with that obtained from extrapolation of the industry data on the backdated 2P conventional oil discovery trend.

The USGS is to be credited for being a solid scientific body, and even in the original year-2000 Assessment admitted their approach to reserves growth in countries outside the US was open to question. As a result, subsequently they have at least twice returned to examining the issue; for example in a study by Klett and others (Klett et al., 2005). This compared the data from the original Petroconsultants 1996 E&P database with that of the IHS Energy 2003 database; see Figure A6.5.

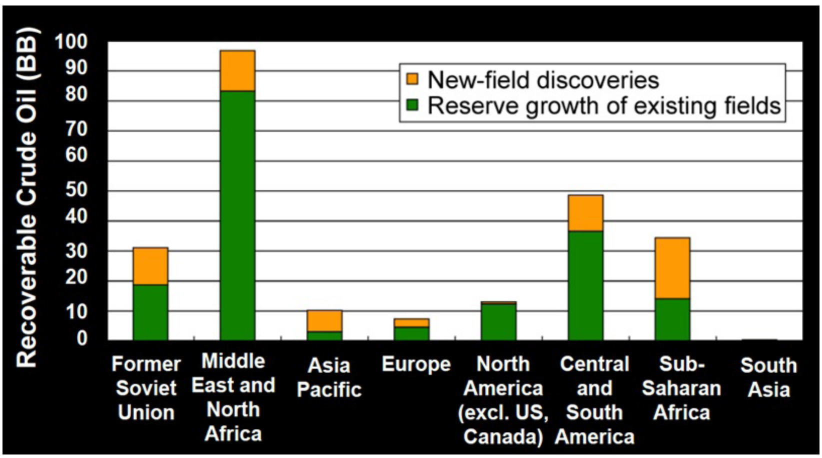

Figure A6.5 USGS Analysis by Region of Reserves Growth vs. New-Field Discoveries over the period 1996 to 2003.
Source: J. Laherrère; USGS chart. Klett & others (2005); data from IHS Energy (1996 to 2003)

As Figure A6.5 shows, the study found that for conventional oil over this period the quantity of 'new oil' from reserves growth significantly exceeded that from new discoveries. But there was a problem with this analysis in that it was not comparing like with like, because the 1996 database was incomplete, missing some 1700 fields compared to present day database; in particular for fields in Russia. And also, as Figure A6.5 shows, the largest part of the reserves growth found in the Klett et al. study was that in Middle East OPEC countries, where it is recognised that the data are questionable.

In the context of 'reserves growth' Laherrère writes:

> *"Chuck Masters, who led the USGS Assessments reporting world oil reserves in WPC from 1984 to 1998, advised me that it is necessary to wait six years after a discovery before getting reliable estimate of a field. The reserve growth curve plotting the ratio current estimate versus estimate first year is misleading (Root & Mast AAPG 1993 "Future growth of known oil and gas fields" with a ratio [for US onshore fields] of 9-fold after 60 years for oil fields; & 4-fold for gas fields). In USGS report FS2012-3052, USGS assessed the potential of reserve growth of 665 Gb in the world known giant fields applying reserve growth from 1P US reserves to the world 2P reserves: this is confusing apples and oranges! In USGS Klett et al 2006 the reserve growth of existing fields was estimated by continent using the same technique, much larger than the estimates of undiscovered."*

For addition discussion of global URR estimates for conventional oil, see Section 11 in Part-1 of this paper.

A6.2.3 Germany's Die Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)

[German Federal Institute for Geosciences and Natural Resources]
- http://www.bgr.bund.de/EN/Home/homepage_node_en.html

Background

The BGR website notes:

> *"The Federal Institute for Geosciences and Natural Resources is the central geoscientific authority providing advice to the German Federal Government in all geo-relevant questions. It is subordinate to the Federal Ministry for Economic Affairs and Energy (BMWi)."*

Production data and Oil reserves data

The BGR provides world oil production data by country, see for example Figure A6.6(a).

Country/Region	Production	Cum. Production	Reserves	Resources	EUR	Remaining Potential
Albania	0.8	54	26	23	104	49
Austria	0.9	122	6	10	138	16
Bosnia & Herzegovina	–	–	–	10	10	10
Bulgaria	< 0.05	9	2	32	43	34
Croatia	0.6	102	8	20	130	28
Cyprus	–	–	–	35	35	35
Czech Republic	0.2	11	2	30	43	32
Denmark	10.2	330	110	172	612	282
Estonia	0.6	5	–	–	5	–
Finland	0.5	3	–	–	3	–
France	0.8	125	12	709	846	721
Germany	2.6	297	32	115	445	148
Greece	0.1	17	1	35	53	36
Hungary	0.7	99	4	20	123	24
Ireland	–	–	–	224	224	224
Italy	5.4	180	82	200	462	282
Lithuania	0.1	4	1	61	66	62
Malta	–	–	–	5	5	5
Netherlands	1.1	144	35	455	634	490
Norway	87.5	3,450	940	2,100	6,490	3,040
Poland	0.7	62	10	260	332	270
Romania	4.1	763	82	201	1,046	282
Serbia	1.0	44	9	20	72	29
Slovakia	< 0.05	3	1	5	9	6
Slovenia	< 0.05	n.s.	n.s.	n.s.	n.s.	n.s.

Figure A6.6 (a) Extract from BGR *Energy Study,* 2012.
Source: J. Wang, from source stated.

The BGR does a good job in assessing the global availability of oil and other energy sources, with their most recent publication in this area being: Energy Study 2015: Reserves, Resources and Availability of Energy Resources, Dec. 2015. In particular, the BGR, like the IEA, is one of the few public-domain bodies reporting oil 2P reserves.

But as also for the IEA, analysts such as Laherrère judge the BGR's global estimated URR for conventional oil to be on the high side, by not matching the 2P discovery trend. As mentioned, this topic is discussed in Section 11 of Part-1 of this paper.

On the BGR data, Laherrère writes: *"BGR annual reports are a* *reliable world analysis, reporting reserves and production. [But] on oil resources, addition or omission of oil shale disturbs their data in Table 1 compared that in their Table 10", Figure A6.6(b).*

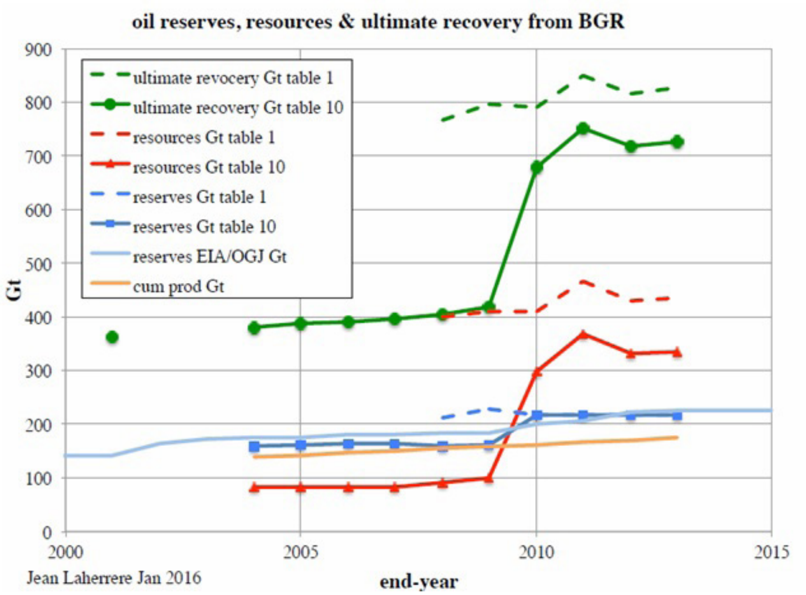

Figure A6.6 (b) Apparent step-changes in BGR data: comparison of data from different BGR tables; and also Comparison to other data sources
Source: J. Laherrère.

In addition, Laherrère has plotted up the changes over time in various BGR global data for conventional vs. non-conventional oil; Figure A6.6(c).

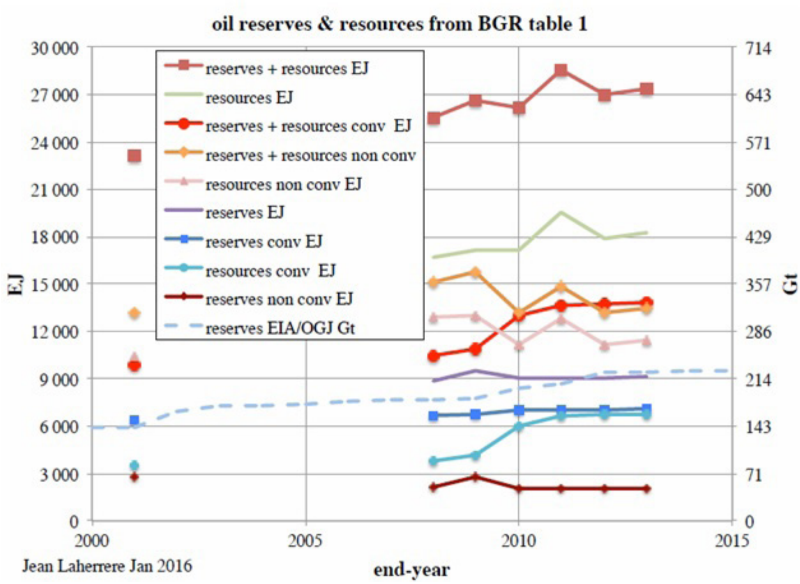

Figure A6.6(c) Addition comparisons on evolution of BGR data over time.
Source: J. Laherrère.

In addition, Laherrère suggests that: *"Possibly like BP, when the BGR changes senior people within the organisation, they may change their estimates on more speculative items, such as the global coal resource."* This possible effect is illustrated in Figure A6.6(d).

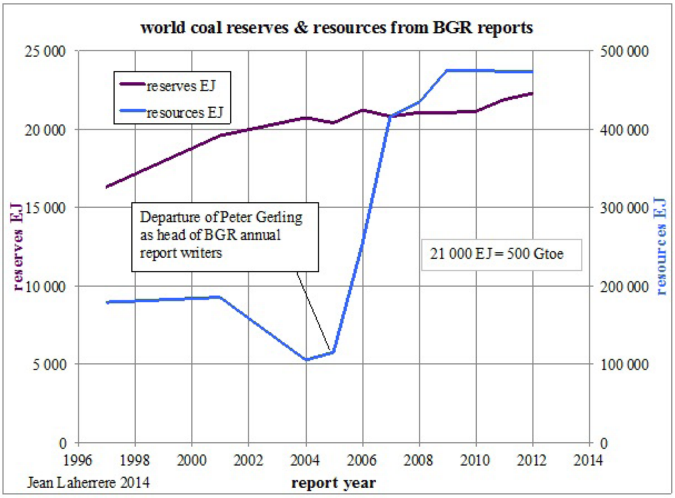

Figure A6.6(d) Showing step-change in BGR estimate of Global Coal Resources (possibly partly explained by a change in senior personnel).

Legend:

- reserves EJ: Evolution over time of BGR estimates of global coal reserves (in EJ). [Left-hand scale.]
- resources EJ: Ditto, for resources. [Right-hand scale.]

Source: J. Laherrère.

Forecasts

On oil forecasts, Wang notes: *"In most of BGR's reports, they just use the IEA-WEO results to outlook the future trend of energy (for example, BGR's 2006, 2007, 2009). However, there are some global forecasts in some of their reports; for example in BGR Energy Studies 2010 and 2011 they have charts that show future global oil production."* See Figures A6.6(e) and A6.6(f).

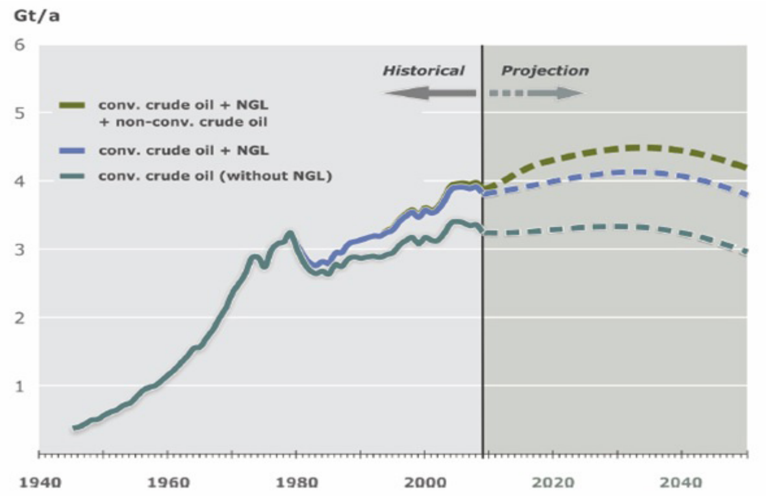

Fig A6.6 (e). BGR 2010 forecast of Global Oil Production, by Category of oil. **Source:** J. Wang, from BGR, *Reserves, Resources and Availability of Energy Resources*, 2010.

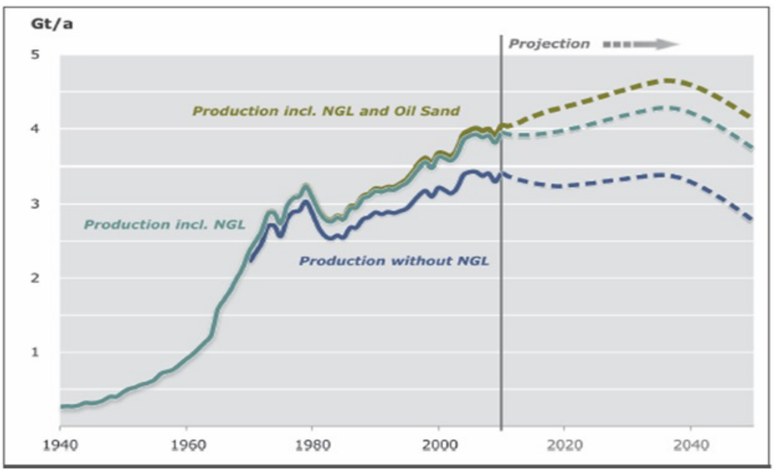

Fig A6.6 (f). BGR 2011 forecast of Global Oil Production, by Category of oil. **Source:** J. Wang, from BGR *Reserves, Resources and Availability of Energy Resources*, 2011.

As can be seen from Figures A6.6(e) and A6.6(f), both forecasts show global production of all-oil (including NGLs) as peaking before 2040, but where the 2011 forecast indicates slightly later production peaks for all three categories of oil shown, but then also more rapid subsequent declines.

A6.2.4 Institut Français du Pétrole (IFP)

- See: Institut Français du Pétrole Energies nouvelles (IFP): http://www.exed.hec.edu/campus/institut-francais-du-petrole-energies-nouvelles-ifp

On the IFP, Laherrère notes:

"The IFP does not report oil data (nor makes forecasts); but its association with CEDIGAZ provides reliable data on gas production and reserves; see; http://www.cedigaz.org/resources/free-downloads.aspx. (CEDIGAZ is an international not-for-profit association dedicated to natural gas information, created in 1961 by a group of international gas companies and IFP Energies nouvelles. CEDIGAZ has around 90 members in 40 countries.)

Since 1950 the organisation has reported data on gross, reinjected, flared, other losses, and marketed natural gas production, as well data on natural gas reserves. Note that changes in the reserves data should be compared with gross gas production less reinjected; and not simply to dry gas production, as done by some, ignoring the losses, in particular of extraction of liquids, which are an important part of world liquids supply (see the issue of NGPL production, as reported differently by the IEA and EIA!)".

A6.3 Government and industry association data on all fields and projects within a given territory.

Now we turn to those government and industry organisations that provide oil data by field or by project (the latter often for non-conventional oil); but where these data are not global, but only for the countries concerned.

A6.3.1 Norwegian Petroleum Directorate (NPD)

- http://www.npd.no/en

Background

The NPD's website (slightly amended) notes:

> *"The NPD is a governmental specialist directorate and administrative body, established in 1972, which reports to the Ministry of Petroleum and Energy (MPE), and has a staff of about 230.*
>
> *The paramount objective of the NPD is to contribute to creating the greatest value for society from oil and gas activities by means of prudent resource management, taking account of health, safety, emergency preparedness and the natural environment, including the climate. [It achieves these aims via]:*
>
> *- Advice to the MPE, through its professional integrity and interdisciplinary expertise.*
>
> *- National responsibility for data from the Norwegian continental shelf. The NPD's data, overview and analyses constitute a factual basis on which activities are founded.*
>
> *- [Acting] as a driving force for realising the resource potential by emphasising long-term solutions, upside opportunities, economies of scale and joint operations, as well as ensuring that time-critical resources are not lost.*

> *- In cooperation with other authorities, ensuring comprehensive follow-up of petroleum activities.*
>
> *The NPD sets frameworks, stipulates regulations and makes decisions in areas where it has delegated authority; is responsible for conducting metering audits and collecting fees from the petroleum industry; [and] contributes administrative competence, mapping of resources, and petroleum data administration for the development aid programme "Oil for Development."*

Production data

Norwegian oil production data by field are provided to the NPD by the operators, and are generally considered reliable.

Oil reserves data

On Norwegian oil reserves, Laherrère writes:

> *"The NPD, for reserves by field, reports the operator values, and these are required to be 2P. In fact, as reported by a company, which in turn decides each field's development, the 2P values are based on net present value calculations, themselves based on mean reserves (which are close to 2P). Note that the NPD, in 'NPD facts', states that 'Reserves include remaining recoverable petroleum resources in deposits for which the authorities have approved PDO'. See, e.g.:*
>
> *http://www.norskpetroleum.no/en/facts/remaining-reserves*
>
> *and: http://factpages.npd.no/factpages*
>
> *In this context, note that NPD reports to end-2015, adding all fields, the total original reserves (assumed to be 2P) of oil and gas as totalling 9.76 G.m3 of oil equivalent, see: http://www.norskpetroleum.no/en/framework/norways-petroleum-history.*
>
> *This compares to the Norwegian oil-plus-gas discovery*

creaming curve vs. date, Figure A6.7, which has total discovery as having now reached over 11 G.m3 oil equivalent; and where this curve shows well the flattening of the curve after the discovery of Sverdrup; and where Norway's oil-plus-gas EUR would appear likely to be around 12 G.m3 oil equivalent, or perhaps a bit under."

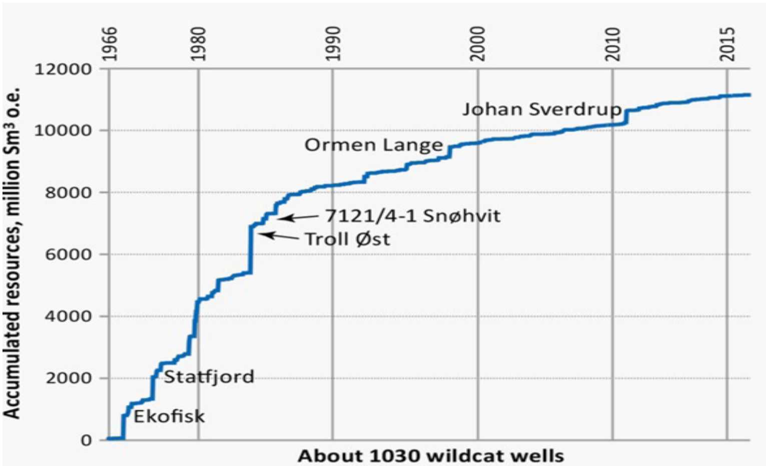

Figure A6.7 Discovery 'Creaming Curve' vs. Date for Norway: Oil plus Gas.
Source: Norwegian Petroleum Directorate.

The oil-plus-gas discovery data of Figure A6.7 from the NPD are supported by the discovery data, separately for oil and gas, from an industry 'scout' source shown in Figure A6.8.

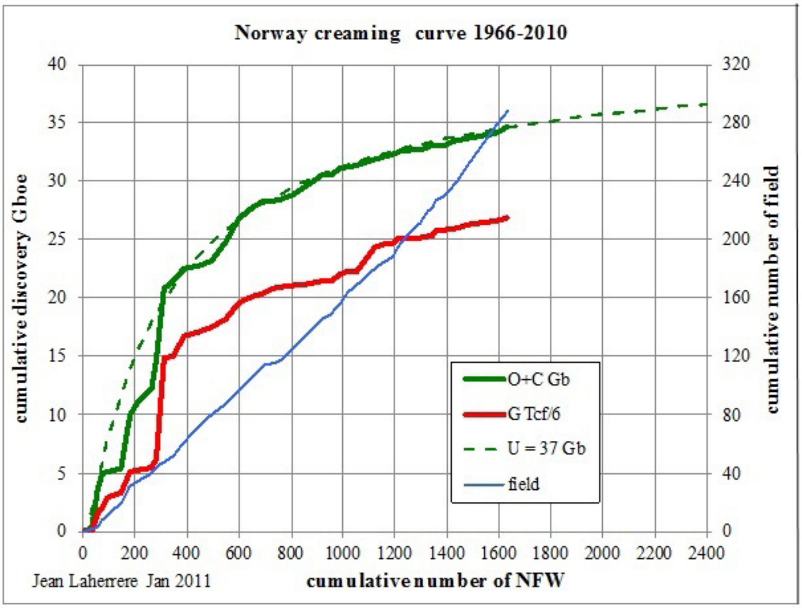

Fig A6.8 'Creaming curves' for Norway: Curves of Cumulative 2P Discovery vs. Number of 'New Field Wildcat' (notionally, true exploration) wells drilled, for Crude-plus-condensate, and Gas; 1966 - 2010.

Legend:

- O+C Gb: Cumulative 2P discovery curve for crude oil plus condensate.
- G Tcf/6: Cumulative 2P discovery curve for gas; with Tcf divided by 6 to give boe.
- U = 37 Gb: Extrapolation of the 2P discovery curve for crude oil plus condensate to yield a possible 'ultimate' of ~37 Gb.
- field: Cumulative number of oil plus gas fields discovered.

Source: J. Laherrère, from an oil industry 'scout' dataset.

The approximate 'ultimate' for crude plus condensate of ~37 Gb in Figure A6.8, if added to a similar estimate for gas - see curve on the same Figure - of about 33 Gboe, yields a total 'oil plus gas' ultimate of ~70 Gboe (11 000 M.m3), in line with NPD data in Figure A6.7.

However, on NPD reserves data Bentley notes that early published Norwegian aggregate reserves for the country may have been reported as 1P, so caution is needed when examining the long-term evolution of Norwegian reserves data over time if early NPD documents are used.

Oil forecasts

The NPD make forecasts of Norwegian production, for example Figure A6.9.

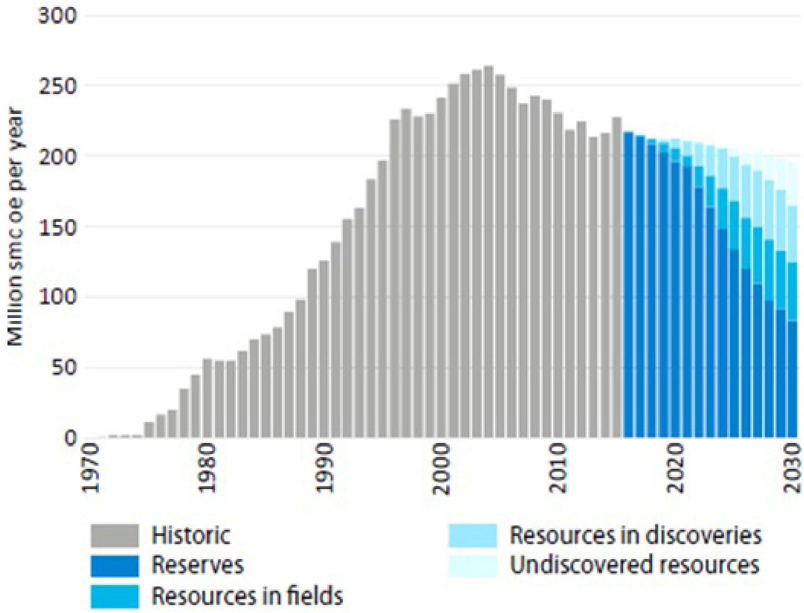

Figure A6.9 Historical data, and Forecast, of Norwegian Production of Oil plus Gas, 1970 - 2030.
Source: NPD, *Resource Report 2016.*

However, comparison of Figure A6.9 with Figures A6.7 and A6.8 suggests to some analysts that Norway's ability to bring on significant future production from 'undiscovered resources', as shown in Figure A6.9, may be fairly limited.

A6.3.2 UK Dept. of Energy (DoE); Dept. of Trade & Industry (DTI); Dept. of Energy and Climate Change (DECC), and most recently, Dept. for Business, Energy & Industrial Strategy (BEIS) and the UK's Oil and Gas Authority (OGA).

Background

Perhaps, with so many parents, see list above, it is not surprising that the UK oil data, while generally regarded as of high quality, has had some unfortunate errors of understanding and presentation.

Production data

UK oil production data by field provided by BEIS are generally considered reliable.

Oil reserves data

Though BEIS reports both 1P and 2P UK oil reserves data (see Table A5.2), as explained in Section A5.4.1 in Part-2, in some aspects the UK government's reporting to the public of the UK's oil reserves, and total oil discovery (including that expected), has been extraordinarily poor; with questions still to be resolved as to exactly what was reported, and why.

In this regard also, see the UK oil reserves data given in Figure A6.30b, below. This shows that for most of the period since 1985 the UK 2P oil reserves as reported by oil industry backdated 'scout' data have typically been twice the volumes reported by UK government sources, also for notionally 2P reserves.

Oil Forecasts

An author at the OGA has recently compared the UK government forecasts for oil and gas production for 2015 and 2016; Figure A6.10.

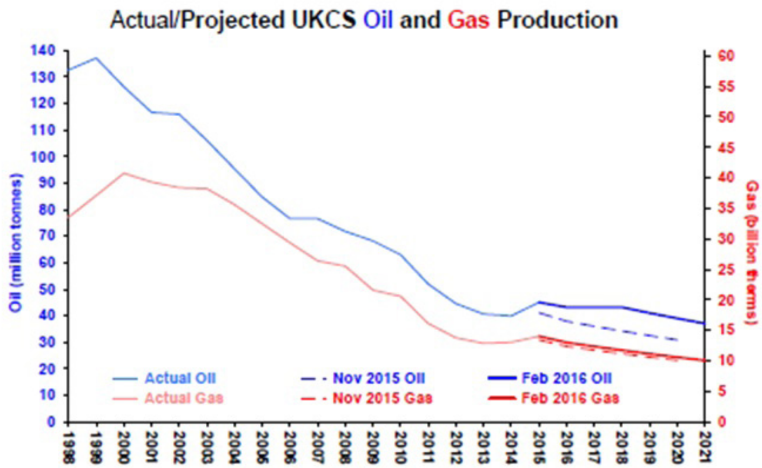

Figure A6.10 Comparison of two recent Forecasts of UK Oil and Gas Production.

Note: For caveats, see text.

Source: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/503852/OGA_production_projections_-_February_2016.pdf

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The author notes:

> *"The current (February 2016) projections are based on detailed field-by-field data provided to the OGA by the current operators of each field in early 2016. We have adjusted some of the operator field level data (for example to reflect OGA officials' judgement about likely uptime and project slippage) and also applied very significant negative contingencies to the aggregate figures. The extent of these contingencies reflect past experience of forecasting deviations; ... [These] central projections are therefore our best estimates rather than a definitive prediction of future production of oil and gas from the UKCS."*

A6.3.3 Oil &Gas UK

- http://oilandgasuk.co.uk

Background, and data

Oil & Gas UK is a UK industry body which also provides oil and gas data. On 'Reserves/Resources', their Economic Report 2016 notes:

> *"More than 43 billion barrels of oil equivalent (boe) have been recovered from the UKCS since first production in 1967. Oil & Gas UK believes that the remaining recoverable resource potential ranges from 10 - 20 billion boe, [as follows]:*
>
> - *6 - 9 billion boe in existing reserves*
> - *2 - 5 billion boe in potential additional resources*
> - *2 - 6 billion boe in yet-to-find potential."*

Incidentally, the same report contains a plot of UK 2P oil-plus-gas discovery data from Wood Mackenzie, given here as Figure A6.11, which support the data shown earlier in Figures A5.4.1 and A5.4.2; and which again illustrates the analytically crucial 'find-a-lot-early-and-produce-this-later' story typical of virtually all regional conventional oil and gas, including that globally (as shown for oil in Figures 24, 27 and 28 in Part-1 of this paper). Figure A6.11 also shows that: (a) oil and gas discovery has tended to asymptote since about 1985; and (b) the UK has now produced nearly all of the oil and gas that have been discovered so far.

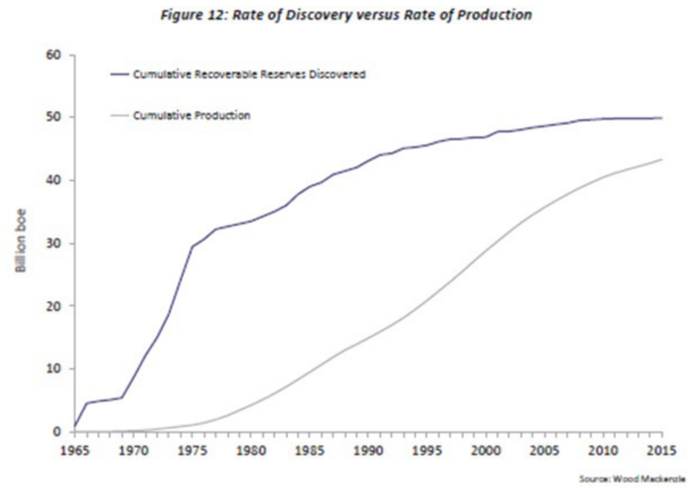

Figure A6.11 UK 2P Cumulative Oil-Plus-Gas Discovery, and corresponding Cumulative Production.
Source: Wood Mackenzie; in Oil & Gas UK's *Economic Report* 2016.

A6.3.4 France's Bureau Exploration-production des Hydrocarbures (BEPH)

-http://www.developpement-durable.gouv.fr/Les-publications-et-les.html

Background, Production data, Oil reserves data, Oil forecasts

Laherrère notes:

> *"BEPH was reporting annual production per field; see: http://www.beph.net/presentation.asp#beph; and http://www.developpement-durable.gouv.fr/Presentation-historique-de-l.html; but where data for recent years are missing.*

Incidentally, for the largest field, Parentis, IHS Energy and Rystad Energy production data (in kb/y) appear not too accurate (or at least, different) compared to the corresponding BEPH data (in kt/y)"; Figure A6.12.

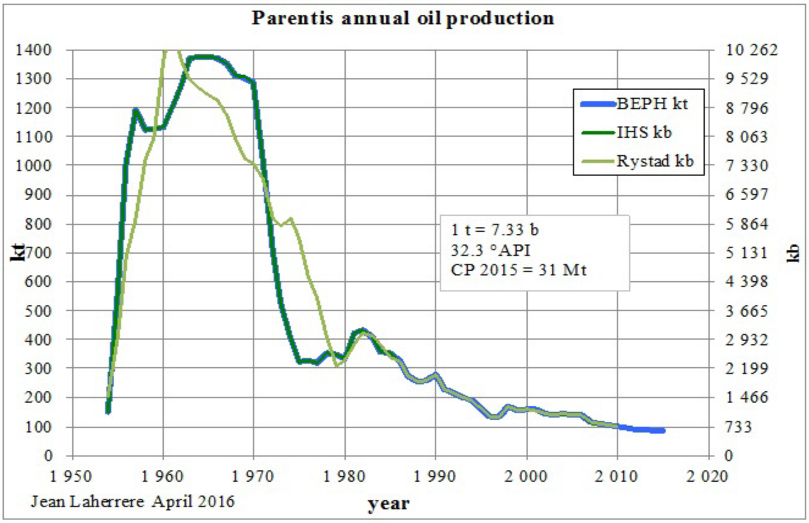

Fig A6.12 Comparison of Oil Production data from BEPH, IHS Energy and Rystad Energy, for the Parentis field.

Note: Here the conversion factor of 1 tonne of oil = 7.33 barrels is used.

Source: J. Laherrère.

A6.3.5 Danish Energy Agency (DEA)

https://ens.dk/en/our-responsibilities/oil-gas

Background

The DEA website notes:

> *"Resources and forecasts: The DEA makes an annual assessment of Danish oil and gas resources on the basis of a pre-defined classification system. The aim of the classification system is to determine resources in a systematic way.*
>
> *Forecasts: Every other year, the DEA prepares a long-term production forecast, the so-called 20-year forecast. In the alternate years, the DEA prepares a short-term production forecast, the so-called five-year forecast. … Additionally, the DEA prepares an oil and gas consumption forecast, a so-called baseline scenario. The DEA uses this consumption forecast together with its oil and gas production forecasts to determine whether Denmark is a net importer or exporter of oil and gas.*
>
> *Resources and reserves: The percentage of resources in a field expected to be recoverable over the life of the field is termed the ultimate recovery. The reserves of the field represent the percentage of ultimate recovery that has not yet been produced at any given time. The DEA makes an assessment of Danish oil and gas resources every other year. The reserves reflect the amounts of oil and gas that can be recovered by means of known technology under the prevailing economic conditions. Thus, not all the resources-in-place are recoverable by means of known technology."*

Production data, Oil reserves data, Oil forecasts

(We have no specific knowledge or comment.)

A6.3.6 Canadian Oil and Gas Data

Background

Oil and gas data for Canada come from a variety of organisations, including Statistics Canada; the Canadian National Energy Board (NEB); Natural Resources Canada; provincial authorities (especially Alberta), and the Canadian Association of Petroleum Producers (CAPP).

Laherrère notes that the most complete oil and gas data for Canada are in the CAPP Handbook, at: http://www.capp.ca/publications-and-statistics/statistics/statistical-handbook; while Canadian syncrude production is reported by Statistics Canada; and see also Natural Resources Canada data.

Production data, and Forecasts

Canadian historical data on production, and also a number of forecasts of this, are shown in Figure A6.13.

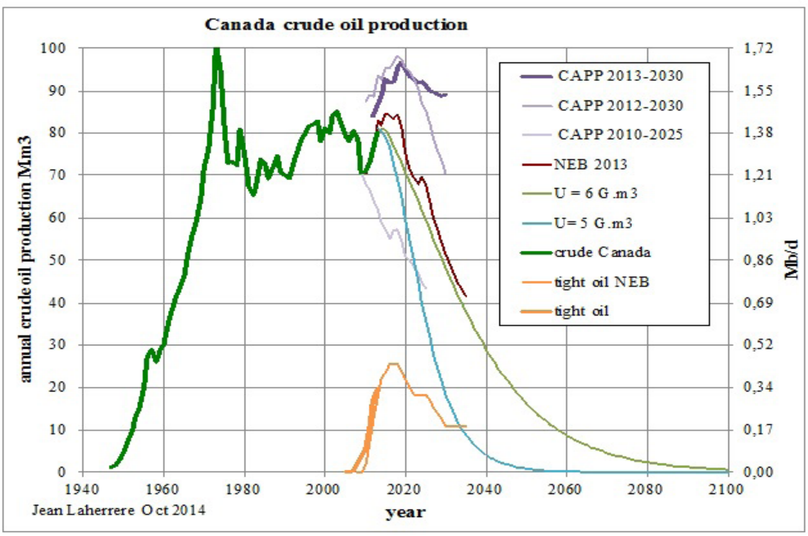

Figure A6.13 Historical data, and forecasts, of Canadian Crude Oil Production

Legend:

- CAPP2013-2030 (& likewise: 2012-2030, and 2010-2025): Forecasts of Canadian crude oil production from CAPP, made for the start years indicated here.
- NEB 2013: Forecast of Canadian crude oil production from NEB, as of 2013; from: http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/2013/nrgftr2013-eng.pdf.
- U = 6 G.m3: The tail end of a Hubbert curve corresponding to a URR of 6 Gm^3.
- U = 5 G.m3: Ditto, for a URR of 5 Gm^3.
- Crude Canada: EIA historical data for crude oil production in Canada.
- tight oil NEB: NEB forecast of Canadian tight oil production.
- tight oil: NEB historical data for tight oil production in Canada.

Source: J. Laherrère.

In Figure A6.13 there are significant differences in the various forecasts shown. In particular, the CAPP forecasts for 2012 and 2013 show a major change to that from 2010, very probably due to inclusion of significant amounts of light-tight oil, By contrast, the NEB 2013 forecast appears considerably more pessimistic on total output, probably borne out by their view of Canadian future tight oil production, also shown in the Figure.

Oil reserves data

Here Laherrère writes:

> *"CAPP used to report backdated annual established reserves. This allowed a good estimate to be made of the Canadian oil ultimate (URR), based on the discovery 'creaming curve'; Figure A6.14. But after my presentation at ASPO Brussels (and possibly due to this?), which showed the huge difference between the backdated and current discovery data, they stopped reporting these backdated annual discoveries, perhaps because the result was too frightening; see Laherrère (2011)."*

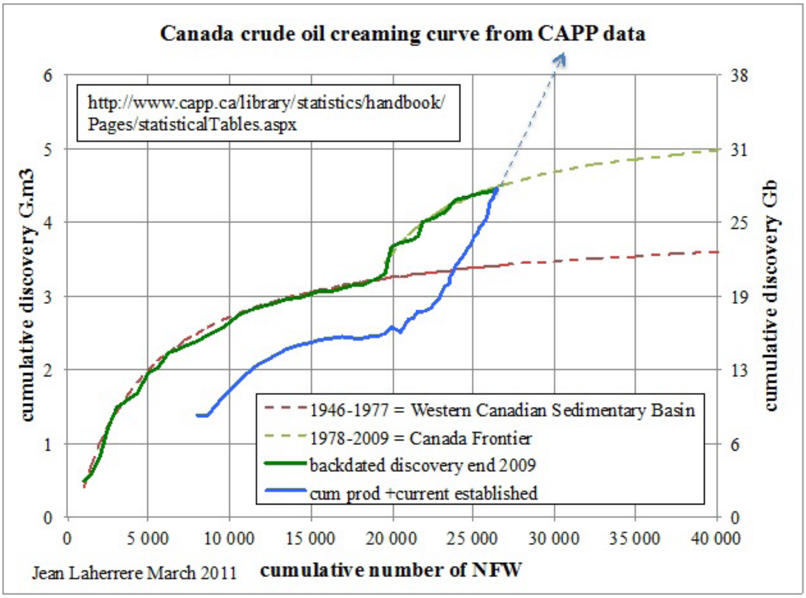

Figure A6.14 Crude Oil Discovery 'Creaming Curves' for Canada, using (a): Backdated discovery data, and (b): Apparent 'current' discovery data; vs. Number of New-Field Wildcat (exploration) wells.

Legend:

- 1946-1977 = Western Canadian Sedimentary Basin: Canadian crude oil discovery trend matched to backdated discovery data, for the period 1946 to 1977 when oil discoveries were principally in the Western Canadian sedimentary basin.

- 1978-2009 = Canada Frontier: Ditto, for the period 1978 to 2009, when the bulk of new oil discoveries were in the Canadian 'frontier region' of offshore East coast; plus a lesser amount in the Mackenzie delta.

- backdated discovery end 2009: Historical data on Canadian crude oil discovery, as indicated by the CAPP backdated established original reserves.

- cum prod +current established: Historical data on Canadian apparent crude oil discovery, as indicated by adding CAPP current-basis remaining established reserves at a given date to the cumulative production to the same date.

Source: J. Laherrère; from CAPP data.

As Figure A6.14 emphasises, and other Figures in this paper have shown, there is usually a dramatic difference in the apparent oil discovery picture for a region depending on whether backdated (and usually 2P) discovery data, or 'current-basis' (and usually 1P) data, are used.

This plot also indicates the argument for estimating a URR for Canadian crude oil of between 5 to 6 G.m3, as was illustrated in Figure A6.13.

A6.3.7 China: National Bureau of Statistics of China (NBSC)

- http://www.stats.gov.cn/english

Background

The above website, for 'Introduction' says:

> *"In 1952, to meet the needs of socialist economic construction, the Central Government of China decided to set up the National Bureau of Statistics at its seventeenth plenary session. The National Bureau of Statistics is a department directly under the State Council of China. It is mainly in charge of national statistical work and national economic accounting work."*

Production data

NBSC publishes its China Statistical Yearbook (CSY) annually, and from the NBSC website, we can find annual CSY data after 1996 (see: http://www.stats.gov.cn/english/Statisticaldata /AnnualData). These data include China's annual oil and gas production, Figure A6.15. NBSC do not give its data source, so we do not know how NBSC obtain these data.

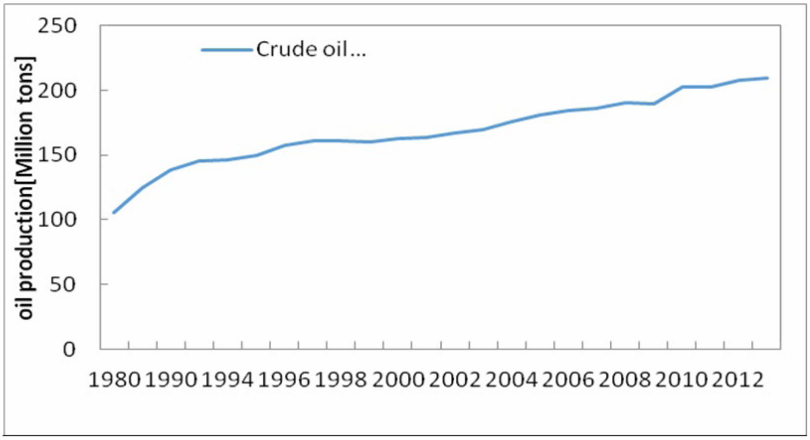

Figure A6.15 Chinese Crude oil Production, from 1980 – 2013, in Mt/y
Source: CSY 1996 - 2015.

Oil reserves data

CSY started to release China's oil and gas reserves data since 2003. As noted by CSY, these data are for 'proved remaining technologically recoverable reserves'; Figure A6.16. According to the NBSC, these reserves data are originally from the Ministry of Land and Resources of China (MLR).

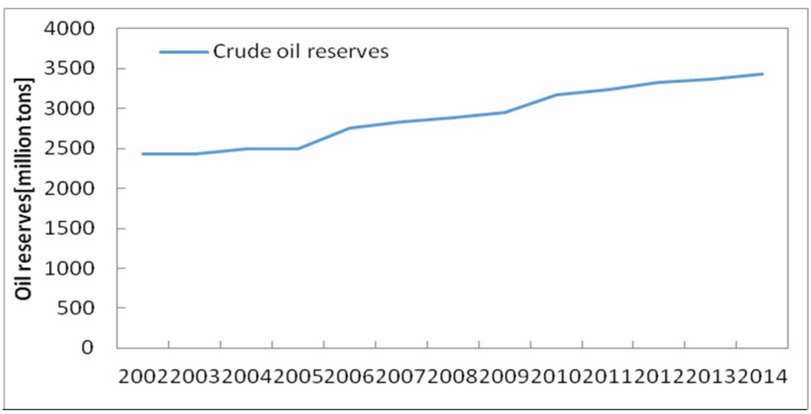

Figure A6.16 Chinese Crude Oil Proved remaining Technologically Recoverable Reserves, from 2002 - 2014.
Source: CSY 2003 - 2015.

Oil forecasts

To our knowledge, NBSC does not provide forecasts of China's oil production.

Indeed, in China, there is no official long-term production forecast from the authorities. If one wants to know the authorities' opinions on future production, this can only be found in the Five-year plans for the energy industry. For example, in the 13th Five-year Plan for Energy Development released by China's National Development and Reform Commission (NDRC), China's future oil production is projected to be around 200 million tons/year from 2016-2020 (website: http://www.sdpc.gov.cn/zcfb/zcfbtz/201612/t20161230_833687.html).

Sometimes, in some specific years, the Chinese Academy of Engineering (CAE), and CNPC or some other institutes or companies may make forecasts of future oil production and release their results. Other forecasts are generally those generated by academics; see for example those summarised in Wang K. et al. (2016).

A6.3.8 China: International Petroleum Economics (IPE)

- http://www.petroecon.com.cn/

Background

IPE is a journal published by CNPC Economics & Technology Research Institute (website: http://etri.cnpc.com.cn/).

Production data

IPE releases oil and gas production data annually by main fields and companies, where according to IPE these oil production data include crude oil and condensate; Figure A6.17.

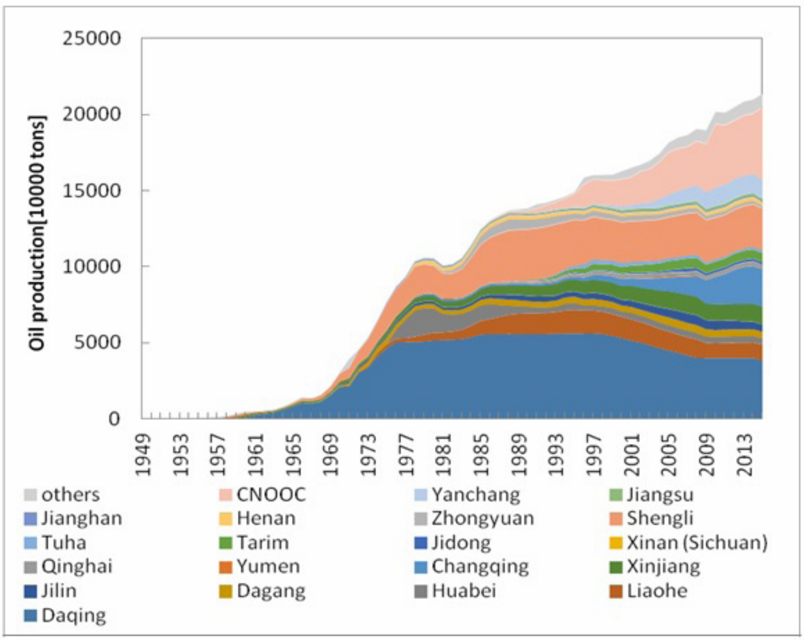

Figure A6.17 China's Production of Crude Oil+Condensate, by Main fields and Companies

Note: Yanchang and CNOOC are companies; the remainder of entries shown are fields.

Source: IPE.

Reserves data, and Forecasts

IPE do not provide data on reserves, nor offer forecasts of oil production.

A6.3.9 China: Ministry of Land and Resources of China (MLR)

- http://www.mlr.gov.cn/

Background

The above website notes:

> *"The Ministry of Land and Resources, which was set up on April 8, 1998, is a department of the State Council responsible for the planning, administration, protection and rational utilization of land, mineral and marine resources. Detailed description of Responsibilities of the Ministry of Land and Resources can be found on the 'Mission' page of MLR, see: http://www.mlr.gov.cn/mlrenglish/about/mission."*

Production data

MLR publishes its annual reports of China Mineral Resources (CMR) since 2011 (see website: http://data.mlr.gov.cn/zybg/) and Communiqué on Land and Resources of China (CLRC) since 2001 (see website: http://www.mlr.gov.cn/sjpd/gtzygb/). In both these annual reports, we can find annual production data for the whole of China›s oil and gas industry. From MLR, we can find China›s oil production data after 2000, Figure A6.18; where these data essentially match those in Figure A6.15.

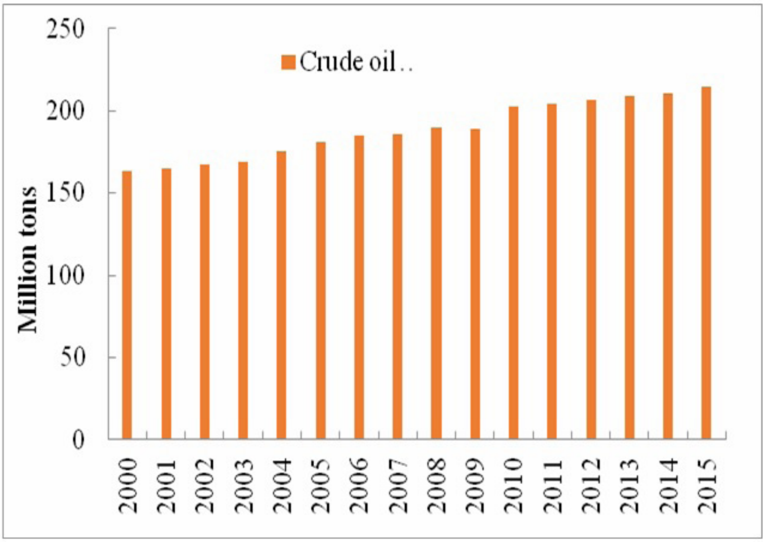

Figure A6.18 Chinese Crude oil Production, from 2000 - 2015, in Mt/y.
Source: CMR 2011-2016; CLRC 2001-2015.

Oil reserves data

MLR has released annual geological reserves and proved remaining technologically recoverable reserves data in its annual report of China Mineral Resources (CMR) since 2011 (see website: http://data.mlr.gov.cn/zybg/). In China, the term ‘geological reserves’ refers to the discovered oil and gas total resource (or ‘discovered oil and gas in-place’, if SPE’s resources/reserve classification system is used). Figure A6.19.

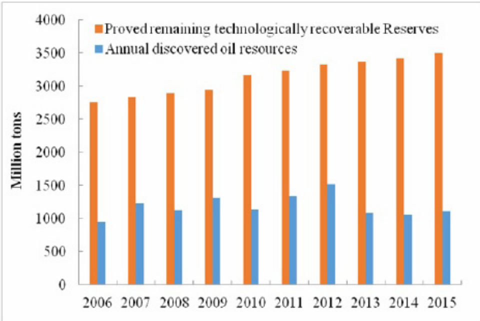

Figure A6.19 Chinese Crude Oil Proved remaining Technologically Recoverable Reserves, and Annual discovered Oil Resources, from 2006-2015.
Source: CMR 2011-2016.

Oil forecasts

MLR does not provide forecasts of China's oil production.

A6.3.10 US Offshore Data

- https://www.boem.gov & https://www.bsee.gov

Now we look at oil data for the US offshore.

Background

Originally US offshore data were provided by the US Minerals Management Service (MMS), but now are provided by the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). For BOEM, their websites says:

> *"The Mission of the BOEM is to manage development of U.S. Outer Continental Shelf (OCS) energy and mineral resources in an environmentally and economically responsible way. … The approximately 26 million (as of*

March 2016) leased OCS acres account for about 5 percent of America's domestic natural gas production and about 16 percent of America's domestic oil production. … The offshore areas of the United States are estimated to contain significant quantities of resources in yet-to-be-discovered fields. The Bureau estimates of oil and gas resources in undiscovered fields on the OCS (2016 National Assessment, mean estimates) total about 90 billion barrels of oil and 327 trillion cubic feet of gas.

Resource Evaluation Program: The primary program objective is to identify areas of the OCS that are most promising for oil and gas development. … [It] consists of eight major components [including]:

- Resource Evaluation Program: Identifies geologic plays on the OCS that offer the highest potential for the occurrence of oil and natural gas development.

- Reserves Inventory Program: Develops independent estimates of original and remaining amounts of natural gas and oil in discovered fields by conducting field reserve studies and reviews of fields, sands, and reservoirs on the OCS.

- Geological and Geophysical Data Acquisition and Analysis: Responsible for the acquisition and analysis of geological and geophysical data used in the development of maps identifying areas favourable for the accumulation of hydrocarbons. …

- Gas Hydrates: BOEM, in conjunction with our U.S. government partners, industry, and numerous universities, has invested significant resources to date in an effort to better understand methane hydrates. With the demand for natural gas expected to increase significantly over the next 10 to 20 years, methane gas hydrates, which are likely present on the OCS in significant quantities, may be a potential source to meet both industrial and domestic needs for natural gas."

The BSEE website says their aim is: 'Promoting safety, protecting the environment and conserving offshore resources'; and included in this is the provision of data on OCS production and reserves.

Production data

Figure A6.20 gives recent OCS production data from BSEE.

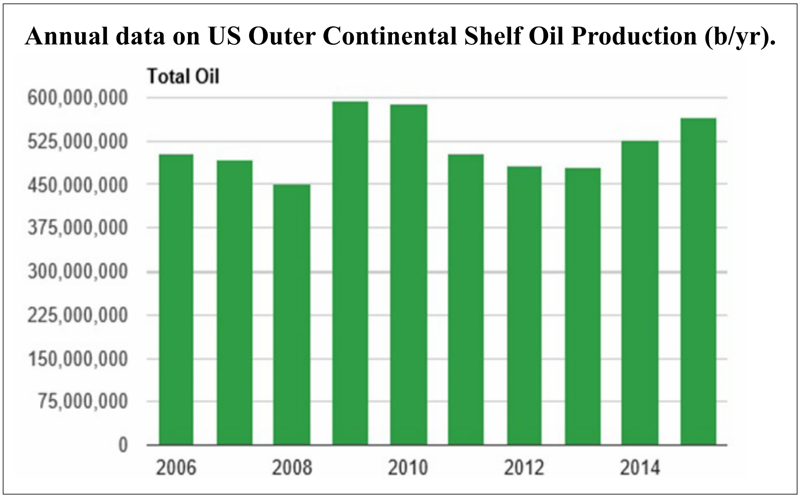

Figure A6.20 Recent Annual data on US Outer Continental Shelf Oil Production.

Note: "Values for most recent five months are estimates from BSEE's Liquid Verification System and Gas Verification System; other data come from Oil and Gas Operations Reports provided by offshore operators to the Office of Natural Resources Revenue."

Source: BSEE.

Oil reserves data

On field and reserves information, the BSEE writes:

> *"Reserves Information includes information on active and expired fields and leases in the Gulf of Mexico. Field data available includes leases assigned to each field, EIA field code number, and cumulative field production. Lease data available includes OCS blocks, operators, effective date of lease in field, expired lease status, and date and portion of*

lease within the field. Additional reserves files are listed in the Recent Publications."

On BOEM Gulf of Mexico (GOM) data Laherrère writes:

> *"Since 2014, BOEM has been reporting GOM reserves (since end-year 2010) as 2P (following SPE rules), whereas in the past reserves were 1P (following SEC rules). This is because BOEM is not obliged to follow SEC rules, while operators listed on the US stock market are obliged to do so. But it is surprising to see the small increase between 1P and 2P data, as indicated in the 'creaming curve' vs. date"; see Figure A6.21.*

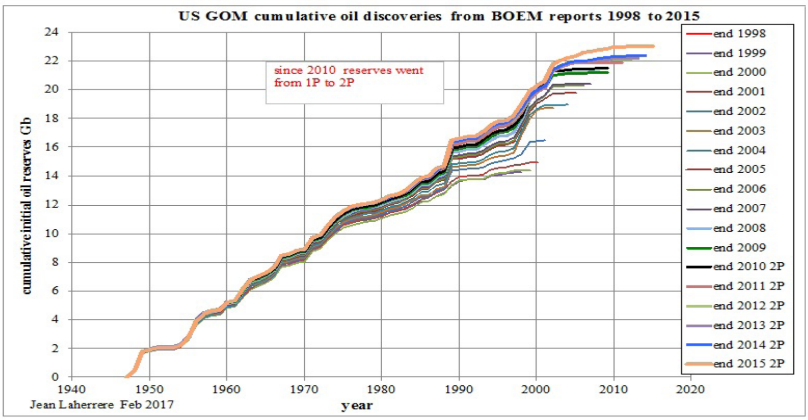

Figure A6.21 'Creaming curve' vs. date of US Gulf of Mexico Oil Discovery.
Note change in reserves data from proved (1P) to proved-plus-probable (2P) in 2010.
Source: J. Laherrère; MMS & BOEM data.

Laherrère writes:

> *"The difference between 2P and 1P is small except for the recent discoveries (below salt as Atlantis, North Thunder and Tahiti) which are new plays."* See Figure A6.22.

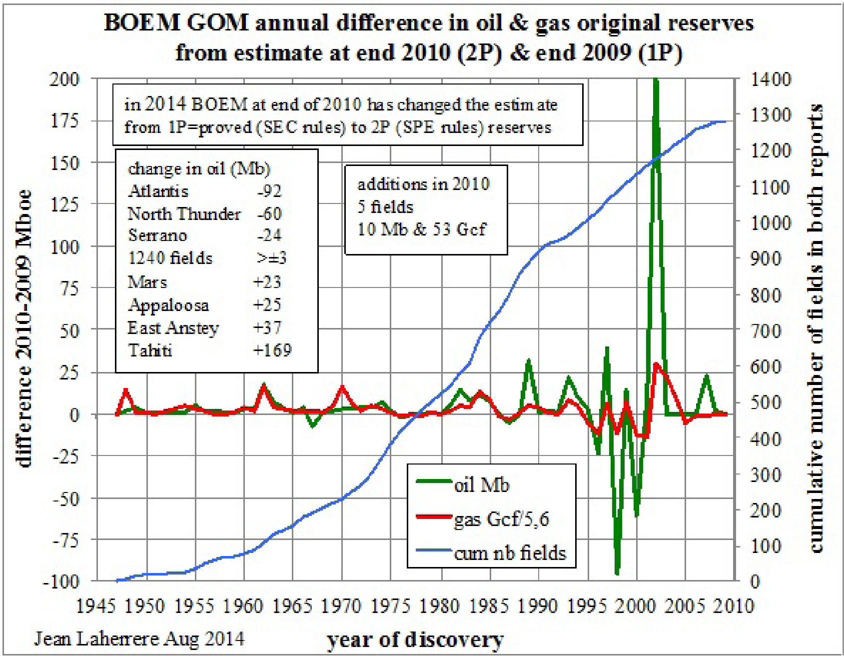

Figure A6.22 Annual differences in Oil & Gas Original Reserves
Source: J. Laherrère.

In connection with the apparent changes shown in Figure A6.21, Laherrère writes:

> *"It is amazing to find that MMS at end-1998 was missing 104 fields (out of a real number of 1088 fields): many operators were omitting to report data with no apparent punishment.*" See Figure A6.23.

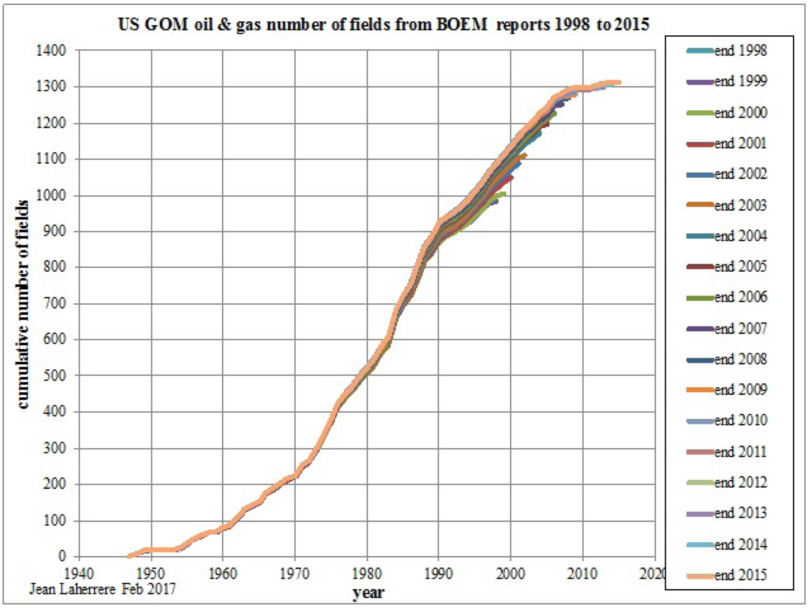

Figure A6.23 Evolution over time of the US Gulf of Mexico number of Oil & Gas fields discovered, as indicated in BOEM reports.
Source: J. Laherrère.

Thus Laherrère writes: *"The data on GOM cumulative oil discoveries varies with time, both because of missing fields and because of reserves changes."* This is indicated in Figure A6.24, which is a 'creaming curve' of discovery, but here vs. number of fields.

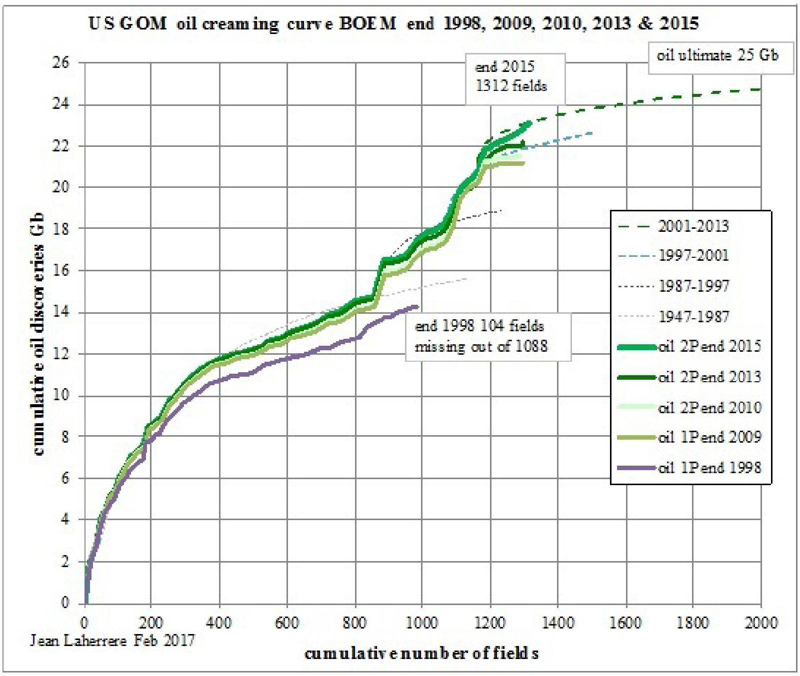

Figure A6.24 'Creaming curve' of US Gulf of Mexico Oil Discovery, vs. number of fields discovered.
Source: J. Laherrère.

Figure A6.25 gives a more detailed look at the evolution of GOM field discoveries at end-1998.

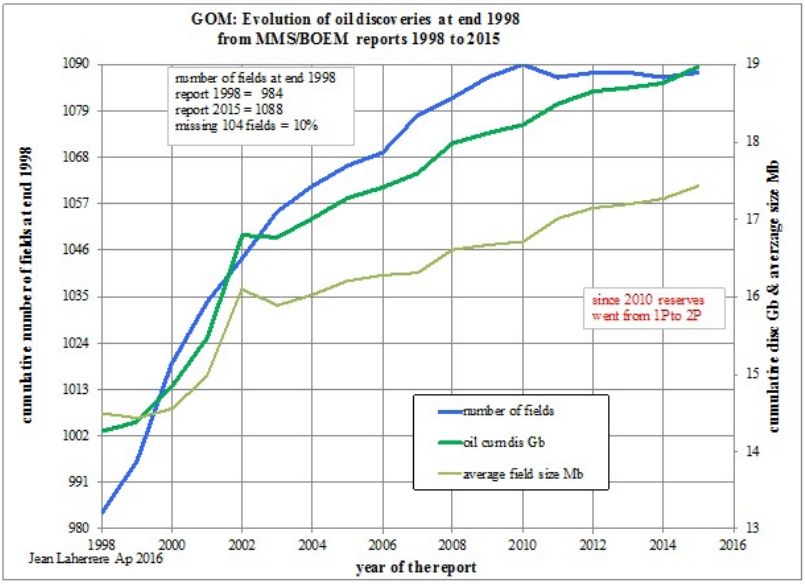

Figure A6.25 Plot of Evolution vs. time of US Gulf of Mexico Oil Discoveries
Source: J. Laherrère.

On Figure A6.25, Laherrère writes:

> *"It is amazing that BOEM on federal lands reports an incomplete number of fields: at end-1998 103 fields were missing in the 1998 edition compared to the 2014 edition. It is also strange to see the number of discoveries decreasing (albeit slightly): BOEM does not know exactly, but sharp increase shows this number is about right! Note that the increase in average oil field size shown is due to the addition of deepwater fields."*

Incidentally, in the context of apparent changes in a field's estimated original reserves ('reserves growth'), Laherrère notes that Schlumberger in 2003 recommended that this apparent problem of reserves growth should be removed globally by the application of better rules on reserves reporting; in fact reporting by true mean values, such that: *"Revision of proved-plus-probable estimates should be neutral."* Neutral here means that if the reserves estimates of a group of fields is correctly done, then future revisions - absent a major change in oil price - will increase reserves in some fields but decrease those in others, such that the total estimate of original reserves should stay about the same. (If this is not the case, Laherrère notes that either the estimator has to change their way of estimating reserves, or that the estimator should be changed!)

Oil forecasts

Here we have no useful information to add.

A6.3.11 Some US states, such as California

-ftp://ftp.consrv.ca.gov/pub/oil/Annual%20Production%20 Data/2014/

As mentioned in Part-1 of this paper, a considerable amount of useful oil data is provided by the individual US states. Here as an example, we give oil and gas production data, and also water production data, for a well-known large California field, Midway-Sunset, Figure A6.26a.'

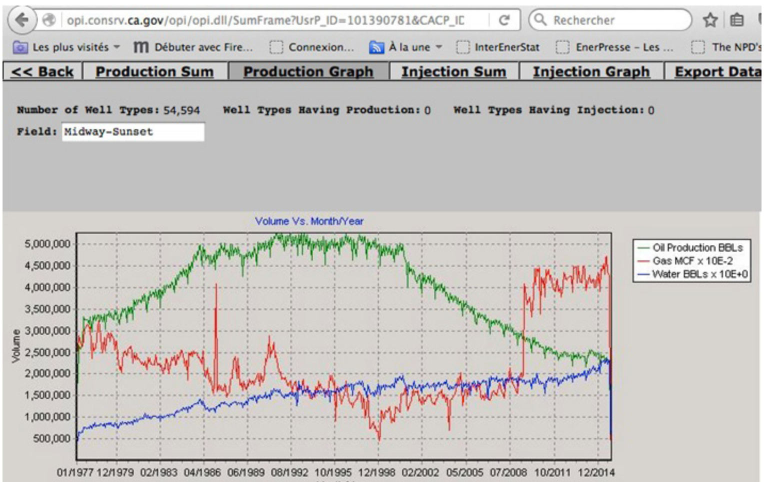

Figure A6.26a Screenshot of data on the Midway-Sunset Field.
Note: Decrease in oil production (green line; b/month) from about 1996;

steady increase in water production (blue line; (bx10)/month) over the period shown, giving a current water-cut of ~90%; and step-change in gas production (red line) in ~2009.
Source: J. Laherrère.

(As background, Figure A6.26b gives nearly the full history of production from Midway-Sunset, which was discovered in 1894. The field is of heavy oil, where production started slowly; both waterflood and fireflood were used, but where production increased significantly with steamflood from 1963; with subsequent production peaking in 1996, more than 100 years after discovery!)

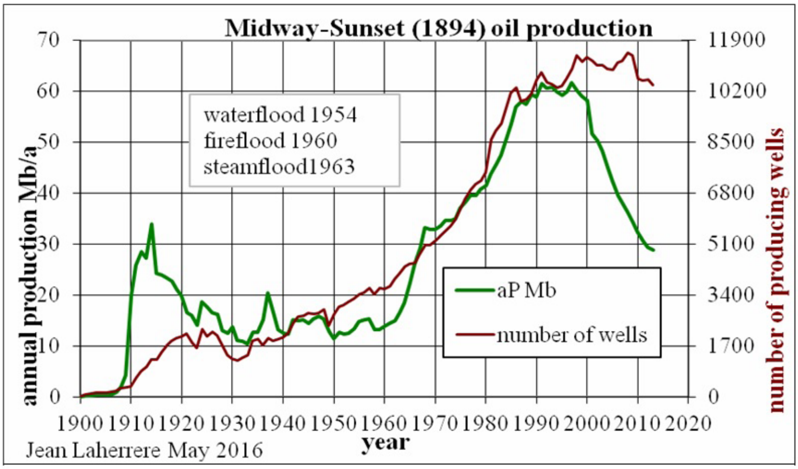

Figure A6.26b California Midway-Sunset heavy-oil field: Annual Production; and Number of Producing Wells.

Note: the high number of producing wells, now yielding on average ~8 b/d; and where the number of producing wells has remained roughly constant since 1996 despite production halving.
Source: J. Laherrère.

A6.4: Widely-used publications

Now we turn to looking at the oil data provided in some publications that are widely used.

A6.4.1: BP Statistical Review of World Energy

- http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Background

Within the company, BP (then Anglo-Iranian) started assembling data on global oil production, reserves and related information from 1952, but where this assembly of data started 'quietly going public' from 1956 (Cragg, 2011). It is assumed that initially the data were based on the company's own evaluations, but we understand that at a fairly early date a Middle East country where the company was active objected to the reserves data BP presented, and threatened the company with expulsion if they did not report the country's own assessment of its reserves. As a result, for reserves the *Stats. Review* has used data provided by governments, often those reported by the *Oil and Gas Journal (O&GJ)*, where the latter data were (and still are) often unaudited, and derived simply from survey forms sent to governments; see the section on *O&GJ* data below.

Also for many years now the data in the reports have not been assembled by BP, but with this work contracted out; for a long time to Energy Data Associates (Alan Clarke and Judith Trinnaman) who were always happy to answer questions on the data, and overall did a remarkable job. Most recently the contractor is the Centre for Energy Economics Research and Policy at Heriot-Watt University.

Production Data

Oil production data in the BP *Stats. Review* are by country (not by field), and are currently defined to include: "crude oil, shale oil, oil sands and NGLs. … [and to exclude] liquid fuels from … biomass and derivatives of coal and natural gas", so generally correspond to the 'all-oil' category defined in Part-1 of this paper. Comparisons of BP Stats. Review production data with those from other sources have been given in Figures 1 and 2 in Part-1 of this paper, while corresponding production data for biofuels are in Figures 15 and 17.

Note that data for any given year frequently change in subsequent editions, so sometimes it is necessary to specify in which year a specific data point was issued. Such changes can be due to more recent data becoming available, revisions to assumptions or methodology, or correction of mistakes. Examples of such revisions for data on global production, consumption, and 'calculated inverse density' are given in Figures A6.27 to A6.29.

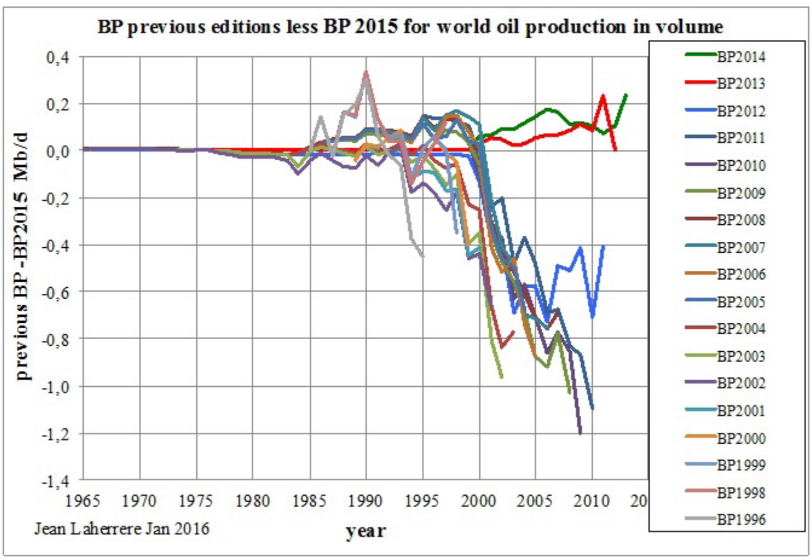

Figure A6.27 Comparison of changes over time in BP *Stats. Review* data of Global Oil Production, shown as differences from the 2015 data.
Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

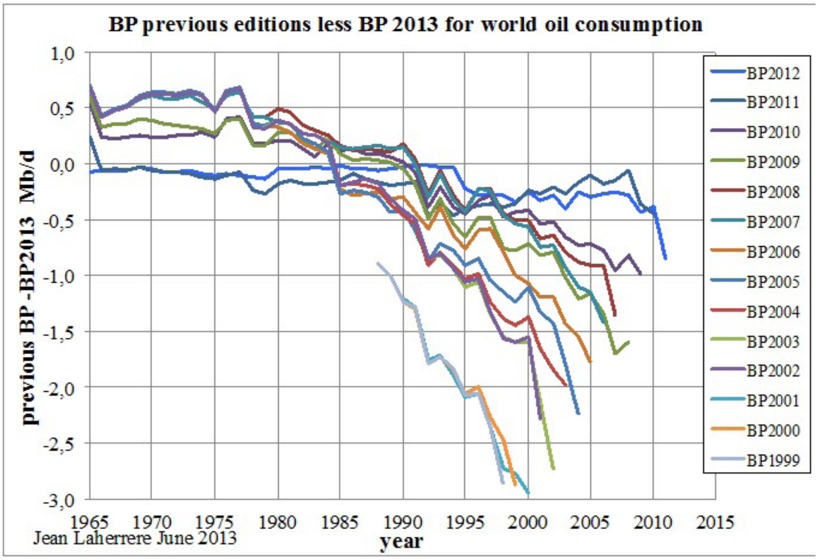

Figure A6.28 Comparison of changes over time in BP Stats. Review data of Global Oil Consumption, shown as differences from the 2013 data.
Source: J. Laherrère; from successive editions of the BP Stats. Review.

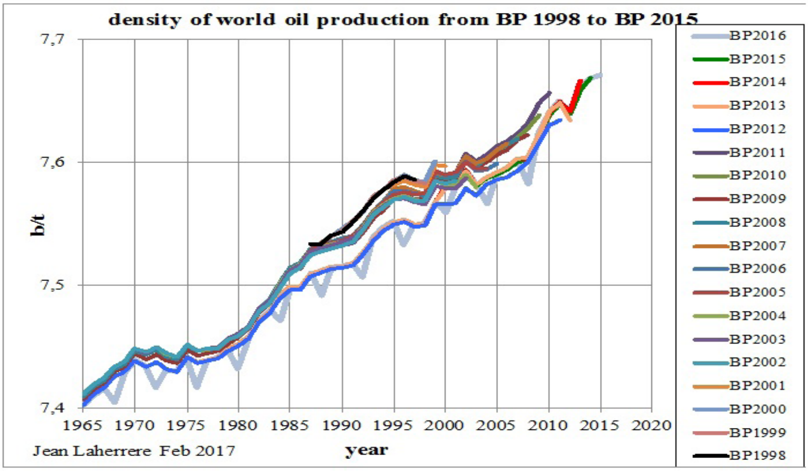

Figure A6.29 Comparison of changes over time in BP *Stats. Review* data of Global Oil 'Calculated inverse density', 1998 to 2016.

Notes: - 'Calculated inverse density' is derived by dividing the production data given in the *Stats. Review* by volume with the corresponding production data given in the *Review* by weight; and adjusting for units (where weight is in Mt/y and volume in kb/d).

- It is obvious that the 2016 edition of BP *Stats. Review* does not use the same number of days in leap years for volume and for weight.

Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

In addition to the revisions as illustrated above, as with all data significant mistakes sometimes creep in. For example, one of the reviewers of this paper noticed a recent apparent error in Syrian production data, writing:

> *"It seems the BP Stats. Review changed their numbers in 2013 to higher ones from 2000 to 2003. Before that their data roughly matched the EIA's. 2013 was the year they got a lot of figures wrong, based I think on incorrectly doubling up on NGLs. I contacted [BP] but they [seemed] not interested in my view."*

Oil reserves data

Now we turn to oil reserves data. Comparison of these data to those from other sources is given in Figures 36 and 40 in Part-1 of this paper. But as with the majority of organisations providing oil reserves data in the public domain, the primary problem with the BP *Stats. Review* data is that they report the very misleading *proved* oil reserves data, see discussion in Annex 5; and where especially the apparent *changes* in these data over time have misled so many analysts.

This is illustrated by looking at the evolution of the *Stats. Review* data on UK oil reserves, Table A6.1.

Year	Gb		Year	Gb	Year	Gb
1975	**16.0**		1991	4.0	2007	3.6
1976	**16.8**		1992	4.1	2008	3.1
1977	**19.0**		1993	4.6	2009	2.8
1978	**16.0**		1994	4.5	2010	2.8
1979	**15.4**		1995	4.3	2011	2.8
1980	**14.8**		1996	4.5	2012	3.0
1981	**14.8**		1997	5.0	2013	3.0
1982	**13.9**		1998	5.2	2014	3.0
1983	**13.2**		1999	5.2	2015	2.8
1984	**13.6**		2000	5.0		
1985	**13.0**		2001	4.9		
1986	5.3		2002	4.7		
1987	5.2		2003	4.5		
1988	4.3		2004	4.5		
1989	3.8		2005	4.0		
1990	3.8		2006	3.6		

Table A6.1 Evolution of data on UK Reserves

Notes:

- Data are year-end reserves for the years shown.
- Data prior to 1983 are presumably from the corresponding year-end issues of Oil and Gas Journal (‘O&GJ’).
- Data 1983 to 1985 are from BP Statistical Review of the years shown plus 1, where the source is given as the corresponding year-end issues of The Oil & Gas Journal; and the category is given as: “Published Proved” Oil Reserves.
- Data since 1986 (but not prior) roughly agree with the BP Stats Review Excel spreadsheets (various dates), where data are listed since 1980. In The BP Stats. Review 1987 printed issue it says the bulk of the reserves data are still O&GJ data, except now the UK reserves specifically are from the UK DTI Brown Book.

Source: BP Statistical Review from 1983; and presumably *Oil and Gas Journal* prior.

There are two main things to note from Table A6.1:

- The step-change in the data from 1985 data to 1986, where it seems the reporting changed from that of proved-plus-probable reserves (see table in Section A5.4.1 above) to proved only.
- The then long period of essentially static values for UK proved reserves - staying at the equivalent of roughly 5 year’s supply for three decades, from 1986 to today. This would not have mattered, except that it fooled many analysts into thinking that something special was going on. Year after year oil was being produced, but the proved reserves were not falling. This annual replacement of the proved reserves was thus very widely ascribed, including by many in the oil industry, the UK government and the IEA, as being mainly driven by improvements in technology; with horizontal drilling and later 4-D

seismic being frequently cited. The real explanation was primarily that as the proved reserves were produced, known reserves already in the probable category became re-classed as proved.

But why did analysts not see this for what it was? The reason lies partly in the misleading definition of proved reserves: those quantities that *"with reasonable certainty can be recovered in future under existing economic and operating conditions."* Most analysts then - and many still today - wholly incorrectly treated proved reserves as a fairly accurate measure of the amount of oil likely to be available.

Figures A6.30a and A6.30b help illustrate this problem of the reporting of UK oil reserves.

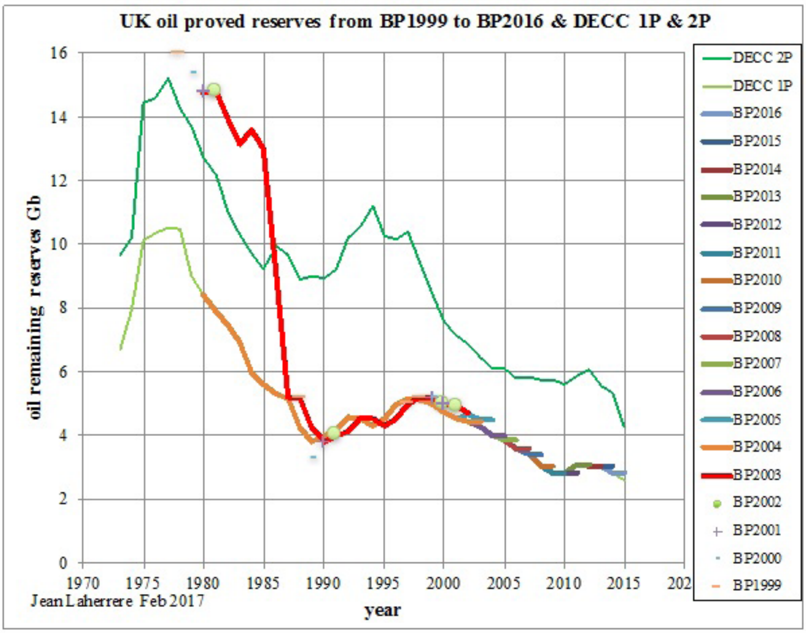

Figure A6.30a Comparison of changes over time in BP *Stats. Review* data of UK Oil Proved Reserves, 1977 to 2015, as reported in BP *Stats. Reviews* for the years 1999 to 2016; also UK Govt. (DECC) 1P and 2P reserves data for the period 1973 to 2015.
Source: J. Laherrère.

As Figure A6.30a shows, BP *Stats. Review* in 2003 reported UK reserves very differently from the 2004 to 2016 editions, in particular for the period 1980-1987, where the reported reserves were higher than even the DECC 2P values. As Laherrère notes: "The BP *Stats. Review* is unable to report correctly reserves data even for its own country!" Laherrère also notes that the *Stats. Review,* like the *Oil and Gas Journal,* reports reserves for the 1st of January of a given year, whereas DECC reports these data for the 31st December of the same year, which is the correct approach.

Figure A6.30b helps clarify this reporting of UK oil reserves:

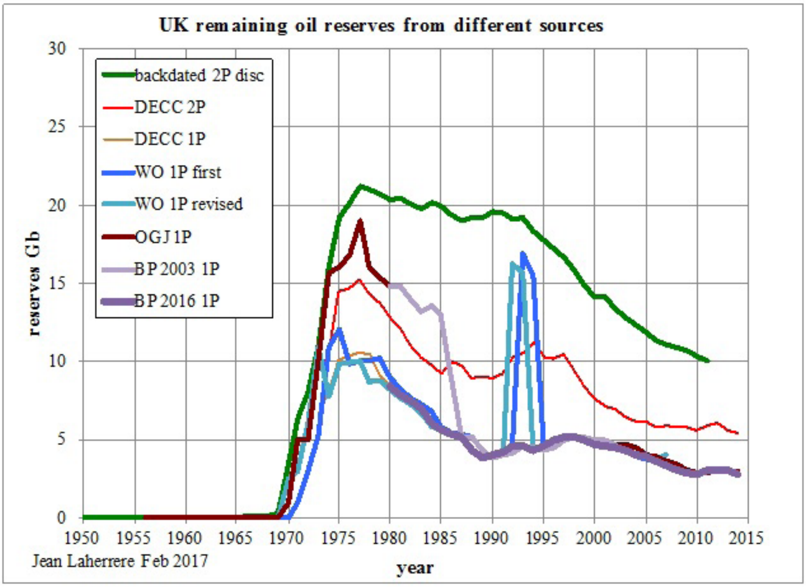

Figure A6.30b Comparison of changes over time in reported UK Oil Reserves: Various sources; including Oil-industry 'Scout' 2P Backdated Oil Reserves data.
Source: J. Laherrère.

Figure A6.30b is a very telling plot, and bears close examination:

- The oil-industry 'scout' backdated 2P reserves data show the rapid early finds of the major oil fields from

1970 to 1975; with the smaller, later finds not being adequate to prevent the 2P reserves from falling as production rose.

- The DECC 2P reserves data roughly match the profile of the oil-industry 'scout' backdated data, but at considerably lower values; almost certainly because they only include fields in (or perhaps approved for) production, whereas the oil-industry 'scout' data include all fields discovered at the dates shown.
- The much lower DECC 1P reserves data correspond almost certainly to the proved oil reserves as reported by the field operators under the conservative SEC rules.
- The *Oil & Gas Journal* reserves (notionally 1P) data clearly switched from 2P to 1P after 1985.
- The BP *Stats. Review* reserves data as of 2003 (again notionally 1P) track the O&GJ 1P data.
- The BP *Stats. Review* 1P reserves data as of 2016 track the UK government ('DECC') 1P data.
- World Oil (WO) 1P oil reserves data track the DECC 1P data, but with a short excursion in the early 1990s to roughly oil-industry backdated 2P reserves values.

Now we turn from the reporting of UK oil reserves to the reporting of global oil reserves. Additional aspects of the unreliability of these reserves data were also discussed in Annex 5; including the reporting of OPEC proved (1P) reserves (in some cases very probably reporting estimates of a country's *original* proved-plus-probable, 2P, reserves, i.e., before production started; and hence being significantly larger than remaining 2P reserves, and also unchanging with date), and more recently the inclusion of large amounts of non-conventional oils, where for Canada these volumes are probably accessible in the long term, but do not fall within any strict definition of proved if the latter means 'close to being produced'; and where the validity of the corresponding Venezuelan Orinoco estimates is even more uncertain.

The resulting changes over time in proved oil reserves, as reported in the BP *Stats. Review,* are indicated in Figures A6.31a to A6.34. First we look at global data with and without Canadian reserves, Figures A6.31a and A6.31b.

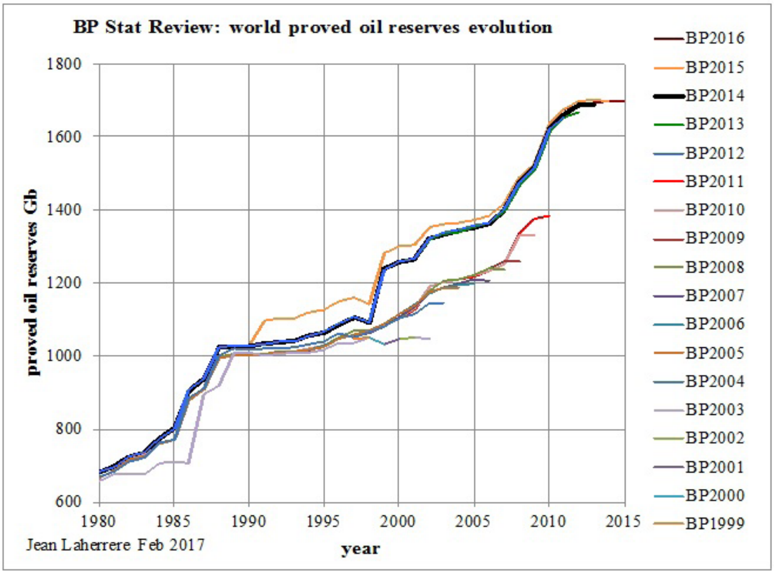

Figure A6.31a Comparison of changes over time in BP *Stats. Review* data of Global Oil Proved Reserves, 1999 to 2016.
Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

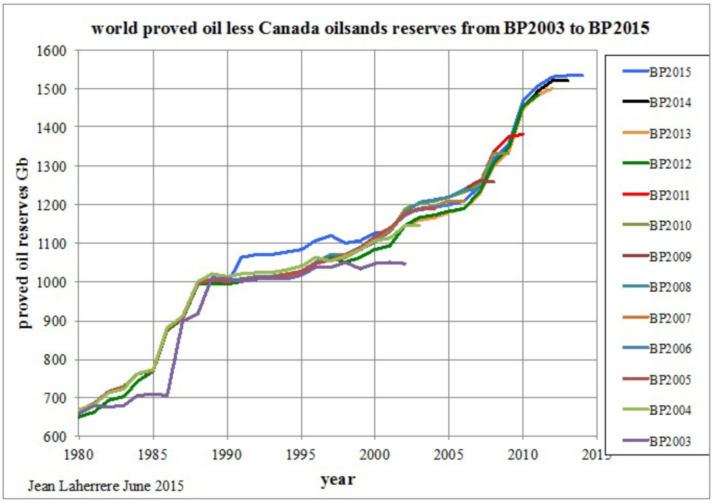

Figure A6.31b Comparison of changes over time in BP Stats. Review data of 'Global-less-Canada' Oil Proved Reserves, 2003 to 2015.
Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

The explanation for these changes regarding the Canadian data can be seen in Figure A6.32, which compares data from the BP *Stats. Review* with those from EIA/OGJ and CAPP (Canada Association of Petroleum Producers).

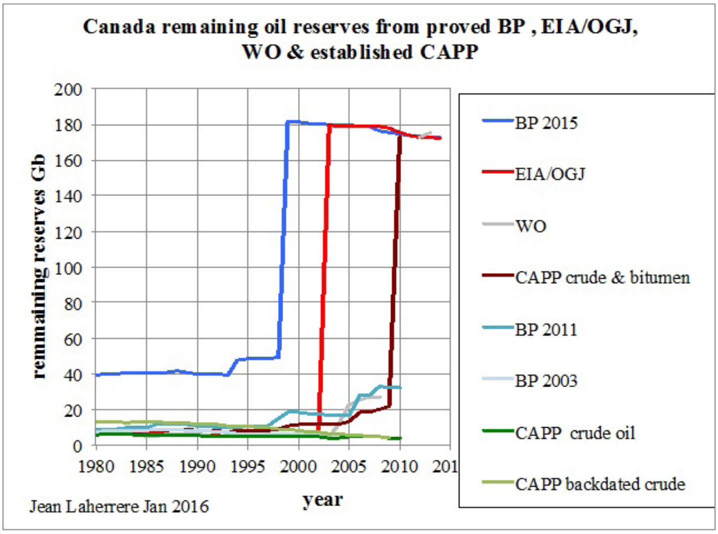

Figure A6.32 Comparison of the evolution Canadian Oil Reserves as reported by different sources
Source: J. Laherrère.

Another drastic revision in proved reserves oil data in the BP *Stats. Review* occurred in the data for Russia; here with a different cause as the reporting changed after TNK-BP was bought by Rosneft; see Figure A6.33.

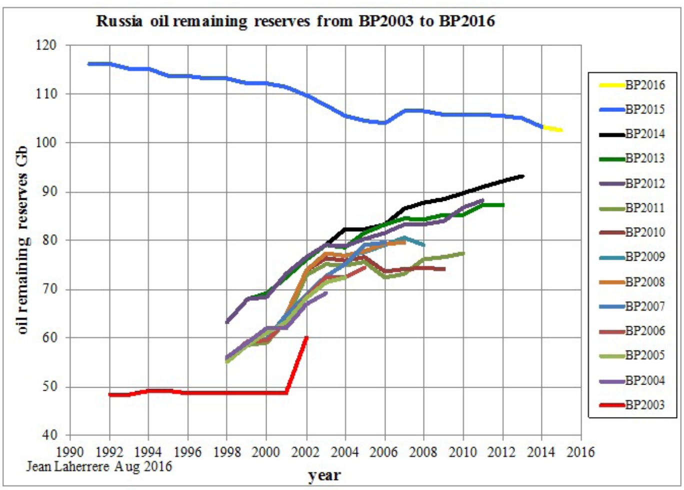

Figure A6.33 Dramatic changes in the reporting of Russian Proved Oil Reserves, 2003 to 2016.
Note: Large change in reported reserves for Russia after that TNK-BP was bought by Rosneft. [Note: Non-zero ordinate.]
Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

And likewise there have been significant changes over time in BP *Stats. Review's* reporting of Australian proved reserves data; Figure A6.34.

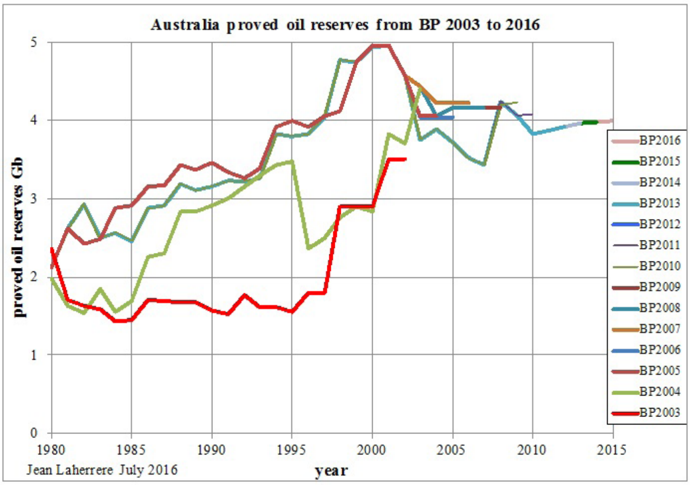

Figure A6.34 Changes in the reporting of Australian Proved Oil Reserves, 2003 to 2016.
Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

Incidentally, although this paper looks primarily at data for oil, for gas reserves also the proved reserves data in the BP *Stats. Review* have shown significant changes over time; see Figures A6.35 to A6.37. (Note that two of these Figures have non-zero ordinates.)

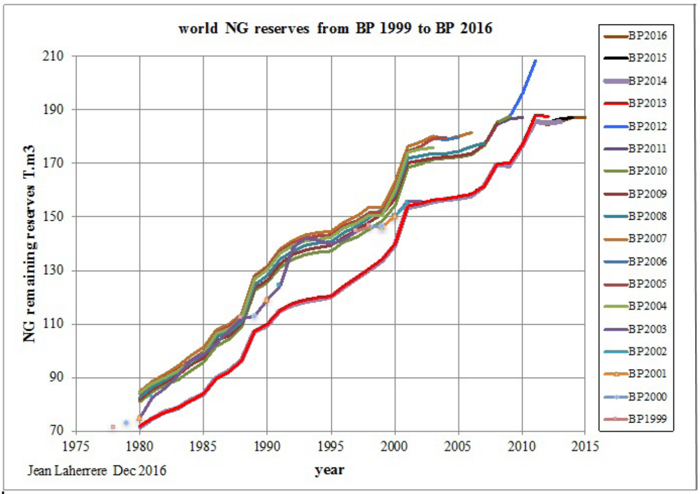

Figure A6.35 Changes in the reporting of Global Gas Reserves, 1999 to 2016.
Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

Perhaps the clearest case of problems in reporting gas reserves is that for the UK, where for a period the BP *Stats. Review* reported DECC 2P reserves data, rather than 1P; Figure A6.36.

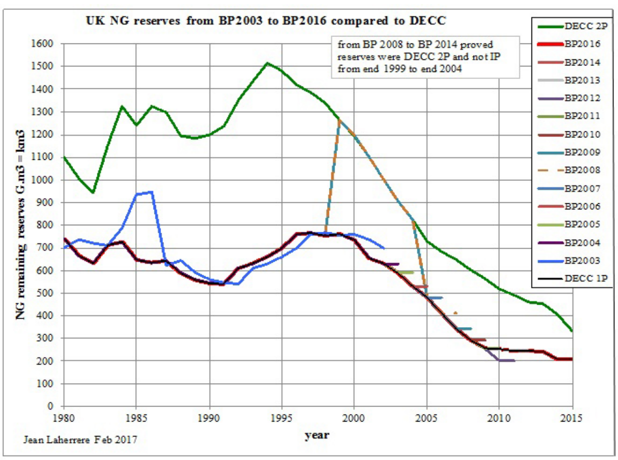

Figure A6.36 Reporting UK Proved Gas Reserves, but where for a period Proved-plus-probable (2P) reserves were reported.
Source: J. Laherrère; from UK DECC data, and successive editions of the BP *Stats. Review.*

Also, the reporting of Russian gas reserves has been problematic; Figure A6.37.

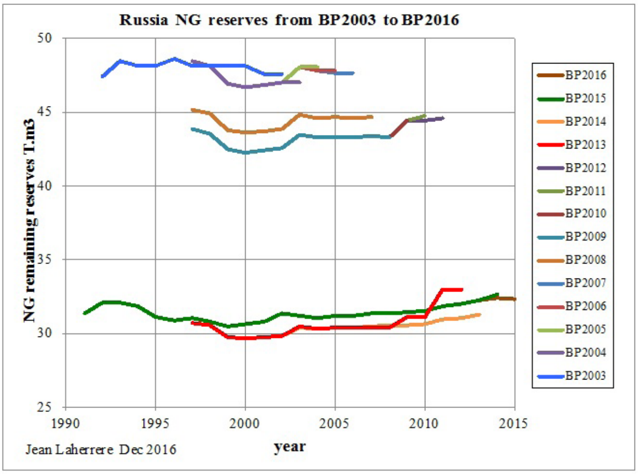

Figure A6.37 Significant reductions over time in the reporting of Russian gas reserves; 2003 to 2016.
Source: J. Laherrère; from successive editions of the BP Stats. Review.

Likewise, there have been changes in how natural gas density (here, the inverse of density) has been reported, Figure A6.38.

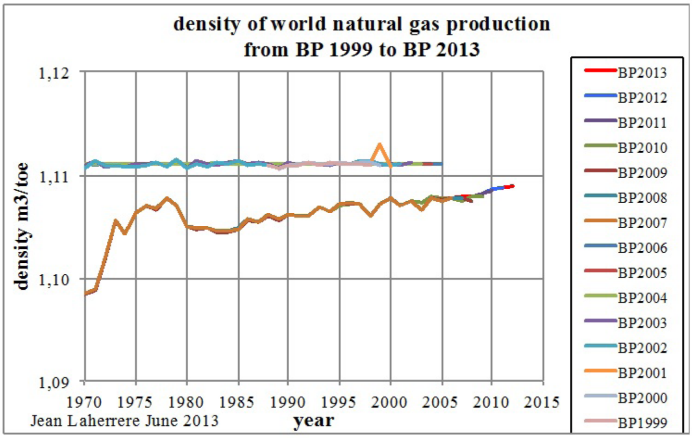

Figure A6.38 Changes over time in BP *Stats. Review* data of Global Gas 'Calculated inverse density', 1999 to 2015.

Note: 'Calculated inverse density' is derived by dividing the production data given in the *Stats. Review* by volume with the corresponding data given in the *Review* by weight; and adjusting for units (where weight is in Mtoe/y and volume in Gm^3/y).

Source: J. Laherrère; from successive editions of the BP *Stats. Review.*

To conclude this rather long section on the reporting of proved oil reserves in the BP *Stats. Review,* we note that at Reading University we long tried, unsuccessfully, to persuade BP to add a strong caveat about the problems with the proved reserves oil data, as the EIA has recently done with the proved reserves data it reports. For our contacts with BP on this topic see Chapter 4 of Campbell (Ed.) (2011).

Oil forecasts

Turning to oil forecasts, the BP *Stats. Review* itself does not give forecasts of oil production, but these are now provided by the company in its annual *Energy Outlook;* and we aim to report on these in a future issue of this journal.

Note that for a long time the company provided no external forecasts, and indeed had little in the way of official internal forecasts at the global level. One of us (Miller) when working for the company did produce an annual detailed bottom-up oil forecast by field that was circulated to a number of the company's senior management. After Miller left he kept this up to date until recently, with its recent results being reported in Miller (2015).

A6.4.2: The *Oil & Gas Journal*

- http://www.ogj.com

Background

The *Oil and Gas Journal* is a respected weekly magazine of the industry that in addition to its generally excellent and wide-ranging articles has considerable research expertise. The organisation provides detailed technical reports on a wide range of subjects, and maintain a range of databases. Of most interest to us here is their Worldwide Oil Field Production database published in the last edition of each year. This includes oil production by country, company, field, depth, discovery date, and gravity; and where they also provide a tables of reserves. The number of fields covered by region as of 2016 were:

Region	No. of Fields
Africa	976
Asia Pacific	993
Eastern Europe	470
Middle East	547
Western Europe	579
Western Hemisphere	2,005
GRAND TOTAL	5,570

Production data

For these data Miller writes:

> *"The field production data in the Oil & Gas Journal (OGJ) are increasingly published consolidated in various ways, notably by operating company, although OGJ may not have a choice in the matter. For example, OPEC data are largely consolidated by country, although the reportedly operating fields are listed; the Chinese onshore production data are seemingly consolidated within some 20 giant fields, and the US data are consolidated by state. Note that the data of the OGJ can clearly sometimes include, or equally clearly exclude, condensate without comment. In addition, errors occur from time to time, for example OGJ once published most of the field production data for Alberta displaced by one position relative to the field name, and smaller typos are not uncommon."*

Nevertheless, despite these problems the OGJ is one of the few public-domain sources where a wide range of by-field production data can be obtained.

Oil reserves data

It is of course with the OGJ reserves data that we have the most problem. Enquiries to the journal some years back established that the data presented were simply responses by individual governments to an annual survey asking for updated reserves data, and where if no response was forthcoming the reserves value the OGJ published remained unchanged. In this context Laherrère writes:

> *"The OGJ reserves estimates have been reported since 1957 in the journal issue of the last week of December. The OGJ's enquiry on reserves is sent to the national agencies during the autumn for the reserves estimates as of the following 1st of January, i.e., well before any technical studies have been carried out, which are available only in the following spring. Moreover, when national agencies do not reply the OGJ assumes that there is no change in reserves, and where this bad practice seems to not bother the national agencies in question. As a result, at end-2015 for example, the OGJ reported oil & gas reserves for 106 countries, with 68 countries showing no change for oil & gas reserves, and 74 countries for no change for oil reserves, implying that the*

> *survey was at least 70% wrong!"*

Equally important, the question asked is about proved (1P) reserves (not proved-plus-probable, 2P), and the many problems with proved reserves have been discussed at length in Annex 5 above. To our understanding the OGJ reserves data are reproduced in the EIA reserves tables.

An additional problem noted by Laherrère has to do with reporting reserves data in the 1970s for certain countries, where proved reserves were not reported, but instead reserves under the Russian ABC1 classification system. On this Laherrère writes:

> *"It is interesting to note that the reserves data in both Algeria and Syria displayed a huge increase in the 1970s because under Russia influence 'proven' reserves were in fact reported under the Russia ABC1 classification system (Khalimov and Feign, 1979), and where such reserves are grossly exaggerated (Khalimov, 1993)."*

This is illustrated in Figures A6.39 and A6.40. As Figure 25 in Part-1 of this paper showed, using the fact that Gazprom in some of their annual reports gave audited estimates of reserves under both ABC1 and 2P rules, 2P oil estimates are roughly typically 70% of ABC1 estimates.

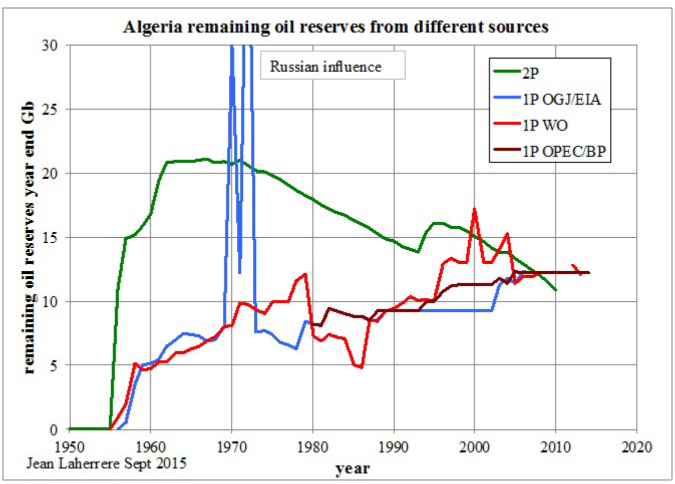

Figure A6.39 Comparison of Algerian Oil Reserves data from Different Sources.

- 2P: Backdated oil-industry 'scout' proved-plus-probable (2P) reserves.
- 1P: Proved oil reserves, form the sources listed.

Note the spike in apparent '1P' data in the 1970s.

Source: J. Laherrère.

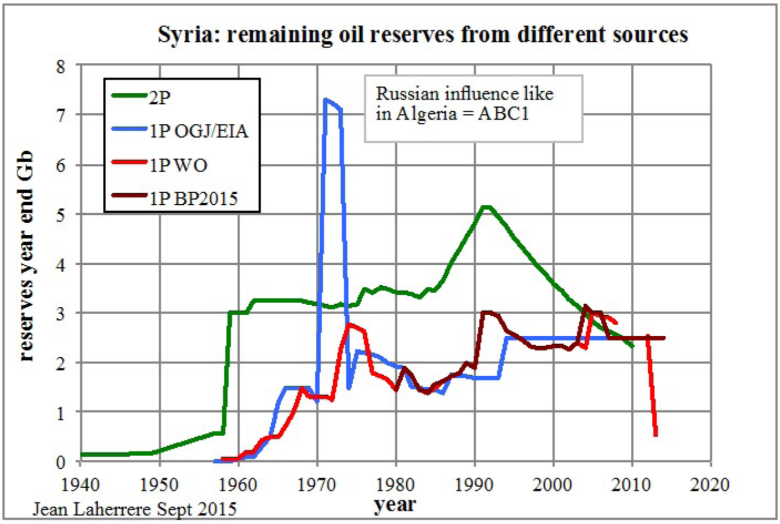

Figure A6.40 Comparison of Syrian Oil Reserves data from Different Sources.

- 2P: Backdated oil-industry 'scout' proved-plus-probable (2P) reserves.
- 1P: Proved oil reserves, form the sources listed.

Note the spike in apparent '1P' data in the 1970s.

Source: J. Laherrère.

Figures A6.39 and A6.40 show - yet again - the stark difference in the evolution over time of oil reserves if given as backdated 2P data, vs. if given as current 1P data. Also notable is the fact that today, as is the case with the majority of all countries, that having produced a significant fraction of their total conventional oil, the 2P and 1P estimates take rather similar values; that is, in these countries there is now little oil left to move from the 2P to the 1P classifications!

Oil forecasts

To our knowledge, OGJ makes no detailed oil production forecasts, although they sometimes publish, as one of us notes, 'a short, data-free … rosy opinion piece' on future oil supply.

A6.4.3: *World Oil*

- http://www.worldoil.com

Background

World Oil (WO) is an industry-standard monthly magazine that in addition to its many excellent articles has at times reported oil production and reserves.

Production data

We have no information to offer here.

Oil reserves data

Laherrère writes:

> *"The world oil 1P reserves from different sources (see Figure 36 in Part-1 of this journal) show that WO estimates differ from OGJ, but also from BP Stats. Review and OPEC. WO stopped reporting reserves from 2009 to 2011, but resumed in 2014 for 2012 and 2013, and stopped again. Today on their website it is impossible to find in their archives any world reserves data. The discrepancy on total reported world 1P oil reserves between WO and BP Stats. Review reached some 300 Gb in 2000, i.e., some 30%; and where inclusion or not of Canadian and Venezuelan non-conventional reserves probably provided a major part of the explanation for this difference."*

Oil forecasts

To our knowledge, *World Oil* themselves make no detailed oil production forecasts.

A6.5: Other Public-Domain Data Sources

Now we turn to three other public-domain sources of oil data. Importantly, these provide 2P data on oil reserves. Campbell and Laherrère present data from commercial sources, but modified by their own judgements; while Uppsala University has a database drawn from company announcements and numerous other sources, with data adjusted for reasonability.

A6.5.1 Campbell's Atlas of Oil and Gas Depletion (Campbell, 2013).

Background

Campbell, as an oil exploration geologist, first came to the issue of future constrained oil supply though having been asked by his employer to analyse the likely oil prospectivity of Colombia, where he had identified the potential of the Llanos basin, but which at the time was considered too remote to develop. Later Campbell was asked by a subsequent employer to analyse the prospectivity of Latin America as a whole. It was then he says that he began to recognise that the oil geologist's view at the time, that *'there was always more* [conventional] *oil to find',* was becoming ever less valid.

Based on this experience, when working subsequently as the Executive Vice-President of an oil company for the North Sea, he suggested to the NPD that they carry out a global assessment of likely recoverable conventional oil resources. This idea was taken up, and led to the publication in 1991 of *The Golden Century of Oil: 1950-2050,* with its many tables of future production of conventional oil by country. (For background to this, see Chapter 6 of Campbell (Ed.), 2011.)

A problem with the *The Golden Century* was that it relied much on proved (1P) oil reserves, which at that time Campbell trusted fairly well, despite long having commercial access to Petroconsultants' data for detailed basin studies. Dr. George Leckie, then at Petroconsultants, picked up on the *The Golden Century's use of* proved reserves, and said to his employer that the study ought to be re-done properly, this time using Petroconsultants proved-plus-probable (2P) oil discovery data. This suggestion in turn was taken up, and led between 1994 and 1996 to a series of ground-breaking oil and gas prospectivity consultancy studies, authored variously by Perrodon, Demaison, Laherrère and Campbell, and which included assessing the global resources of non-conventional oil and gas.

These studies led in turn to the publication in August 1997, jointly by Multi Science Publishing and Petroconsultants, of a book by Campbell: The *Coming Oil Crisis;* and later, in March 1998, to the publication with Laherrère of a *Scientific American* article: *The End of Cheap Oil*. Both these publications, as with *The Golden Century* previously, flew in the face of the then widely-accepted paradigm that further investment in conventional oil would, at least for many years into the future, succeed in turning 'resources into reserves' – as the evolution of proved reserves for many years in the past had apparently indicated was the case.

Subsequently Campbell continued to update the detailed by-country oil forecast model that underlay the Petroconsultants' oil forecast study. For this he used a wide variety of oil-industry 2P by-field and by-country data, including those from Petroconsultants (and later IHS Energy) and Wood Mackenzie, but adjusting these data as detailed geological knowledge and a variety of 'reasonableness tests' indicated. These updated results were published fairly widely, including in the extensive volume: *An Atlas of Oil and Gas Depletion*. The latter was written with the help of Siobhan Heapes who prepared the graphs and tables, and was published privately in 2008. A second edition, now titled *Campbell's Atlas of Oil and Gas Depletion,* was commissioned by Springer and published in 2013. This was prepared with the help of Noreen Dalton and Sonya Fagan, with the work being funded by Alexander Wöstmann.

Production data, Oil reserves data and Oil forecasts

Campbell's Atlas of Oil and Gas Depletion, Campbell (2013), mentioned above, provides production and 2P reserves data by country in chart form, as well as production forecasts out to 2030. Data are given for the 64 major oil producing countries of the world in the form of graphs of annual production of oil and gas; of the evolution over time of cumulative 2P discovery and cumulative production (and hence of 2P reserves); and in various additional analytical graphs including 'Hubbert linearisation' plots to indicate likely 'exploration extrapolation' URR estimates.

The 2P cumulative discovery and production graphs are especially telling, as these show exactly 'how much of, and when,' each country's conventional oil was found, and also when this oil has been (or will be) produced.

The data in the main graphs refer to Campbell's *Regular Conventiona*l oil (see definition in Annex 1 in Part-1 of this paper), but charts for global all-oil by type of oil, and also of all-gas are given at the end of the book. In addition, for each country there is a brief description of the country, its relevant general history, and a more detail description of its petroleum geology, and exploration and production history.

To get around the problem of using commercial data, but not being allowed to release these (a problem, incidentally, that has contributed much to the failure of authors like Campbell, Laherrère, Miller and others to be able to communicate their results in a manner that would be more convincing to sceptics) Campbell in the Atlas describes a methodology that while technically true hides the underlying industry data, writing:

> "*I evade the issue of having to report a county's true* [i.e., 2P] *reserves by adopting a different system as described in the introduction to the Atlas. I make a guess as to the Total Production by the year 2100. I think that production* [of Regular Conventional oil] *in most countries will have ended by then, although there might be a few tail end drops of negligible significance. Subtracting Past Production gives Future Production, of which a certain percentage is deemed Known (in other words "Reserves") with the balance being Yet-to-Find. By not identifying reserves as such I was able to use the confidential oil-industry data that I managed to get through various back doors without referring to it."*

As with Laherrère (see below), in the last two or three years Campbell no longer has access to the up-to-date oil-industry discovery data, and perforce must use estimates based on the historical data, announcements of recent finds, and subtraction from prior valid reserves of subsequent production. But given that the bulk of the world's *Regular Conventional* oil was found many years ago, and the current and future production of significant quantities of non-conventional oil come from relatively few countries - and hence are fairly easy to model - the resulting forecasts maintain their general validity. A detailed description of Campbell's current oil forecast model and its results, including - importantly - the modelling of the net-energy of by class of oil produced, is given in Campbell (2015).

A6.5.2 Data from Jean Laherrère

Background

Bentley writes:

> *"Jean Laherrère is a former Director of Exploration Techniques at Total, and has long provided the oil analysis community with some of its most valuable charts and data, as well as deep insight."*

As with Campbell, Laherrère after participating in the Petroconsultants studies in the md-1990s continued this modelling work; but whereas Campbell for commercial data relied to a significant extent on continued access to the IHS Energy by-country 'PEPS' database, Laherrère was able to draw on the more detailed IHS Energy by-field 'EDIN' database. In addition, both modellers had access to a wide variety of other commercial data sources, and both significantly adjusted and corrected these data in light of other information and experience.

Production data, Oil reserves data and Oil production forecasts

Note that Campbell primarily models production of *Regular Conventional* oil by country, with this declining away exponentially once each country's mid-point of its assessed URR is passed.

Laherrère, by contrast, generally models production by class of oil at the global level, and does this using Hubbert curves, not always symmetric; see for example Figure 19 in Part-1 of this paper. As described in Section 6.4.1, also in Part-1 of this paper, Laherrère makes significant adjustments to the EDIN and other commercial data to account for: separate modelling of the production of the extra-heavy oils, including early production of heavy oil production in Venezuela; reducing FSU ABC1 reserve values in the database to closer to 2P; reducing 2P reserves for some Middle East countries in the database to values more in line with the exploration history; and modelling NGLs and the other various classes of non-conventional oil separately.

As the modelling is largely at the global level, the corresponding production, reserves and forecast data are explicit on the graphs presented. The latter are generally not in print, but are on a number of websites; see for example the detailed paper: Laherrère J.H. (2016). More recently Laherrère noted: "After my two papers:

http://aspofrance.org/files/JL_2016USoilultimate.pdf and

http://aspofrance.org/files/JL_2016_California.pdf

on US & California oil production, I continue to study the oil reserves data of mature oil basins."

Note that like Campbell, Laherrère in the last few years has not had access to most of the industrial datasets. But again because the fundamentals of future oil production are based on discoveries of conventional oil made long since, and on knowledge of the resources of most of the non-conventionals also long understood, current models are still valid. More details of Laherrère's recent oil forecast model and its results are given in Laherrère (2015).

Oil price forecasts

Recently Laherrère has looked in more detail at the issue of oil price, and notes that since 2003 this has correlated well with the value of US dollar. This is indicated in Figure A6.41a, and over the more recent period in Figure A6.41b, and where Laherrère writes:

> *"As long as dollar value is high the oil price will be low, but the dollar has many problems (such as very high debt levels) and its value is high because problems are larger outside the US, and where no-one is able to forecast what will happen in the short term (for example, following Brexit and the election of Trump). With the recent low price of oil, investment in oil exploration and production is down, but also the cost of oil field services, and it is hard to forecast in detail how production will behave: but it is likely to reduce (and consumption to stay high) and hence the oil price will go up again, but by how much is not predictable."*

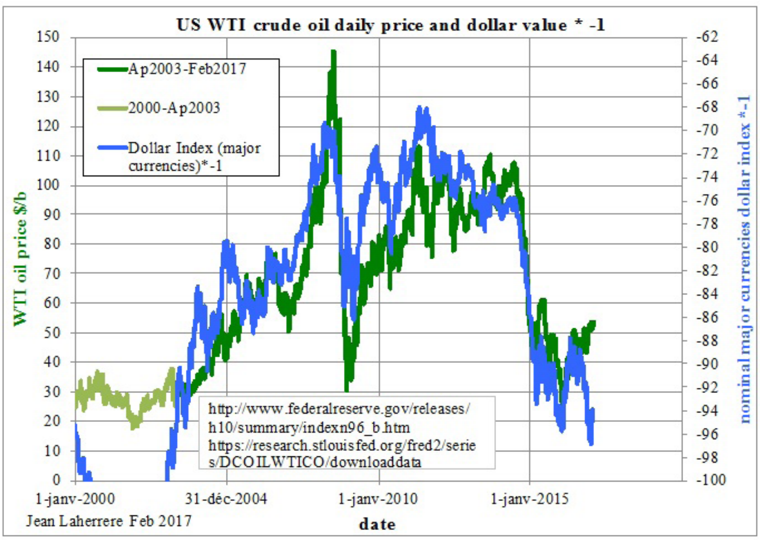

Figure A6.41a Correlation of the WTI price of oil vs. the inverse of the value of the US dollar against other currencies, Jan. 2000 to Feb. 2017.
Source: J. Laherrère.

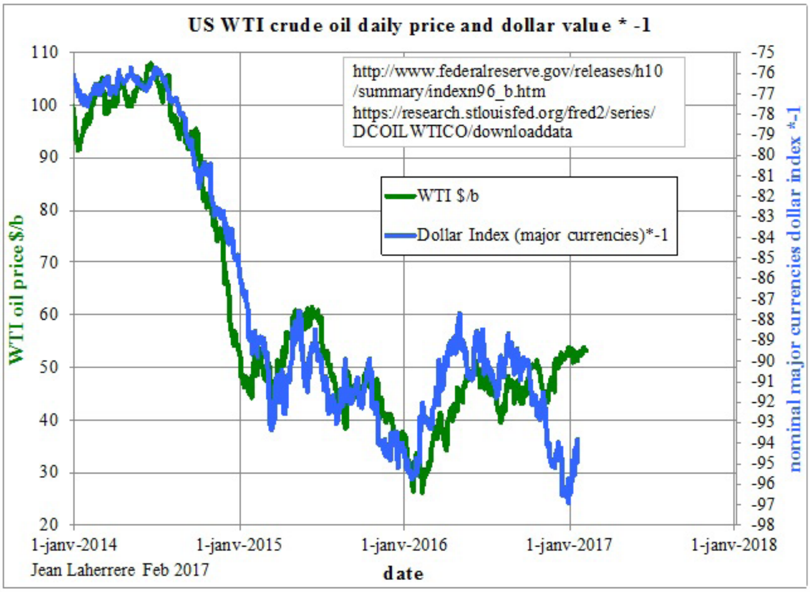

Figure A6.41b Correlation of the WTI price of oil vs. the inverse of the value of the US dollar against other currencies, Jan. 2014 to Feb. 2017.
Source: J. Laherrère.

As Figure A6.41b shows, the correlation is less good since the recent OPEC production agreement. Figure A6.42 looks at the longer-term correlation between oil price (both WTI and Brent) and the €/$ ratio.

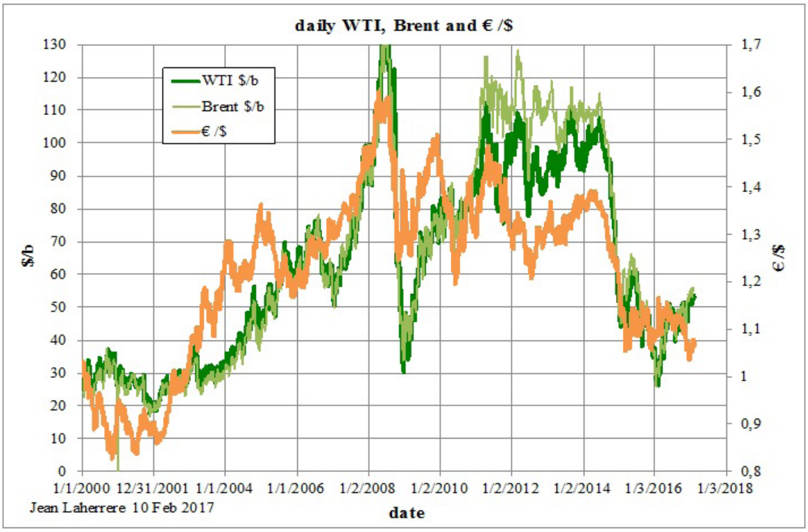

Figure A6.42 Correlation of the WTI and Brent oil prices vs. the €/$ ratio, Jan. 2000 to Feb. 2017.
Source: J. Laherrère.

As Figures A6.41 (a and b) and A6.42 show, there is indeed a good correlation, at least since 2000, in the oil price and the international value of the US $ (in which most oil contracts are denominated).

A6.5.3 University of Uppsala

Background

Professor Kjell Aleklett worked for many years in nuclear physics, but in more recent years the topic of global oil depletion caught his attention. Recognising its importance he set up a small group at the University of Uppsala to study this, originally within the Department of Physics. Later it moved to the Department of

Earth Sciences and became a part of the Natural Resources and Sustainable Development research programme. For many years Aleklett led this group, but recently this role has been ably taken over by Associate Professor Mikeal Höök. The background to this, as well as much about the topic itself, is covered in Aleklett's book *Peeking at Peak Oil,* originally published in 2012, and with an updated version to be published shortly.

Production data, Oil reserves data and Oil forecasts

At Uppsala, the PhD student Fredrik Robelius spent a considerable part of his research in assembling oil data from scratch, using a very wide range of sources, and concentrating on the world's large oil fields. This dataset has subsequently been extended and updated with many more fields of all types. It predominantly relies on data available from the public domain, trade journals, company reports, statistical yearbooks, etc.

Publications using these data include Robelius' PhD thesis (Robelius, 2007), Höök et al. (2009a, 2009b, 2014) and Höök (2014). Other publications from the group on oil tend to focus on methodology; and on national forecasts, such as Sällh et al. (2014) and Höök et al. (2010). In addition, the group has published a small number of studies on global oil forecasts, including Jakobsson et al. (2009), and Aleklett et al. (2010), where the latter looked at how realistic was the Reference Scenario in the IEA's *World Energy Outlook,* 2008.

The Uppsala group retains its interest in peak conventional oil, but has also expanded its focus to include shale ('light-tight') oil, critical materials, energy security, and wider social issues.

A6.6: Data from Commercial Data Providers.

This section covers the oil data available from commercial data providers. These are presented in alphabetical order.

A6.6.1 Enerdata

- https://www.enerdata.net

Background

Enerdata is a respected 25-year old independent energy consultancy which provides data, forecasting and consulting on a wide range of energy-related topics, including climate-change strategies. For 20 years they have published their annual *Global Energy Trends* report, and their research has fed into a number of recognised EU energy studies.

Production data and Oil reserves data

Enerdata provide oil production data on their website, but we have not so far compared these to data from other sources. Enerdata do not explicitly provide oil reserves data on the website, and we are not certain how they assemble the reserves data we assume they use internally for oil forecasting.

Oil forecasts

Their forecast model is an extension of the POLES model. It runs to 2040, and covers gas, coal, electricity, biomass and CO2 emissions, modelled for some 65 countries and regions. Forecasts are made under three scenarios, largely driven recently by different assumptions on energy price and severity of envisaged CO2 restraints.

Bentley writes:

> *"If memory serves, on the conventional oil supply side, at least in the past, Enerdata have used the USGS estimates for URR values."*

A6.6.2 Globalshift Ltd.

- www.globalshift.co.uk

Background

Globalshift Ltd assembles its data from public and industry sources; see details on its website. Past data, and forecasts, of production of all-liquids oil, and gas, by country are free on this website; and where for the underlying data a relatively modest fee must be paid. If one wants to see at a glance what will likely happen to future oil production, either globally, or for example in Russia, Nigeria or Iran, this is perhaps the easiest website to use.

The company states

The company was incorporated in 2009 after its owners sold Energyfiles Ltd., which was also engaged in energy forecasting. At first an energy adviser, the company also now provides oil and gas forecasts to the oil and gas industry, and to other energy suppliers and users.

Although the company is a commercial enterprise, it believes that the world must adapt its use of fossil fuels to a changing world. As such its currently free website aims to spread knowledge about future supplies of oil and gas, as well as giving details of exploration and development activity within the oil and gas industry and globally. As a source of free and low-cost historical and forecast oil and gas production, and also of well drilling and other information on oil and gas, the company aims to encourage independent and realistic analysis of the future of oil and gas supply, unfettered by wishful thinking or dogma.

Production data, and Oil reserves data

Globalshift Ltd. states that it aims to provide comprehensive global oil and gas coverage, using a wide range of on- and offline sources, and consistent methodologies. Histories of oil and gas production are derived from trusted sources as well as less rigorous or reliable ones. These data are sense-checked, and modified where deemed appropriate; and may be estimated or interpolated where the data are unavailable. Although oil and gas reserves data are not provided explicitly, they are implicit in the modelling. The numbers used represent the 'most likely' value, and in the terms of this paper generally approximate to 2P.

Oil forecasts

The company states that its forecasts are based on 'realistic geological, engineering, investment criteria, and on other criteria, including environmental, political, economic and social'. Oil and gas production profiles by country are created by bottom-up analysis of individual oil and gas fields, projects and basins, with the results being validated by application of geological and engineering principles. Analyses are consistently applied with clear definitions, and conversions (or approximations) adhere to industry standards.

Country groupings are used to analyse regional supply and demand levels. Drilled and active well numbers are modelled from plans and production forecasts. The data are collated and input into easy-to-use spreadsheets and kept up-to-date daily.

Further details on the data available, and the forecast model, are given on the website, and are described in detail in Smith (2015).

A6.6.3 IHS Energy

- https://www.ihs.com

Background

This section on IHS Energy (now within IHS Markit) is written at some length. This is partly because the company has long been recognised having one the world's best oil and gas databases, but also because a number of the authors of this paper (Laherrère, Campbell, Miller and Bentley) have used these data extensively. The following description of the company and its data is adapted from Bentley (2016):

> In 1956 Harry Wassall set up a consultancy, originally based in Havana, to assemble oil field data. This became Petroconsultants S.A. when its headquarters moved to Geneva in 1968; and the company was bought out by IHS Energy in 1996 after Wassall's death.
>
> The company collects data, *inter alia,* on oil and gas wells, fields and projects, from around the world, and aims to give global coverage. The data are 'scout' in that they are assembled by company employees scouting for information from a wide variety of sources. In the early days (and to some extent still today) this was done mostly by personal contact within the oil companies; and where often the latter, not allowed legally to discuss data with rival organisations, were happy to share data with the consultancy in exchange for access to data which the other companies were willing to supply.
>
> When the 'Oil Group' at Reading University first encountered the issue of 'peak oil' in about 1995, much of its effort went into understanding the data that the various proponents for and against peak oil were using. It became clear that while other commercial oil and gas field datasets existed at that time (and more now), that of Petroconsultants' was generally seen by the oil industry as preeminent, especially in its degree of international coverage. As mentioned above, these data were the basis of the Petroconsultants' studies that led to the Campbell and Laherrère 1998 *End of Cheap Oil* article. As also mentioned, Petroconsultants data were used in the USGS Year-2000 Assessment (but where Laherrère notes that the 1996 data used were missing some 1700 fields already discovered at that date); and probably in subsequent USGS assessments. Note that though the data are purchased by many oil companies, the full by-field dataset has been

too expensive for some of the national and international energy agencies.

Over several years, the Reading 'Oil Group' had useful conversations with Dr. George Leckie of Petroconsultants, who at that time was responsible for entering many of the estimates of oil and gas field size into the database. These estimates were seen as specifying the most likely amount of oil or gas a field would produce over its lifetime, in light of both currently committed infrastructure and technology and what might reasonably be assumed in future. Such estimates were taken to reflect the nominal 'mean', or proved-plus-probable (2P), values for each field, and hence contrasted sharply with the proved-only (1P) data that oil companies were required to report publically under SEC rules.

Since production by the individual fields is recorded, each field's remaining 2P reserves at any given date is generated by subtracting cumulative production from the estimate of the field's original volume of oil or gas. And because the discovery and reserves data are notionally statistically mean values, data for individual fields can be correctly added within the dataset to yield basin, country and global totals.

Then, since the aim is to capture 2P information on all fields globally (except for non-frontier US and Canada, where the data are only 1P), a picture can generated of how much oil or gas has been discovered in a region at a given date, and hence a region's trend of 'true' (2P) oil or gas discovery over time can be determined.

One problem however arises with these data, at least as far as analysis is concerned. The company (almost certainly like other data providers) was generally requested by customers for the best current estimates of the size of fields. This meant that if a revised estimate for the original size of a field became available, the database was simply updated with this new number, put against the original date of the field's discovery. That is the database reflects current knowledge of the size of fields, and not the estimates made at the dates the individual fields were discovered. Such data are said to be 'backdated'; and where, as a result, information on how the estimate of a field's size has changed over the years (its 'reserves growth') has become lost; unless earlier versions of the database are accessed, which can sometimes be done. Recently, IHS Energy has begun recording the change in field size by date in some fields; but a 'phone call to the company a short while back confirmed that such 'reserves' growth' data are not yet available on a global basis.

A second aspect of the data of which analysts need to be aware is that originally the data were largely (or entirely) only for oil in fields (i.e., for conventional oil). Today, with the growth of production of the non-conventional oils, the database contains information on the oil volumes expected from *specific projects* of non-conventional oil production. As a result, for example for the Canadian tar sands, estimates of the volume to be produced from announced projects are available in the database, but not (and quite correctly so) estimates of the total amount of tar sands oil potentially recoverable, despite the fact that all this oil might be classed as 'discovered' in the sense that its general location is already known. (As Laherrère notes, these tar sands were discovered by the Hudson's Bay Co. in 1717, and have been produced since 1930.)

Production data, and Oil reserves data

The IHS Energy exploration and production ('E&P') data, on well, field, project, seismic and related statistics, are held in the company's EDIN database, which reports oil and condensate separately, and which is updated on a continuous basis. A licence to these E&P data costs of the order of $100 000/year.

Of the data, Laherrère writes: "*IHS EDIN world data cover about 27 000 fields (as of 2011), but do not cover the US & Canada non-frontier areas (i.e., onshore US and the Western Canadian*

Sedimentary Basin."

Incidentally, on these latter fields, Laherrère notes that: *"It is hard to get detail on these over 30 000 fields; see Ivanhoe and Leckie (April 1991). The EIA did report backdated US discoveries once, in 1990, in 'US oil and gas reserves by year of field discovery' (Open file EIA-0534), but this report is not available anymore, and was not updated despite being introduced as the 'first of a series'!*"

In addition to the main EDIN dataset, very useful E&P total data on a by-country basis (i.e., not by well, field or project) are available in the company's much more affordable PEPS database, where data for this are extracted from EDIN on an annual basis. The data in PEPS are split between 'liquids' (which roughly corresponds to 'all-oil' as defined above, and so do not include GTLs, CTLs or biofuels) and 'gas'; and also between onshore and offshore. Despite being only by-county, some extraordinarily useful information on past and likely future oil production can be drawn from these PEPS data; and graphs using these data of oil and discovery and production (up to the year 2000) for a number of countries are given in Bentley (2016).

In Part-1 of this paper, quite a number of charts have been given that contain either EDIN data directly, or these data as adjusted by Laherrère. As Section 6.4.1 in Part-1 explained, the various adjustments Laherrère considers necessary include:

- Removal of the data on extra-heavy oil (including the Orinoco extra-heavy oil reserves in four fields discovered from 1936 to 1939, totalling some 215 Gb), if the intention is to analyse the discovery of only conventional oil.
- Adjustment for FSU ABC1 reserves to 2P, by reducing by ~30%.
- Adjustment of the reported 2P reserves data for some Middle East Countries, where it is judged by Laherrère, Campbell and some others that more recently higher reserves estimates are being carried in the database that match the producer-countries' own data (either for political reasons, or perhaps due to inexperience of staff); see for example Figure 26 in Part-1 of this paper. One of us (Bentley) raised this issue with IHS Energy a little

while back, but obtained a fairly unclear response.

In addition, Laherrère notes: *"Comparison of field data from IHS and Rystad shows that there are many discrepancies, indicating that* [probably in both companies] *the data collection is being done with insufficient checking."*

Thus, while recognising that the IHS Energy data are some of the best available, the above cautions need to be borne in mind, as do the two caveats mentioned earlier: that the discovery data are 'backdated'; and that for the non-conventional oils current and announced projects are reported, but - correctly - not the total oil whose location is generally known, and hence which some might consider as 'discovered'.

Oil forecasts

IHS Energy produces forecasts of oil production, both regionally and globally, out to 2040. It is our intention to examine these forecasts in a future issue of this journal.

A6.6.4 Nehring Associates

- http://www.nehringdatabase.com/index.html

Background

On the company's 'Significant Oil and Gas Fields of the United States Database', its website notes:

> *"We collect, develop, and organize data to meet the strategic information needs of the upstream oil and gas industry. … The key features of the database include:*
> - *Complete integration of information by field, major reservoir, and play.*
> - *Thoughtful organization (both geologic and geographic) of the data to facilitate a broad variety of data groupings.*

> - *Accurate economic field and reservoir production and size histories.*
> - *Wide range of relevant information.*
> - *Conceptually uniform variable definitions.*
> - *High rates of coverage by variable.*
> - *Thorough testing and editing.*
> - *Complete cross-referencing of our field codes and names to the IHS field names and codes.*
> - *Design that facilitates GIS applications.*
>
> [The database] *covers all producing provinces (basins) in the United States except the Appalachian Basin and the Cincinnati Arch; … and provides information on all fields with an estimated ultimate recovery of 500,000 boe (3 bcfe) or more. More than 16,600 fields are included in the current version of the database (fields discovered through 2009). Together these fields contain more than 99% of the known recoverable petroleum resources of the United States (excluding the Appalachian Basin). The field-level data consists of four basic types of information:*
>
> - *General field information.*
> - *Field discovery well.*
> - *Field production, reserves, and wells.*
> - *Field original oil-in-place and gas-in-place.*
>
> [In addition, the database] *provides information on all major reservoirs within the significant fields* [and notes that]: *The current version of the database incorporates more than 175 person-years of intensive research."*

It is excellent to have these data for the US non-frontier, not covered by IHS Energy as noted above. Even so there may be issues with some of the data, where for example Laherrère notes:

> *"Studying California field data from CA DOGGR I found hundreds of detailed reports on oil production but very little synthesis. On San Joaquin Valley (SJV), Nehring Associates' production data may be wrong in 1903, and also the data from SJV geology, with reported production*

being smaller than that of Kern River;" see Figure A6.43.

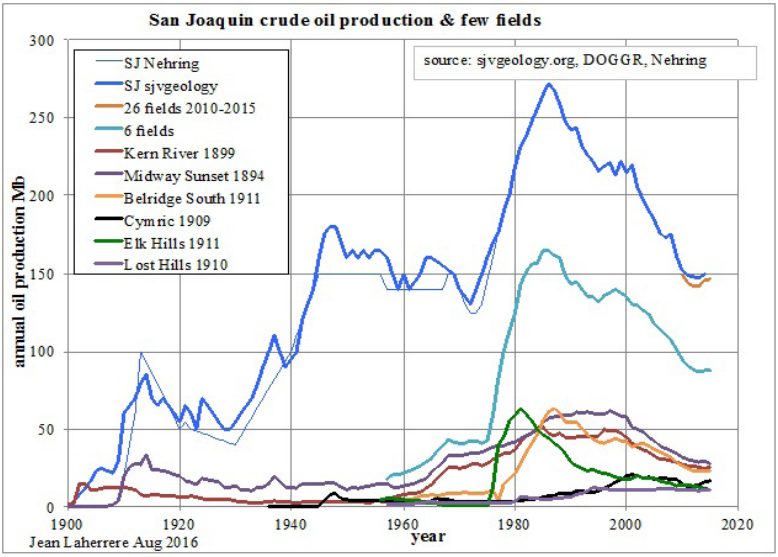

Figure A6.43 Comparison of Annual Oil Production data for the Californian San Joaquin Basin.
Source: J. Laherrère; from sources listed.

A6.6.5 Rystad Energy

- https://www.rystadenergy.com/

Rystad Energy is a fairly new but now significant player in the provision of oil and gas data and forecasts. The company started in 2004, providing information initially on Norwegian oil supply, but quickly expanding to give global coverage. Given the difficult anticipated oil supply transitions ahead, an intention of the company's owners (rather as in the case of Globalshift Ltd.) has been to improve access to reliable global oil and gas data, and to provide some of their aggregated data and forecasting for free. The company's website notes:

> *"We are an independent oil and gas consulting services and business intelligence data firm offering global databases, strategy consulting and research products. … Known for our up-to-date, fast and comprehensive product and service delivery, we engage with E&P and oilfield service companies, investment banks, investors and governments alike."*

Production data, and Oil reserves data

The company's main global upstream oil and gas database is UCube, while its global exploration database 'with detailed well-level coverage' is ECube. Other databases include oilfield services demand, services contracts, drilling rig supply and demand, and detailed data on North American shale ('light-tight') oil and shale gas wells, assets and plays.

Data are collected from a wide variety of sources by a global team now numbering perhaps sixty or so people, and as with all 'data provision' companies, these data undergo a range of consistency and reasonableness tests; with perhaps especial caution on oil company announcements of new fields and projects. Not surprisingly the underlying data have a significant cost, though thought to be substantially less than that of IHS Energy; but where, as mentioned above, summary aggregate data and the 'base-case' results of the company's forecast model are available for free via the company's UCubeFree database.

For countries where it is recognised that reliable data are scarce, in particular in the Middle East, older (pre-nationalisation) records sometimes need to be accessed, and a range of 'reasonable' field production profiles generated by analogy, extrapolation and common sense.

Section 7.4.1 in Part-1 of this paper presents and discusses some of Rystad's oil reserves data globally and by country; and where on the basis of Table 1 in Part-1, Rystad oil reserves data tend to be significantly towards the more conservative end of published estimates.

Even so, Laherrère urges caution in general about light-tight oil (LTO) original reserves estimates (i.e., cumulative production when the field is exhausted), including those of Rystad, writing:

> *"If reserves estimates of conventional oil are reliable, and recovery factors fairly well estimated, it is because the techniques have been checked and improved based on thousands of mature fields close to exhaustion. Moreover, the conventional oil & gas reserves ultimate of a basin represent only a very small percentage (about 1%) of the hydrocarbons generated by the source-rocks, leaving a large amount in the ground as resources.*
>
> *By contrast, because LTO fields are new (after 2008) and are 'continuous type accumulations', and usually without a water contact, they are far from exhaustion, and there are not enough historical data to check the recoverable resource estimation methodology, and in particular the recovery factors assumed.*
>
> *Most LTO reserves estimates are generated by estimating the amount of oil and gas generated by the source-rocks, and by assuming a relevant range of recovery factors. But only a small part of a so-called shale play area is economical, and most current production is located in 'sweet spots', which have often now been heavily drilled and fractured. The increase in LTO production reported using longer horizontal wells and more fracking is indeed real, but most forecasts are based on assumptions about the number of wells to be drilled in the future, but often without any geological study of where these can be drilled. Primarily, because as yet there are as no abandoned LTO fields, no-one can claim to be right in estimating LTO original reserves.*
>
> *As an example of LTO production, the first LTO Bakken large field was Elm Coulee in Montana (in the North Dakota Bakken, the Antelope field found in 1953 was small, ~12 Mb). Elm Coulee started production in 2000, and peaked in 2006 with a first decline rate of about 15%/a. It then saw a new peak in 2014 (as the growth of the number of wells increased in 2010) but then followed*

> *a decline rate of about 12%/a, suggesting an ultimate for the field of ~200 Mb; less than was forecast in 2006.*" (See Figure A6.44).

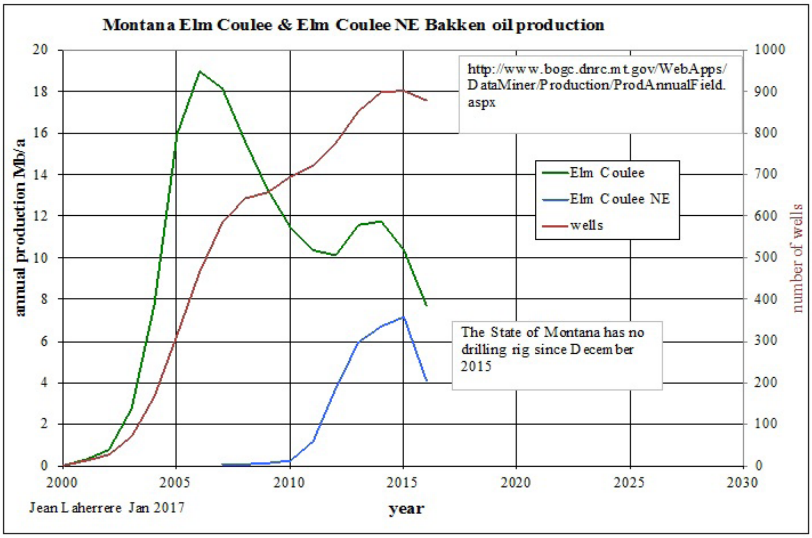

Figure A6.44 Oil Production of the Elm Coulee and Elm Coulee NE zones of the Bakken; and Number of Wells

Note: Elm Coulee peaked in 2006, with a secondary peak in 2014 with more wells.

Source: J. Laherrère; from source listed.

Oil forecasts

In terms of the company's estimate of global oil yet-to-find, Laherrère writes:

> *"Rystad estimates that 940 Gb* [of oil] *globally are yet-to-find* [a figure obtained by subtracting the global 2PC estimate from the 2PCX estimate given in Table 1 in Part-1 of this paper; and see also that Part's Figure 37]. *This estimate should be justified by data, and the best way*

to estimate yet-to-find is by extrapolation of past discovery. [My] *graph of global oil discovery as of 2016* [see Figure 27 in Part-1 of this paper] *shows that global oil discovery displays three cycles:*

- surface exploration, 1860-1940, mainly from drilling surface anticlines;

- geophysical exploration, 1940-2000, drilling anticlines mainly found by geophysics;

- deepwater exploration, 2000-present.

Based on these discovery data [I estimate] *the global crude less extra-heavy oil 'ultimate' as 2200 Gb, leaving a yet-to-find of only about 250 Gb; which is far from the 940 Gb estimate quoted above from Rystad* [but where it is accepted that, as Figure 37 in Part-1 makes clear, the latter figure also includes an estimate of the yet-to-find of non-conventional oil]."

A recent description of Rystad Energy's detailed asset-based oil forecast modelling is given in Wold (2015). This includes forecasts of global all-liquids production (including crude oil, condensate, NGLs, refinery gain, biofuels and CTLs) under assumed real-terms oil prices of $120, $100 and $50/bbl. The '$100/bbl' real-terms forecast indicates global all-liquids production as reaching a peak around 2020, staying roughly on-plateau to about 2035, and then declining away fairly steeply.

A6.6.6 Wood Mackenzie

- https://www.woodmac.com

Background

Along with IHS Energy, Wood Mackenzie has been seen as a preeminent supplier of well and field-level global oil data, with now Rystad Energy joining this group. Like IHS, much of Wood Mackenzie's original oil and gas data are thought to come from detailed 'scout' enquiries', rather than other often less reliable published sources.

On its upstream data, the company's website says:

> *"Upstream Data Tool (UDT) sets the industry standard in upstream oil and gas data analysis. It lets you quickly study trends and identify and benchmark opportunities at the infrastructure, asset, country and company level. … Covering 150+ countries, 31,000+ fields and more than 157,000 E&A wells (including planned), UDT has now been enhanced with:*
>
> - *10,000+ transport systems*
> - *29,000 offshore facilities*
> - *Field gross cashflows and company net cashflows from 1965 to 2064*
> - *Improved data and chart download functionality."*

Production data, Oil reserves data and Oil forecasts

Wood Mackenzie data on annual global discovery of conventional oil since 1948 are given in Figure 33 in Part-1 of this paper. But although three of us have had access to Wood Mackenzie data over the years, here we offer no especial analysis, except to note that - at least in the past - the company's data covered fewer fields than IHS Energy.

A6.6.7 Other oil forecasters / possible data providers

Finally in this Section on oil data by source, we note that in addition to the organisations listed above, there exist a number of other consultancies, academic groups and individuals that analyse oil data, some of which also make oil forecasts. These entities may be in a position to provide certain oil data for a fee, or in some cases possibly for free. The following list of these is in alphabetical order, and is far from comprehensive:

a). ABM Analytics

- http://abm-analytics.com

ABM Analytics is possibly unique among energy consultancies in that it provides solutions based on agent-based modelling, an approach which the company suggests can bring far more accuracy into modelling the complex interactions of the real world. The company's website says:

> "*We at ABM Analytics believe that an agent-based, fundamentally-driven analytical process that focuses on energy/fuels market dynamics can generate a risk-adjusted outperformance of (upstream and downstream) investments decisions irrespective of market cycles. We provide clients with world-leading intelligent analytics for making informed judgements about emerging business megatrends, opportunities and associated risks.* [Among the tools the company offers are:]
>
> • *ACEGES: An agent-based model for exploratory energy policy and long-term investment decisions by means of controlled computational experiments. ACEGES is designed to be the foundation for large custom-purpose simulations of the global energy system.*
>
> • *GAMLSS: Semi-parametric regression type models where the exponential family distribution assumption for the response variable is relaxed and replaced by a general distribution family, including highly skew and/or kurtotic continuous distributions.*"

A recent agent-based global oil forecast model produced by the company is described in detail in Voudouris et al. (2016); and where some of the 2P oil reserves data required for this model were from the dataset assembled by Miller (see below).

b). Bloomberg Energy

- https://www.bloomberg.com/energy

Bloomberg is seen as one of the 'heavyweights' of oil and gas news and analysis. We do not know what data they have. They have recently written a number of reports and opinion pieces on 'peak oil demand', based in part on recent WEC and Shell publications.

c). Chinese University of Petroleum, Beijing (CUPB)

- http://www.cup.edu.cn/internationaloffice/en/

A group at this University, under Professor Lianyong Feng of the School of Business and Administration, has done excellent work in understanding China's oil and gas resources, and in putting together plausible forecasts of production taking into account the uncertainties in the underlying data.

They have also done studies on more specific topics, such as on the expected water demand for hydraulic fracking in China, as well as participated in studies of global reach, including on global fossil fuel recoverable resource quantities, and hence likely future production; and on the likely effect of fossil fuel production on climate change. Some of these papers are listed in 'References' below, including Höök et al. (2010 and 2014), Mohr et al. (2015), Wang J. et al. (2016) and Wang K. et al. (2016).

In addition, this group founded the China branch of the Association for the Study of Peak Oil (ASPO). To contact the group, in the first instance please e-mail Professor Feng at: fenglyenergy@163.com

d). Citi

- http://www.citigroup.com

Citi is a major bank that often provide analysis of the global oil market, but we do not know what data they have. They currently espouse a 'peak oil demand' view.

e). Douglas Westwood

- http://www.douglas-westwood.com/

Douglas Westwood is a highly thought-of consultancy working in the oil and gas sector for now some 25 years. Its website says: *"Our research is supported by proprietary data, insight and knowledge."* One of its founders, and current director, John Westwood is one of those in the industry who has long understood peak oil.

f). European Commission

The European Commission from time to time produces reports on the European and global energy situation, including discussion of oil supply. One of us (Bentley), along with Rayner Mayer of the University of Reading, visited officials at the Commission in DG-TREN on a number of occasions and built up a good rapport, but never succeeded in convincing them of the validity of a 'peak oil' view; they were strongly swayed at that time by Peter Davies' view that 'global proved oil reserves have always increased', and that peak oil overlooked the critical economics perspective that higher oil prices would always yield increased supply; see discussion in Chapter 4 of Campbell (Ed.) (2011).

g). International Monetary Fund (IMF)

In 2012 the IMF produced two excellent working papers considering the future of global oil supply, and the macroeconomic implications. The first was *The Future of Oil: Geology versus Technology,* by Jaromir Benes et al., WP 12109, produced in May 2012; and the second was *Oil and the World Economy: Some Possible Futures* by Michael Kumhof and Dirk Muir, WP 12265, produced in October 2012.

The first paper (and probably the second also) was one of the very few papers aimed at combining macroeconomic data with global oil reserves data, and at combining traditional economic theory of price-elastic oil supply and demand with geological theories of finite resource production profiles. The paper found importantly that such a combined approach had historically been able to forecasts oil prices better than either the economic or geological approach alone.

Both papers suggested that based on the oil supply constraints, and on the current best guess for price elasticities, future oil prices might be expected to rise very high indeed; although recognising that in practice elasticities would in fact probably change, as 'demand destruction' would likely be triggered by such high prices.

Subsequently Dr. Kumhof moved from this group to the Bank of England, and there is continuing his research on the macroeconomic implications of fossil fuel shortages.

h). Miller, Richard

As mentioned earlier, Dr. Miller used to work for BP, and there produced and annually updated a detailed bottom-up by-field '2P data' oil forecast model. Since leaving BP and until recently, he updated this model and revised his forecasts – and unlike nearly all in the oil forecasting field, took the trouble to compare his current forecast with those he had produced earlier! His model, along with a number of others, was discussed in Technical Report 7 *(Comparison of Forecasts)* of the 2009 UKERC Global Oil Depletion study. Subsequently Dr. Miller was Co-editor of the landmark special issue of the *Philosophical Transactions of the Royal Society A on The Future of Oil Supply,* published in Jan. 2014.

Note that Miller's underlying 2P oil discovery (and hence reserves data) are by field, and start from 1992; these include announced field discoveries (and projects in the case of non-conventional oil) whether they are eventually likely to prove economic or not. Miller's most recent version of his oil forecast model and its predictions are described in Miller (2015).

j). Oil Majors

Many observers are surprised when told how little, typically, the oil majors are involved in trying to understand the world's oil future. But in fact this is not so surprising. The general outlines of global oil supply are fairly easy to forecast, and follow factors discussed in this paper such as the falling discovery of conventional oil, and increased production of the various non-conventional oils.

But an oil company's business is driven into profit or loss mostly by the oil price, and this is far harder to forecast; being determined as mentioned earlier largely by a very small difference (of perhaps 1 Mb/d or so), between the two large numbers of global oil supply and demand (currently at not far from 100 Mb/d). Oil price in the short term is thus extremely hard to forecast, and this is usually a company's main focus when looking ahead.

Oil majors of course well know their own oil reserves under a range of probabilities and vs. price, and typically report the aggregated 1P values (and now sometimes 2P values) of these data in their annual reports. But in general they do not have data of global scope, and must go to the commercial data providers for these.

Some oil majors provide public forecasts of global oil production; for example ExxonMobil; fairly recently, BP; or give scenarios for this, as is the case with Shell. But the public pronouncements of many senior executives within these organisations indicate that the latter are often poorly aware of the oil future ahead, and where - in the past - these have included Chief Economists (BP, ENI), and CEOs (Chevron; perhaps ExxonMobil); see the discussion on this in Annex 5 of Bentley (2016).

k). Peak Oil Consulting

Peak Oil Consulting's data started simply as a listing by Chris Skrebowski (then Editor of the Energy Institute's *Petroleum Review)* of announced large oil production investment projects (the 'mega-projects' list); but this grew to a more complete list of announced projects. In turn these data have underpinned three reports produced for a consortium of UK companies concerned about future oil supply, the Industry Taskforce on Peak Oil and

Energy Supply (ITPOES) group.

It is not known if this valuable dataset is being kept up to date; certainly the ITPOES group has largely lost interest in the topic of global oil supply following the price fall produced by US light-tight oil, and by Saudi Arabia recently increasing production slightly, rather than reducing production in the face of weak oil prices as had been expected.

m). Petroleum Analysis Centre

The Petroleum Analysis Centre (PAC) is very much the 'new kid on the block', and so far has not made any data available. It was set up by Colin Campbell and Noreen Dalton in Ireland with the intention of assembling and making available for free, or at low cost, a wide range of data on oil, including the crucial 2P oil discovery data; but this is still for the future. Currently the main activity of PAC - which takes up all our time - is production of the journal you are reading. Its website will be: http://theoilage.org.

n). PIRA Energy Group

- https://www.pira.com

The company has been in existence for forty years, and provides, inter alia, oil data and forecasts. We have not looked at either of these in detail.

p). S&P Global Platts

- https://www.platts.com

The company website says:

> *"S&P Global Platts is the leading independent provider of information and benchmark prices for the commodities and energy markets. … Founded in 1909, Platts' coverage includes oil and gas, power, petrochemicals, metals,*

agriculture and shipping. A division of S&P Global, Platts is headquartered in London and employs over 1,000 people in more than 15 offices worldwide. ... From an original focus on petroleum, S&P Global Platts expanded its purview and publishes news, commentary, fundamental market data and analysis, and thousands of daily price assessments that are widely used as benchmarks in the physical and futures markets."

We have not examined the data this company uses.

q). The Shift Project

- http://theshiftproject.org

The Shift Project (not to be confused with Globalshift Ltd., listed earlier) grew out of a concern about peak oil, but now has widened its focus to include a wide range of energies and minerals, as well as climate change. Its website says:

"Creation of The Shift Project - Window of opportunity:

The financial crisis that has gripped the economies of Europe for the past 3 years has opened up a breathing space in which to consider step change scenarios. Governments have shown themselves capable of injecting several thousands of billions of dollars (between 15% and 25% of global GDP, according to sources) to save the struggling global banking and financial infrastructure, which they believed crucial to their economies.

Since our planet - the source of all the resources that 'make the machine work'- is even more crucial to the economy, it is now becoming acceptable to envisage step change scenarios of a size at least equivalent to that implemented to save global finance. Repeated crises have created the widespread feeling that the old recipes are working less and less effectively, which in turn is creating a major opportunity to suggest different ways forward.

> *The positioning of The Shift Project: The Shift Project wishes to promote a sustainable economy that is neither anti-capitalist in principle nor out of step with scientific fact. Although we share certain characteristics, we do not define ourselves as a scientific body nor as a 'traditional' environmental NGO. Neither do we represent a particular strand of business."*

The Shift Project provides a very nice user-friendly 'Data portal; but we have not looked at the underlying data on oil in any detail.

Annex 7: Using the Data to Forecast Oil Production

In this Annex we look, very briefly indeed, at some issues to do with use of the data discussed in this paper for the production of oil forecasts.

Oil production can be forecast by a wide variety of methods, and in general each has different data requirements, and different strengths and weaknesses.

At one end of the 'data requirement' spectrum, successful forecasts of production - at least for conventional oil - can be made with only a region's past *production* data; data which are usually fairly well known. This is the case if the region's production is following a roughly 'Hubbert' curve. Once this curve is sufficiently well established, Hubbert linearisation can be used with reasonable confidence to predict future production.

For a region where sufficient reliable oil *discovery* data are available (generally meaning backdated 2P data) then the method of estimating the region's 'ultimate' can be used, where this ultimate is used to predict future production. As was shown in Section A5.4.1 above, this method could accurately predict the date of the UK production peak right from the point when the region's production was just starting, because even at that early date the bulk of the UK's major fields had already been discovered.

At the other end of the 'data requirement' spectrum, oil forecasts can be made based on detailed bottom-up by-field models; or in some cases (for example, Rystad Energy) by more detailed models still, where individual field investment projects are modelled.

The topic of oil forecasting methods is a large one, and is discussed in Bentley (2016). We intend to return to this topic in more detail in a future paper in this journal.

Annex 8: Accuracy of Some Past Oil Forecasts and Projections

This Annex looks briefly at the accuracy of some past oil forecasts and projections. (Some organisations prefer to classify their outlooks as 'projections', being based on a set of stated assumptions. For simplicity, here we will often use the general term 'forecast', but recognise that this also covers projections produced under specific assumptions and scenarios.)

Only a little over a decade ago forecasts for global oil production fell into two distinct camps:

- 'Mainstream' forecasts (for example, those from the IEA, EIA, OPEC and some oil majors) which saw global oil production as continuing to rise in a business-as-usual manner, and hence the oil price to remain low.
- By contrast, forecasts from many of the 'independents', typically consultants and individuals, predicted a near- or medium-term peak in the global production of *conventional* oil (and sometimes also, of 'all-oil'), and hence that the price of oil would see a near-term sharp increase to meet the cost of producing the marginal barrels of non-conventional oil required to meet growth in demand; e.g., Campbell and Laherrère's: *The End of Cheap Oil* (1998).

Forecasts primarily in these two classes were reported in the UKERC *Global Oil Depletion* report (Sorrell et al., 2009). Since then the range of forecasts has become decidedly more complex:

- Today most 'mainstream' forecasts now see global production of *conventional* oil as *not increasing,* but remaining flat out to their forecast horizon. As a result, these forecasts see the expected price of oil as on-average fairly high, being set by the marginal barrels of non-conventional oil required to meet rising demand. (For example, see the current forecasts from the IEA, BP and ExxonMobil).

- By contrast, the 'independent' forecasters maintain their earlier view that the peak of global *conventional* oil production is either past, or expected in the near or medium-term. Such forecasts include those from IHS CERA (Jackson & Smith, 2014), Miller (2015), McGlade (2015), Rystad Energy (Wold, 2015), Globalshift Ltd. (Smith, 2015), Campbell (2015) and Laherrère (2015). In these forecasts, the production of non-conventional oil must rise not only to meet increased demand, but also to compensate for the expected decline in the production of conventional oil.

- A small number of forecasts hold a far more 'cornucopian' view of future oil supply, based mainly on a strong view of the potential for technological gains in oil extraction; for example, forecasts from BP's Chief Economist (Dale, 2015), and Aguilera and Radetzki (2016).

- Finally, an increasing number of forecasts now see 'peak oil demand' as occurring soon (and well before any peak in oil supply), driven by the increasing efficiency of transport fleets, the switching to alternative power sources of motive power such as CNG, biofuels or electricity, and by an increasing number of the new 'urban young' choosing not to own cars. These 'peak demand' forecasts come from Ricardo Engineering, Shell, the World Energy Council, Citi and a number of others.

A future article in this journal will discuss this range of forecasts in more detail. In this annex we examine recent past forecasts and projections from the IEA and the EIA, discussing separately those for production and price.

A8.1 Projections of oil production

Figure A8.1 gives the evolution since 1994 of the projections of global oil production from the IEA in their World Energy Outlooks; originally biennial, and latterly annual.

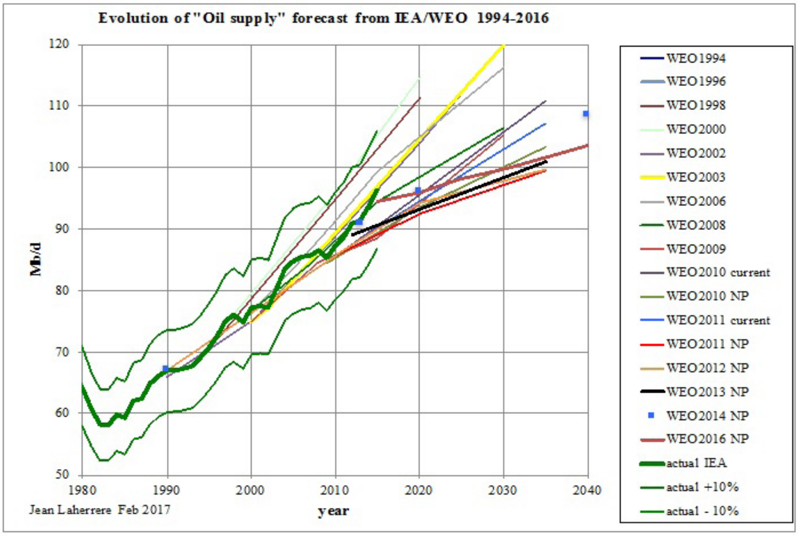

Figure A8.1 Projections of Global Oil Production from IEA *World Energy Outlooks,* 1994 - 2016.

Legend: - current: 'Current policies' scenario. - NP: 'New policies' scenario.

Note: - A projection is not a forecast *per se,* but values that seem reasonable under a set of specified assumptions (a 'scenario').

Source: J. Laherrère, from sources listed.

Overall the accuracy of these projections over the period shown has, so far, been pretty good, staying within the ± 10 % bound up to the present. But a closer look reveals a number of interesting things:

- Projections made in 1994, 1996, and from the year 2000 to perhaps 2010, were essentially forecasts of *demand,* because there were assumed such large adequate volumes of oil potentially available that the supply side did not have to be modelled in detail. The fact that these forecasts have - so far - stayed within the ± 10 % bound attests to the robustness of demand, even in the face in recent years of significant fluctuations in oil price (where these have been reflected in the actual trajectory of global demand, but not in its general trend).

- The 1998 projection was special, in that it followed a key 1997 meeting at the IEA called by J-M Bourdaire, and following which the IEA first recognised the expected peak in global production of *conventional* oil (as likely to occur around 2016, if memory serves), and where future supply of all-oil, adequate to meet forecast demand (see the '1998' line on Figure A8.1), came from both 'identified unconventional' oil, and from a large quantity of 'unidentified unconventional' oil; and where we have been told this use of this latter term was indeed a signal that the IEA thought such oil unlikely to be forthcoming at sufficient rate, and that hence an 'all-oil' production peak was likely. Details of this 1997 meeting, and of the consequent step-change in the IEA's oil forecasting, is covered in several chapters of Campbell (Ed.) (2011).

- But for the year-2000 *WEO,* this predicted peak of global conventional production was forgotten, possibly in large measure due to the publication earlier in the year of the USGS year-2000 Assessment of global undiscovered oil. This now included a large volume for 'reserve growth' outside the US, which resulted in a mean estimate of the global conventional oil URR, including NGLs, of 3345 Gb (up from about 2700 Gb, including NGLs, in the 1994 Assessment; see Bentley, 2015 & 2016, Part-3).

- Subsequent *WEO* projections up to about 2010 maintained this view; but then Dr. Birol obtained permission to study field decline in detail, which at once pointed to the peak of conventional oil production. As a result, *WEO* forecasts afterwards were more circumspect about future global production of conventional oil, and where - as in the 1998 forecast - meeting anticipated future oil demand had to rely on increasing production of the non-conventional oils.

- And once the US started significant production of 'light-tight' oil (included by some in 'conventional oil'), the making of these forecasts became more difficult still; the questions being: by how much, and for how long, could US production of this oil rise; and how prospective was 'light-tight' oil in countries outside the US?

- Today, as indicated above, *WEO* projections now see production of conventional oil as no longer increasing (as was always the case in the past, except for the 1998 *WEO*), but on plateau, but where scope for future production is still informed (see IEA website on model details) by the - to some - high USGS estimate of the conventional oil global URR.

Figure A8.2 gives the corresponding evolution of US EIA *International Energy Outlook* production forecasts of world liquids supply, from 1995 to 2014:

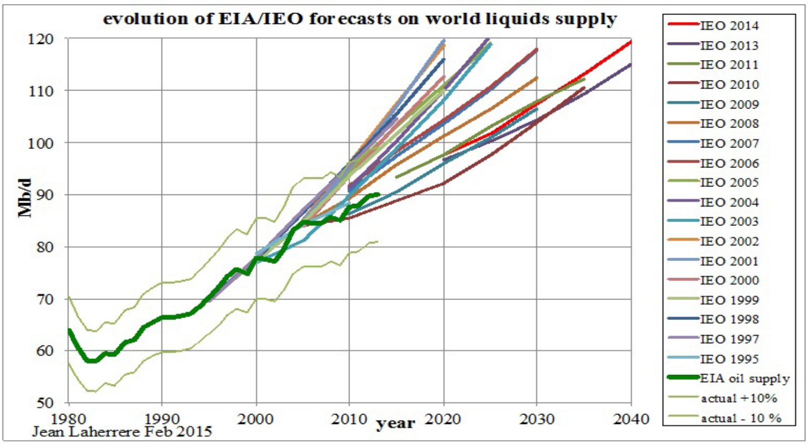

Figure A8.2 Forecasts of Global 'All-liquids' Production from EIA *International Energy Outlooks,* 1995 - 2014.
Source: J. Laherrère, from sources listed.

As can be seen in Figure A8.2, the general perception is borne out that for a long time the EIA forecasts have been more bullish on global production than those from the IEA. We know far less about how the EIA forecasts were produced, and hope to engage more with the organisation in future.

A8.2 Forecasts of oil price

Now we turn to looking at past projections from these organisations of oil price. To put these into perspective, we start with a brief history of views concerning both oil supply and oil price over the last half-century or so.

Historical background: Expectations of oil production and price

For the period from at least 1920 to 1970 large volumes of conventional oil, significantly in excess of production, were discovered globally (see Figure 24 in Part-1). As a result the price of oil fell steadily over this period, from about $30/bbl (in current real-terms) in 1920 to close to $10/bbl (real-terms) by 1970. Not surprisingly, this long price decline supported major increases in the use of oil, and in global economic activity.

Often under-recognised, however, is that for most of the period since fossil oil was first produced in significant quantities in the 1860s, its production has in large measure been controlled to prevent the price from collapsing to commercially unsustainable levels. These controls included those of Standard Oil's market rationalisations (including buying-up rivals under duress); the long period of pro-rationing in the US to prevent over-supply; and control by the 'Seven Sisters' oil majors, particularly in restricting supply from the then vast new Middle East discoveries (usually against the wishes of the owners of this oil, who wanted their production shares increased).

But then came the first 'oil shock' in 1973 with its sharp rise in price, see Figure A8.3. When coupled with the second price shock in 1978, the view developed widely among analysts, and also the general public, and partly driven by the then-size of global proved reserves of oil, that global oil supply would soon 'run out'; with this view being expressed dramatically in President Carter's 'Moral Equivalent of War' speech in 1977.

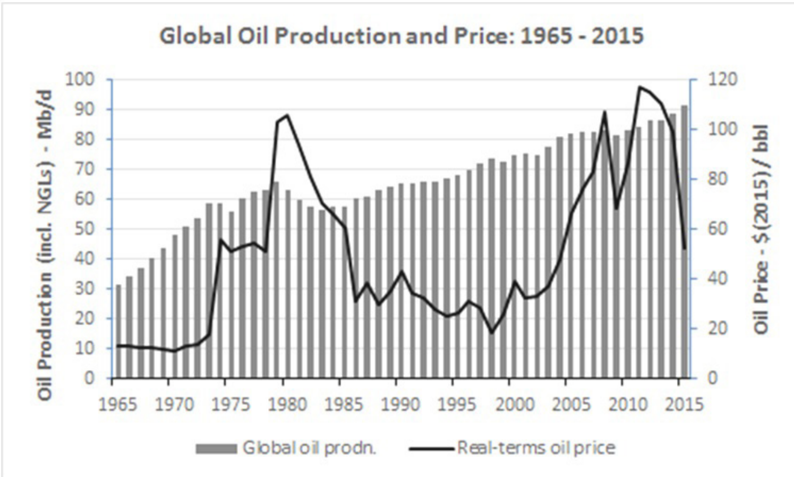

Figure A8.3 Global Oil Production, and Real-terms Oil Price: 1965 - 2015.

- Vertical bars, and left-hand scale: Global 'all-oil' production, in Mb/d.
- Solid line, and right-hand scale: Annual-average real-terms oil price, in 2015$/bbl.

  Source: BP *Statistical Review* 2016; based on an original plot by E. Mearns.

However the price rises of the 1970s should not have come as such a shock. 'URR resource-based' oil forecast models used by Hubbert and others had shown that the US would reach its peak of conventional oil production between about 1965 and 1970. Then because OPEC since its founding in 1960 had stated clearly that it wanted a significant increase in the oil price, and since the US at that time was the major non-communist supplier of oil outside of OPEC, once US production peaked, OPEC could flex its muscles and short-term oil supply constraints were to be expected.

Importantly, the fairly consensus view of the late-70s, early-80s, that global oil supply would soon 'run out' was at variance with the 'URR resource-based' forecast models of the time for the world as a whole. These showed that combining the quantity of conventional oil that had been discovered globally with that for which discovery could be reasonably anticipated was sufficient for global production of conventional oil to continue increasing until around the year 2000, before only then peaking and starting to decline.

In the event these global 'URR resource-based' models were indeed also correct, and after the 1970s price shocks large volumes of oil came on-stream from already discovered provinces, including Alaska, Mexico, the North Sea and elsewhere. In face of this new supply, OPEC initially cut production to maintain price, but with Saudi Arabia taking the bulk of these cuts, in about 1985 the latter gave up the game, and the price of oil fell dramatically.

Unfortunately then, and on the basis of the new and sustained low price for oil after 1985, and hence the realisation that the previous widely-accepted view of 'oil soon running out' had not been correct, the majority of analysts switched instead to an 'oil cornucopia' view, driven now by the concept that the proved reserves were simply inventory that could be replaced as needed.

A noted example of this latter view was the paper by Adelman (1990), where he opens with: "*The Problem Stated: The vision of mineral and particularly oil prices forever rising has many and distinguished adherents…*", for which Adelman cites, *inter alia,* Starrett (1987), who wrote: *"The price of oil should increase through time, growing at the rate of interest."* Disagreeing with this 'Hotelling' view of an ever-rising price of a depleting mineral resource, Adelman then famously wrote:

> *"There is no such thing* [as a fixed stock of an exhaustible mineral] *… only a flow into current inventory, i.e., reserves. … Development outlay per added unit of reserves or capacity is also a proxy for finding cost and resource rent. Worldwide stability of development cost shows oil has not become more scarce since 1955.*
>
> *… The total mineral in the earth is an irrelevant non-binding constraint. If expected finding-development costs exceed the expected net revenues, investment dries up, and*

> *the industry disappears. Whatever is left in the ground is unknown, probably unknowable, but surely unimportant; a geological fact of no economic interest."*

This view in one sense is correct: as both Laherrère and Miller note, no-one knows how to quantify, nor find, all the molecules of oil in the ground, as so little of that originally generated has ended up in well-defined conventional oil fields.

But where Adelman and fellow analysts got it wrong was as follows: They did understand that the cost (and hence, ultimately, price) of extracting a mineral goes up as the mineral is depleted, and hence more effort (primarily energy) is needed to extract the next leaner source; and where this increase in cost can be offset by technological improvements in extraction, and - historically also - by ever-falling energy costs. But their use of an over-simple model (reliance on the R/P ratio), and on data (global proved oil reserves) that were - and still are - so misleading, meant that their analyses missed the depletion of conventional oil, and hence they dismissed the 'end of cheap oil' view that was clear to those with a robust model (peak at 'mid-point'), and access to good (i.e., 2P) data.

Unfortunately, despite the continued warnings from those running the global 'URR resource-based' models that that the global peak of *conventional* oil production was to be expected from about the year 2000, the 'reserves-as-inventory' cornucopia view dominated. As a result, the rapid rise in oil price from 2003 (fairly quickly back up to the 1978 real-terms price of ~$100/bbl, and above) came as a shock to most; where the widely cited reason for this price rise was increased demand for oil, particularly in Asia; rather than from the correct reason of ever-tightening resource limits on global conventional oil supply.

The above is an important narrative, as it provides background to the evolution of the EIA and IEA projections of oil price presented below. For a more detailed discussion of the shifts over time in both analyst and public expectations of future oil supply and price, see Bentley & Bentley (2015a and b), Bentley (2016), and Inman (2016).

IEA and EIA projections of oil price

We start by looking at the EIA's oil price projections, from 1998 to 2016, given in Figure A8.4.

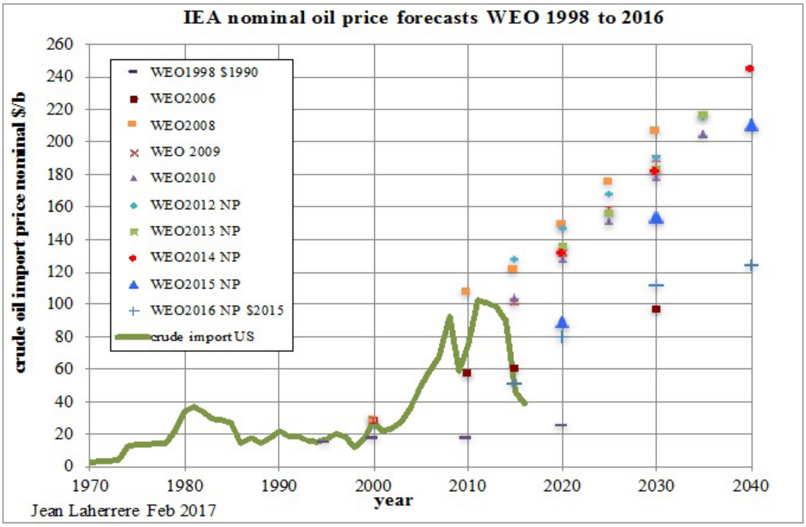

Figure A8.4 Projections of Oil Price from IEA *World Energy Outlooks,* 1998 - 2016.

Legend: - NP: 'New policies' scenario.

- crude import US: EIA data on the annual-average oil price paid in nominal terms (i.e., money of the day) for imports of crude oil to the US.

Notes: - A projection is not a forecast *per se*, but values that seem reasonable under a set of specified assumptions (a 'scenario').

- IEA *WEO* oil price projections are generally in nominal (money of the day) terms.

Source: J. Laherrère, from sources listed.

As Figure A8.4 shows, the oil price forecast in 1998 was for a continued low oil price, of the order of $20/b or so. But more recently, since 2008, the *WEO* forecasts have been of essentially ever-rising oil price, up to over $240/b by 2040 in the *WEO* 2014 'New Policies' forecast. We do not know the full details, but it is likely that this forecast high oil price reflects assumptions on the increased production of ever-more expensive non-conventional oils, combined with the imposition of fairly high carbon taxes.

The corresponding oil price forecasts from the EIA are shown in Figure A8.5. These show somewhat similar conclusions: forecast oil prices in the $20/b - $30/b range in the early forecasts; but with higher prices predicted later; reaching, for example, ~$160/b by 2040 in the 2013 forecast. Subsequent EIA forecasts have predicted significantly lower prices. The 2015 AEO forecast for example, predicted $140/b by 2040; and the 2017 forecast lower still, at only $110/b by 2040; the latter presumably on the assumption of relatively inexpensive ‘light-tight’ oil then being available from a number of countries.

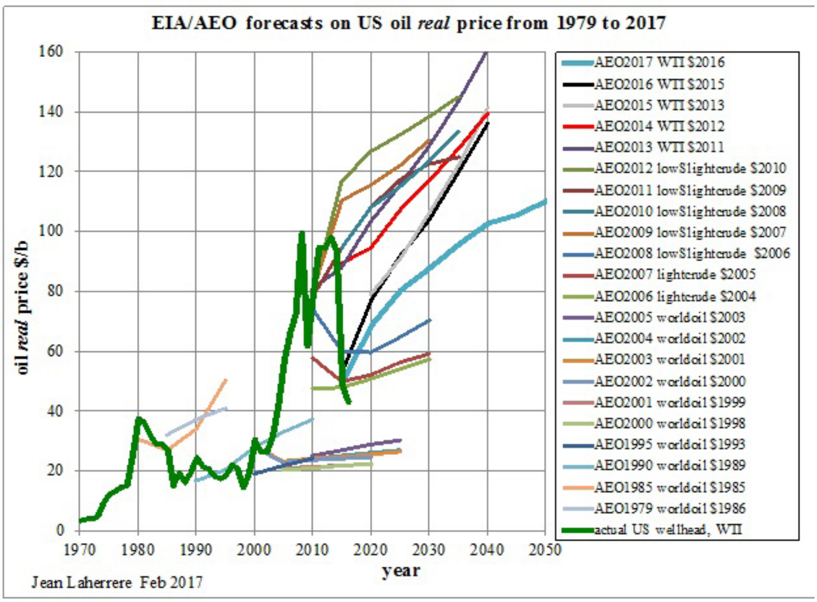

Figure A8.5 Forecasts of Oil Price from EIA *Annual Energy Outlooks*, 1979 - 2016.
Source: J. Laherrère.

However, an important conclusion to draw from both Figures A8.4

and A8.5 is the generally increasing forecasts of oil price from these organisations, and up to very high prices in the IEA projections. Unfortunately, these warnings of a generally high future price of oil seem not yet to be incorporated in much of the thinking of industry, academia or government.

Finally, we can summarise the current situation on oil price by noting that oil now - in some measure - is a typical 'commodity', open to the market, and lacking major underpinning market controls. The downside of this as mentioned above, and as with any commodity, is that a very small difference between supply and demand can push prices wildly in one direction or the other; and with this intrinsic difficulty in forecasting price being compounded by the new complexities of forecasting demand listed in Section 12 of Part-1 of this paper. In this context, and as a fitting conclusion to this section on forecasting oil price, it is perhaps no surprise that Laherrère notes:

> *"The present situation* [i.e., since the advent of significant production of 'light-tight' oil] *has shown that oil price is a key factor in forecasting oil production, and no one knows how to forecast price. … I always refuse to forecast oil price, because human behaviour is always erratic. It is why I will not forecast anything precise, except that the cheap oil has peaked, and will continue to decline. The expensive oil is hard to forecast."*

Notes:

- The authors are grateful to a several external reviewers who helped improve sections of this paper.

- Subscribers to *The Oil Age* may obtain without charge a PDF version of this paper giving the Figures in colour. Please contact Noreen Dalton at: theoilage@gmail.com.

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