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.

A subscription form is provided at the back of the journal.

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Editorial

Call for Funding

Dear Readers,

We have been publishing *The Oil Age* for now nearly three years. As you know, the journal addresses one of the important factors affecting the modern world, that of oil supply. But oil is a finite resource, formed in the geological past and subject to depletion. And in turn, the price of oil has major impacts on the world's economies. The journal aims to raise awareness of the subject of oil depletion, both for governments and the people at large, to help in planning for the changes that lie ahead.

Because of our present financial situation, we need here to call for additional funding to assist this not-for-profit undertaking. Specifically, we are seeking funds for the following:

1. Publishing The Oil Age

After taking subscriptions into account, it still costs us roughly 1200 euros per issue to cover the costs of preparation and printing of this journal. This is despite the fact that, as with most academic journals, the bulk of the work, namely that of the authoring, editing and peer-reviewing of papers, is carried out at no cost.

Up to now we have been funding publication from a variety of sources, but these are coming to an end. If we are to continue printing *The Oil Age* we will need funds of the order of 5000 Euros to cover publication in 2018.

We will continue to seek to grow our subscription base, and if successful will be able to reduce each issue's 'net-after-subscription' cost. But for the present, and without additional external funds, production of a print version of the journal will unfortunately have to cease at some point.

2. Work associated with Colin Campbell's Oil Forecast model

There are two tasks here: model enhancement, and model updating:

Model enhancement requires a researcher to understand the model, tidy it up, and auto-link the model's spreadsheets. This will improve operation and reliability of the model, and allow researchers other than Dr. Campbell to operate it. Anticipated cost here is 6 000 euros, of which the bulk is salary of the researcher involved.

Model updating requires the researcher to input recent EIA data on oil and (if now available) gas annual production by country, and provide greater detail within the model on forecasting production of the increasingly important non-conventional oils, including 'light-tight' oil from fracking, and Canadian tar sands and Orinoco oil; as well of the 'other liquids' (primarily NGLs, and biofuels). This update is required to better assess the future global production of 'all-liquids', as global production of conventional oil declines. Anticipated cost here is around 6 000 euros.

3. Populating the Petroleum Analysis Centre (PAC) website

Our goal is to populate the PAC website with key and often hard-to-get data for use in oil and gas forecasting. The aim is to provide a service to the forecasting community, to allow better understanding of future prospects for hydrocarbon production by country and globally, based on solid data.

Over time, it is intended that the data that will be made available will include:

- Oil production by-field for the 10 largest oil fields of all main producing countries.
- Cumulative oil and gas '2P' discovery data, and production data, by country; from *Campbell's Atlas of Oil and Gas Depletion* (2013), updated.
- An updated version of the global oil production summary Table 1 in the *Atlas*, plus a second table providing production of the non-conventional oils (deepwater, polar, very-heavy, light-tight, etc.).

- Oil URR data by country. These data will come from a number of sources, including Campbell (for *Regular conventional* oil), Globalshift Ltd. (for oil in fields), Rystad Energy (all-conventional oil) and BGR (also for all-conventional oil).
- Dates of peak; and percentage of the conventional oil URR produced at peak. This will draw on data from the USGS (year-2000 assessment, plus updates); Campbell (*Regular conventional* oil) & Globalshift Ltd. (for oil in fields).

Some of the data are to-hand (within Campbell's model and other datasets, and in data published to-date in *The Oil Age*); while other data will be drawn from mainly industry data sources. Anticipated cost for this activity, assuming a researcher is hired for the bulk of the work, is in the region of 10 000 euros.

If an organisation or individual is interested in helping finance any of the above activities please contact Noreen Dalton, Administrator of The Petroleum Analysis Centre at: theoilage@gmail.com, or else 'phone either Dr. Campbell on +353 283 7533, or myself on +44 7799 728988, to discuss.

Any help towards these ends would be very much appreciated.

- Roger Bentley, October 27th 2017.
Websites: www.theoilage.org
www.petroleumanalysiscentre.org

Becoming Aware of Peak Oil: An Autobiographical Sketch

C. J. Campbell

Abstract

This paper sets out the processes by which I became aware of the issue of *Peak Oil*, and outlines the subsequent modelling and publications I produced that address this subject.

Awareness of the issue stemmed primarily from a number of regional - and subsequently, global - studies carried out within oil companies. These focussed on gathering reliable data, primarily on quantities of oil discovered; and also on obtaining estimates of the likely amounts of oil yet-to-find. The work included writing internal company reports, consultancy reports, a widely-quoted 1998 *Scientific American* article (*The End of Cheap Oil*, written jointly with Jean Laherrère), and a series of other articles and books. While the primary object of these studies was the distribution of *Conventional* oil, attention was also paid to the impact of improving discovery methods and extraction technology; of higher oil price; and to the likely production of various classes of *Non-conventional* oil. Included in the paper is discussion of how my estimates for the ultimately recoverable resource (URR) of *Regular conventional* oil have changed over time.

The prediction we made in the *Scientific American* article was that global production of *Conventional Oil* would reach peak before 2010. The peak in the global production of *Regular Conventional* oil occurred in 2005, and global production of 'all-conventional' oil has been on-plateau since this date. As a result, the world's increased demand for oil since then has had to be met by production of the generally more-expensive, and lower EROI, *Non-conventional* oils.

1. Early Experience

I was born in 1931 and spent my early years as an isolated but happy only child, living on Chapel Point, a remote promontory in the west of England where my father, an architect, built three fine houses, before the Second World War brought the project to an end (for photographs see *Chapel Point* on Google Search).

In the days before television, I read children's books including *Pigeon Post* by Arthur Ransome, which referred to a geologist looking for gold in the Lake District. It prompted me to look more closely at the rocks of Chapel Point, even spotting quartz-veins in the hope that they might contain gold.

The war brought the days in Cornwall to an end and I was sent to various boarding schools, which I hated, before being moved to St Paul's School, a day school in London, where at the age of 16 we were required to state our future career ambitions. I had none, but for want of a better answer wrote that I wanted to be a geologist: physical geography being the only subject that attracted me at school. Despite a mediocre academic record, I managed to get into Oxford University on my third attempt in 1951 when the college forgot to set an entrance exam in geology that I had requested. I enjoyed my time at Oxford and began to find my feet. I even stayed on to do a D. Phil., based on mapping the geology of the hills of Connemara in Ireland and an area in central Borneo to which I went on a university expedition.

On leaving Oxford in 1957, I applied to oil companies for a job, and eventually secured one as a field geologist with Texaco in Trinidad, which had taken over Trinidad Leaseholds, a British company. I came under the influence of Dr Hans Kugler, a remarkable Swiss scientist who had pioneered the use of micro-palaeontology to help unravel the complex geology of the island. The company's head office, in New York, then decided to apply such palaeontological support for its exploration in South America, and I was transferred to Colombia in 1959 to help do so. I then married Bobbins Ludford, whom I had met in Trinidad, and we were blessed with two children.

I had some very colourful experiences mapping the Eastern Andes with a field party that consisted of about ten men, riding mules and camping in the forests. I found a very complete Cretaceous sequence, rich in ammonites and other fossils, which I had identified by Dr Hans

Burgl at the University in Bogota. I photographed them and included the pictures in the report I wrote. But the Chief Geologist called me in to his office and informed me that it was the company's practice to give presentations, rather than write lengthy reports. I had the impression that my presence was resented.

2. Beginning to See the Oil Limits

In 1961, we took our first home leave, and I approached BP in London for a job. To my surprise they offered one, sending me back to Colombia, where they were building a new position. My job was primarily to interview other companies seeking partners to explore their new concessions. Gradually, I was able to compile a major report evaluating the prospects of the many different geological basins making up the country.

It became evident that these basins were very different. The Llanos Basin bordering the Eastern Andes seemed to have great potential. The company laid out applications for several concessions, which in those days involved setting concrete blocks at the corners to mark them, but the Head Office economists finally rejected the proposal as it was not profitable to produce oil in this very remote area, far from the coast for export. Several years later, the area did deliver a number of giant fields, and the company succeeded in buying its way back in. This assessment of the country showed the range of potential of the different geological basins of which it was composed, and gave me my first insight into the finite limits of the resource. In those days, we had limited knowledge of geochemistry but the Cretaceous *La Luna Formation* was seen as a primary oil source.

In 1967, I was transferred to Australia and made a field survey of the remote highlands of Papua-New Guinea, where I witnessed several massacres as conflict raged between different tribes. I missed my growing interest in the geology of South America and decided to resign and accept an offer to be Regional Geologist for South America with Amoco, based in New York. The office was staffed by an interesting group of people with world experience. My supervisor was Dr Nestor Sander, who had used palaeontological studies to help find the giant Abqaiq Field in Saudi Arabia. In the new job, I made many trips to South America and became gradually aware that the pattern I had seen in Colombia applied in varying degrees to other countries: each having a wide range of potential with a few prime areas flanked by others of negligible or limited interest.

The New York office was then closed and international operations were moved to the Head Office in Chicago, which was characterised by tiers of committees with little international experience. At a certain point, the company decided to make a world evaluation of oil production, reserves and potential. I was responsible assessing Latin America. This provided me with a global insight into the finite nature of oil and gas resources, which laid the foundation for a future prime personal interest in oil depletion, and the issue of *Peak Oil*.

3. *The Golden Century of Oil* study

It is not necessary to cover my subsequent career in detail. After my time in Chicago I was transferred as Chief Geologist for Amoco in Ecuador, and had some colourful experiences negotiating oil rights but we failed to find oil. On the threat of a recall to Chicago, I then decided to return home and took a job as manager of a small independent oil company based in Texas. I opened an office in London and had more colourful experiences forming exploration ventures with other companies in the UK, Portugal, Holland, Turkey and Ireland, but none made significant discoveries.

When the company was bought out, I re-joined Amoco's London office as Regional Geologist for Europe before being transferred to Norway as Chief Geologist. It was there that one of my staff, Ray Leonard, pioneered the mapping of effective source-rocks based on temperature and their depth of burial. He is now Chief Executive of Hyperdynamics, an oil company exploring a promising new province offshore West Africa.

We made a small discovery off Northern Norway, which has subsequently been developed as the Tyrihans Field. It pointed to another prospect in an adjoining area that had not been licensed, which later delivered the giant Heidrun Field. But Amoco decided to suspend exploration in Norway and rather than accept a transfer to Houston, I joined the Norwegian branch of the Belgian company, Fina, as Executive Vice-President. It had a successful few years, and supported an important study of Peak Oil by the Norwegian Petroleum Department (NPD). But then the Head Office was restructured following the death of the Chairman, and the new executive sought more control of Norwegian operations, resenting the independence that I had previously enjoyed. I was accordingly dismissed, but given six months' notice, which I dedicated to writing the book: *The Golden Century of Oil 1950-2050.*

This evaluated the status of oil depletion by country, using production and reserve data published by the *Oil and Gas Journal*, which I had assumed to be valid. In fact, I had already been invited to give talks on the subject at various conferences and private meetings. The first was to the Irish Chamber of Commerce in 1978, which has been followed by about 150 others, including ones organised by the European Union and the British Parliament. There have also been many press interviews and participation in television programmes.

My wife and I then retired to live in France and later the west of Ireland, where I continued to follow my interest in the Peak Oil issue, and helped to found this journal.

4. The Petroconsultants Studies

The *Golden Century* book found its way to Petroconsultants, which maintained the confidential industry oil and gas database in Geneva. They contacted me saying that they would like to produce a comparable study, but this time based on their more valid data. I was joined on this project by Jean Laherrère, a notable French oil expert. He had already collaborated with Petroconsultants on a major study of the world's undiscovered petroleum potential, co-authored with Perrodon and Demaison.

A comprehensive study on future oil supply entitled *The World's Supply of Oil, 1930 – 2050* was produced. However, the marketing manager of Petroconsultants was not in favour of publication of this report, rightly concluding that it would give away the company's basic information assets, and therefore said that he could agree to its publication only if it was sold at a price of $50 000 a copy. A few copies were sold before the project was suppressed under pressure from an oil company.

5. Reporting the Results of these Studies

5.1 *The Coming Oil Crisis*

To meet a goal of wider dissemination of these findings, which interested me, I authored another book, *The Coming Oil Crisis,* published jointly in 1997 by Multi-Science and Petroconsultants.

5.2 *The End of Cheap Oil,* Scientific American

Interest in the subject was then taken up by the *Scientific American*, which published in March 1998 an article by Jean Laherrère and myself entitled *The End of Cheap Oil*. This was published in an issue of the journal which had as its focus technologies to "prevent the next oil crunch". Our article received much attention, including adverse criticism as it was a sensitive subject, especially for economists with their confidence that the market would always deliver.

6. Subsequent Modelling, and Publications

Subsequent to the above publications, I continued updating my oil and gas forecast models, using data from a wide variety of sources, including some provided on a confidential basis.

I have also written several more books on the subject, the most recent of which is *Campbell's Atlas of Oil and Gas Depletion* published by Springer (Campbell, 2013). I also published and edited a fascinating book called *Peak Oil Personalities* (ISBN 978-1-908378-06-4), in which 26 people from many walks of life who had become interested in Peak Oil very kindly provided autobiographic sketches.

Two other important developments over this period were:

- The formation of a small charity in London, the Oil Depletion Analysis Centre (ODAC), funded by an Astor family Trust and ably led by Sarah Astor. This ran for a number of years and eventually led to Roger Bentley, ODAC's first Coordinator, publishing the comprehensive *Introduction to Peak Oil*.
- - The setting up of the Association for the Study of Peak Oil and Gas (ASPO), led by Professor Aleklett of Uppsala University in

Sweden. This had associate organisations in more than thirty countries and held an annual series of important conferences.

7. Considerations when Modelling Depletion

The foregoing summarises my background in assessing the status of oil and gas depletion. In earlier years, it was a relatively simple process as oil prices were stable, reducing economic risks. The related geological and geophysical assessments were relatively straightforward. The most prolific oil provinces were discovered early, as were the giant oilfields within them, being too big to miss. They delivered the production needed to support an expanding world economy during the *First Half* of the *Oil Age*, which was perceived to be the normal result of an efficient market. A key element has been progress in the recognition of source-rocks by advances in geochemistry. The bulk of the world's resource was deposited in just two epochs of global warming, 90 and 150 million years ago. But now, as shortages begin to appear marking the dawn of the *Second Half* of the *Oil Age*, the position becomes much more complex and difficult to define in detail. The following points dominate the assessment:

(a). Definitions

There are no standard definitions of the different categories of oil and gas, meaning that published statistics may refer to differing elements, which is a cause of much confusion. The *Atlas,* mentioned above, defines the differing categories as follows:

Regular Conventional oil and gas.

Non-Regular Conventional oil and gas, made up of:

- a) Deepwater oil and gas (>500m water depth)
- b) Polar oil and gas
- c) Heavy oil (10-17.5^{o} API)
- d) Extra Heavy oil (<10^{o} API; this includes tar sands and Orinoco oil)
- e) Oil from fields dependent on artificial fracturing of reservoirs (also called 'light-tight' oil, produced by 'fracking')
- f) Oil from coal, and from kerogen (oil shale)

g) Liquids from gas plants

h) Coalbed methane

i) Gas from gas hydrates

In addition, both oil and gas can be produced from biomass sources.

(b). Reserve reporting

In earlier years, attention concentrated on so-called *Proved Reserves*, namely conservative estimates of production from existing wells under stable market conditions. *Probable* and *Possible Reserves* were also recognised for potential additions with the uncertainties that the adjectives imply. Statistical probability methods were also developed with the *Mean* value perceived to be the best estimate. It was general company policy to report the minimum needed to deliver a satisfactory financial image and provide a safety net to cover any setbacks they might experience around the world.

(c). Databases

The major international oil companies did not like to contact each other (and often were legally prohibited from doing so); but certainly wanted to know what their competitors were doing. Tracking oil and gas discoveries and their size was clearly of critical importance to these companies. In earlier years, they did effectively cooperate by providing Petroconsultants with genuine information, where the latter retained the services of retired, experienced oilmen who had contacts with governments and industry around the world. But the company was sold to IHS Energy following the death of its founder in 1995, and many of these special relationships were lost.

There are several other commercial and State-owned entities reporting fairly reliable reserves and production data. IHS is still perhaps the prime source of data, but these data are costly to access and subject to strict confidentiality rules. Other generally reliable commercial databases include those of Wood Mackenzie, Rystad Energy in Norway, and Globalshift Ltd.

BP publishes an annual *Statistical Review*, but here the oil reserves data are only the very flawed ‘proven’ reserves; and where the company states that the reserves data do not represent the company's own data. For example, the *Review's* latest issue shows unchanged reserves for more than thirty countries, although it is utterly implausible that new discovery should have exactly matched intervening production in these countries.

The Energy Information Agency, an arm of the US government, provides another very useful database, but again here for oil reserves the data are only the flawed 'proved' data; and where the Agency has so far failed to update its gas data beyond 2014.

In addition, the Internet contains a massive amount of information on specific oilfields around the world, but it is a challenge to collect this information, and also much is naturally of uncertain and varied validity.

For more information on oil data, and in particular on its reliability, see: *Oil Forecasting: Data Sources and Data Problems, Parts 1 to 3* (Laherrère et al., 2016, 2017).

(d). The modelling

Modelling oil and gas production is a difficult and sensitive issue as production is much affected by economic and political factors. The production of a finite resource, formed in the geological past, obviously must rise and then fall to approach final exhaustion. It is therefore reasonable to assume that the peak of production must come around the mid-point of depletion, although local circumstances may advance or delay this peak by a few years. See, in this context, the simple 'field-additive' example illustrated on page 80 of *The End of Cheap Oil* article; or the equivalent example in Fig 2.4 (based on UK North Sea fields) in Bentley (2016).

(e). Increasing technical complexity

In earlier years, exploration relied on little more than geologists mapping the outcropping rocks to find a place having the right combination of source, reservoir, trap and seal to deliver an oilfield. But then came geophysics, where an explosion was released and recorders picked up the echoes from buried rock surfaces, allowing them to be mapped in greater detail.

Geophysics and the interpretation thereof have now become extremely sophisticated allowing the identification of ever smaller and subtle prospects, especially offshore. Geochemistry has also allowed the much more accurate identification of source-rocks. Oil comes from organic material deposited in restricted lakes and seas, much coming from just two epochs of global warming 90 and 150 million years ago, which heated the surface waters of lakes and restricted seas. That reduced circulation, giving anoxic conditions at depth that preserved the organic material from which oil is derived.

It is clear that better discovery and extraction technology can increase the quantities of oil available, but based on extensive experience it unlikely that much can be added. While enhanced technology (EOR) in some fields can achieve significant gains, overall on average for *Conventional Oil* it might raise the recovery by no more than 10% to 15% of original recoverable estimates.

(f). Impact of price

High prices prompt more profits and the development of more remote, and more difficult fields but also cause economic recessions, and hence kill demand. Low prices by contrast prompt reduced exploration and the premature abandonment of ageing fields, especially offshore. See discussion of this topic in Campbell and Gilbert (2017). Evidently, normal market forces are not suited to the production of finite natural resources providing the modern world with a critical source of energy on which it has come to depend.

(g). The role of OPEC

Had OPEC not been formed, the international oil companies would no doubt have developed the easy and cheap oil and gas, which these countries possess, making reasonable profits at low prices before turning under normal market pressures to more costly other regions, including offshore and *Non-conventional* sources. The pattern of world depletion would have been evident. OPEC has faced various tensions in the recent past as demand collapsed, following a surge in oil price in 2008, but now seems to be recovering its control. As explained in the above-mentioned *Atlas*, oil reserve data published by the OPEC countries are extremely unreliable. This partly reflects the fact that reported reserves set the production quota between the OPEC countries.

The high prices imposed by OPEC were in a sense inflationary because production costs are low in most of these countries, and much of the income no doubt found its way to Wall Street. At the end of the day, money should reflect human energy.

King Abdullah of Saudi Arabia once wisely said that he wished to leave as much oil as possible in the ground for his grandsons. In fact, it might have been a better policy for oil producing countries to have limited exports, and developed their resources slowly to make them last for as long as possible for their own benefit. Venezuela, with a modest population of only 32 million people who had come to rely on the revenue from oil exports at high prices, now faces a deep recession with severe political tensions.

(h). 'Fracking'

The high prices of 2008 prompted a surge of so-called fracking (hydraulic fracturing producing 'light-tight' oil) in the United States. Argentina has also recently started an extensive fracking programme, but there are widespread objections as the process can damage aquifers and cause minor earthquakes.

It is a technique that has long been used to improve the recovery from poor reservoirs. It involves drilling highly deviated wells to run parallel with a poor reservoir into which sand and chemicals are injected to improve permeability. The wells are costly and short-lived, draining only the immediate vicinity of the wellbore. The world resource in the ground is enormous but the net energy yield is low, making most *fracking* viable only at oil prices above about $70 a barrel.

(i). Evolution of the forecasts:

Analysts addressing the subject, including myself, have always recognised the large uncertainties of the depletion model due to unreliable data, and the differing definitions of the various categories of oil and gas. We hoped that our work would attract attention and better data, allowing the models to be progressively improved; but recognise that the topic of depletion is a sensitive subject.

The table below shows how my estimate for the global URR of *Regular conventional* oil has changed over the years.

Table: Evolution of URR estimates	**Date publ'd.**	**Date of data**	**Oil type**	**Cum. prod. (Gb)**	**Res'vs. (Gb)**	**Y-t-F (Gb)**	**URR** (Gb)**
Global Century of Oil, 1950-2050	1991	~1990	Conv.	628	806*	216	1650
The End of Cheap Oil, Sci. Am.	1998	1996	Conv.	800	850	150	1800
The Essence of Oil & Gas Depletion	2003	e-2002	R. Cv.	896	871	133	1900
" "			All-Lq.	986	---- 1714 ----		2700
Atlas of Oil & Gas Depletion	2013	e-2010	R. Cv.	1090	800	110	2000
My model, 2016	2016	2015	R. Cv.	1210	740	150	2100

Notes:

Oil volumes in billion barrels (Gb). Cum. prod.: Global cumulative production of the oil type specified, to the date given. Res'vs.: Global oil reserves (either proved, 1P; or proved-plus-probable, 2P; see below). Y-t-F: Yet to find. URR: Ultimately recoverable resource.

e-: Data as of end of year specified.

*: Reserves data used in this study were 'proved' (1P) data from the *Oil and Gas Journal*. (This is in contrast to all the studies from 1995 onwards, which used 'proved-plus-probable' (2P) oil reserves data from industry sources; primarily from Petroconsultants / IHS Energy.)

**: URR values were originally defined as cumulative production to the point that production ceases. Later, to avoid consideration of long-late trickles of oil, I re-defined this as cumulative production to a distant date; generally here first modelled as 2070, and subsequently as 2100.

Conv.: Conventional oil. All light- and medium-density oil in fields, produced by primary or secondary recovery methods. Excludes heavy oils (10 - 17.5 °API); extra heavy oils (<10 °API, including oil from tar sands and Orinoco oil); natural gas liquids (NGLs); 'light-tight' oil produced by hydraulic fracking ('shale oil'); as well as oil produced by retorting kerogen ('oil shale' oil); or from gas to liquids (GTLs) or coal to liquids (CTLs) processes; and oil produced from biomass.

R. Cv.: '*Regular conventional*' oil. Around the year 2000, an increasing proportion of the world's conventional oil was coming from sources having a different production profile than earlier 'oil in fields'. These sources were oil from fields deep offshore (at > 500 m water depth), and in the Arctic; where the expense and difficulty of production meant that only large fields were produced, and - with capital costs high - production rates had to be fast. Therefore, from about this date my main forecast model was of production of what I then termed '*Regular conventional'* oil; i.e., conventional oil but less these two categories of very deepwater, and Arctic oil. Forecasts of production of the non-'*Regular conventional*' oils, including deep offshore and Arctic; as well as heavy and very heavy oils, NGLs and 'light-tight' oil, etc. (see Section 7 (a), 'Definitions', above), I modelled separately.

All-Lq.: All liquids: This includes 'All-oil' [which includes conventional oil (i.e., *Regular conventional* oil plus deep offshore plus Arctic oil); plus heavy oil, very heavy oil (including tar sands and Orinoco oil), 'light-tight' oil, NGLs, oil from kerogen, and GTLs and CTLs], plus refinery gain. (Note: Some authorities include also oil from biomass in their 'all-liquids' category, but my model does not.)

As can be seen, over the quarter-century covered by these estimates, my estimate for the global URR of *Regular conventional* oil has grown some 450 Gb, or by roughly a quarter.

In fact, given that the *'Golden Century'* estimate was based on the poor 'proved' (1P) reserves data, perhaps a better comparison, using the 2P reserves data, is of my global *Regular conventional* URR estimate growing from 1800 Gb for the 1996 data to 2100 Gb for the 2015 data. This represents an increase in just under 20 years of 300 Gb (~ 17%); which would result in postponement of the estimated date of the global *Regular conventional* oil peak by about 5 years if a simple 'mid-point' model is assumed.

Such growth in the URR estimate is not at all surprising. As I and others have consistently warned, the underlying data are very poor and no great accuracy should be expected (see, for example the sections 'Unreliable Data-base', and 'The Importance of Revision

Analysis' in *Golden Century*). Moreover in general, one should expect somewhat more oil to be available at a higher oil price, see Campbell and Gilbert (2017). In the five years to 1990, for the first URR estimate, the oil price averaged $18/bbl real-terms, while over the five years to 2015 for the latest URR estimate the oil price was over 5 times greater, averaging $97/bbl in real-terms.

But as I and others have consistently pointed out, it is not the *precise date* of peak production of conventional oil (and likely all-oil) that matters, but the fact of peak itself. As already indicated, the global production of *Regular conventional* oil probably peaked in 2005; and where global production of 'all-conventional oil' has been on-plateau since that date.

(j). Modelling the global 'All-oil' and 'All-Liquids' peaks

Of course, it is one thing to forecast the global peak of *Regular conventional* oil, another that of 'all-oil' or 'all-liquids'. This is because - as has long been known (see, e.g., Bentley, 2015/2016) - the estimated remaining quantity of technically-recoverable non-conventional oil is very large, perhaps of the order of 4 500 Gb or more; see Chart 2 in the 'Charts section' of *The Oil Age*, Vol. 1 No. 1.

But in my modelling, and in similar modelling by a number of others (e.g., Laherrère, 2015, Smith, 2015), we judge the difficulties involved in the production of these non-conventional oils - including the investment required, their production costs, lack of technical readiness in some cases, and not least, generally lower EROI ratios - mean that only about 650 Gb of these non-conventional oils (out of the ~4 500 Gb) are likely be produced by 2100. As a result, the global production peak of 'all-oil', and possibly also that of 'all-liquids', may well be as early as 2020 or so.

(k). Attitudes, and politics

Finally, it is important also here to recognise the different attitudes of geologists, engineers, economists and managers that influence their behaviour, actions and what they report. The politics of the various countries and the corporate structure of the industry are other key factors. Scientists tend to think that they are working with valid data, without fully appreciating the different postures of those involved in reporting. Geology is a descriptive science calling for much imagination to piece together the record of the long past, spanning hundreds of millions of years, over which the rocks were deposited. Exploration wells, termed *wildcats*, in new areas face high risks but provide valuable information that may eventually lead to a profitable find. Geologists face many challenges in justifying them to their companies, which are reluctant to invest in unsure prospects. It is noteworthy that the Russian State oil company was willing to drill wildcats simply for geological information.

Engineers are responsible for the difficult and costly operations that have to be conducted in extracting oil in a profitable way, with oil price forecasts being a critical issue. The economists are dominated by market considerations with little perception of the finite nature of resource. Forecasting future oil prices is also a critical element in the economic evaluations. (A greater discussion of this topic is given in Campbell and Gilbert, 2017.)

Managers face many other political and sensitive pressures. Those running a subsidiary have to deal with many personnel pressures to optimise the output of their staff. They also have to project a favourable image to their partners in ventures and the Government authorities. Head Office managers have to try to optimise the results of many affiliates around the world, without necessarily fully appreciating the local pressures under which they have to operate.

Governments too face many challenges in building appropriate national policies, dealing with the conflicting demands of foreign companies, national companies and State-owned enterprises. Politicians in democracies win elections only by telling the voters what they want to hear, which makes it very difficult for them to admit to natural depletion and the implied economic contraction that results.

8. Reflections and Conclusions

8.1 Reflections

Initially, like most petroleum geologists at the time, I was optimistic about future hydrocarbon prospects: there would always be more regions to explore; deeper horizons to investigate; better geological understanding of oil formation and entrapment - including more types of trap to understand/discover; better discovery processes and techniques (geo-magnetics, seismic, etc.); and better extraction methods to raise the recovery factor of the oil that was discovered. My experience in identifying the prolific Llanos basin in Colombia in my early days helped support this view that much more was to be found. It is worth noting that this basin, by *not* being developed immediately, helped confirm the notion that discovery alone was not enough; that adequate demand, and a high enough price, were also needed if exploitation were to take place.

But then - as outlined above - I gradually began to see the global limits to *Conventional* oil by being involved in a series of oil industry studies.

Certainly my forecasts have changed over time as better knowledge has become available; but the *Atlas*, mentioned above, cautioned that 'the only correct numbers in this study are the page numbers'. That said, the main thrust of the argument, that the world is close to its peak production, remains valid. It is unlikely that the *Non-conventional* oils will be able to fully take up the slack as *Conventional* oil declines.

8.2 Conclusions

There now seems no doubt that *Regular Conventional* oil passed its world production peak of 66.7 Mb/d in 2005, and is set to continue to decline at about 2.5% a year such that the total produced to the end of the century will amount to about 2100 Gb (billion barrels).

Moreover, global production of what might be termed 'all-conventional' oil has been on-plateau also since 2005. Many countries are now long past their peak, and seems unlikely that production can hold a plateau for much longer.

Prices surged to almost $150 a barrel in 2008 following the peak of *Regular Conventional* oil production in 2005, and led to a serious economic recession and a financial collapse with the failure of several prominent banks, which in turn prompted a fall in demand and a collapse in oil price. As mentioned above, the high prices triggered the rapid expansion of *fracking* in the United States. The situation also prompted serious political tensions in many countries, especially in the Middle East and North Africa. There was also a massive increase in immigration to Europe and North America as people found that their homelands could no longer support them. Oil prices have since recovered to about $50 a barrel, allowing the OPEC countries to regain more control of the market.

There are far-reaching implications. There can now be little doubt that the world faces the dawn of the *Second Half* of the *Oil Age* as production declines due to natural depletion. The energy that oil and gas provided fuelled the economic expansion of the *First Half*, which allowed the world population to increase about seven-fold. Logic suggests that the *Second Half* may see a comparable decline, with many associated tensions.

This is however not necessarily a doomsday message, as communities in reduced numbers can learn to live again on whatever their particular region can support. They may increasingly tap renewable energy from wind, tidal, solar, hydropower and geothermal sources. Nuclear energy can also contribute, although the production of prime grade uranium has also passed its peak. Indeed, there are already signs of such moves to a new regionalism as Britain plans to leave the European Union, with similar pressures growing in several other countries. The critical issue is to properly inform people that this radical change is imposed by Nature, and does not reflect a human or political failure.

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A Perspective on Oil and Gas Produced by 'Fracking'

Walter Youngquist

Abstract

This article looks at the developments of oil and gas production resulting from hydraulic fracturing ('fracking') of sources of these hydrocarbon in shales and related rocks. The paper concludes that such fracking will change the world geopolitical scene regarding oil and gas supply for a time, and will provide some countries with relatively cheap fuel for many years. But around the world, producing oil and gas by fracking from shales is likely to take a considerable time to be fully implemented. Moreover, in contrast to optimistic recent projections, this paper considers that oil produced by fracking from shales will reduce, but not eliminate, the U.S.'s need to import oil. The paper concludes with an 'Editor's Note' which presents a recent forecast from Wood Mackenzie of U.S. Lower-48 onshore oil production out to 2035. This supports the view that the US is likely to remain an oil importer unless U.S. demand for oil decreases significantly.

1. Introduction

In the United States we have recently had a plethora of articles, mostly highly optimistic, on the effect of the technology of 'fracking' shales to produce oil and natural gas and eventually eliminate our need to import both. Prominent has been the recent statement by the International Energy Agency that U.S. oil production could exceed that of Saudi Arabia by 2020. This has been enthusiastically interpreted by some to mean that the United States could be energy independent, and also oil independent, by 2020.

As experience develops with fracking of shales for both oil and natural gas, some facts are beginning to emerge relative to the production, and also rate of production decline, from this technology; and also of the impact of this technology on both U.S. and world oil and gas supplies, and hence the corresponding geopolitical implications.

2. Hydraulic Fracturing

Hydraulic fracturing, or 'fracking', of oil and gas reservoirs is not a new technology. It has been used for more than 40 years. What is new is the discovery that the source beds of oil and natural gas (organic rich shales), previously thought of only as rocks from which oil and gas would migrate to porous and permeable reservoir rocks, could themselves be reservoirs; and be made to produce oil and gas if fractured with high pressure fluids (mostly water, with a thickener to carry sand to prop up the fractures) to release their oil and gas. As shales are widespread around the world, this technology has greatly enlarged the exploration frontier for oil and gas.

As recently as 1950 the United States produced half the world's oil. The peak of U.S. oil production occurred in 1970 at 9.3 million barrels per day (Mb/d). Added natural gas liquids brought the total to 11.3 Mb/d. But in the 1960's, the United States had already become a net oil importer, as demand exceeded growth of domestic oil production. As of October 2012 the U.S., including lease condensate, but excluding natural gas plant liquids, produced only 6.65 Mb/d. Major producers were Texas at 2.27 Mb/d, Louisiana 1.28; North Dakota 0.69; California 059; and Alaska at 0.55 Mb/d.

Enter the facts of shale fracking technology: Decline rates for the Bakken shale wells of North Dakota are high. A typical well coming in at 367 b/d flow will be down to 136 b/d by year end, and be on a pump; a decline of 63 percent. To maximize production from the Bakken play, as many as 40 000 wells are projected to be drilled. These wells cost from four to 10 times more than conventional wells, and therefore depend on a continued high price of oil.

These statistics broadly apply to all U.S. shale oil and gas developments. For example, the big fracking 'play' in Texas is in the Eagle Ford formation. It has wells coming into production at a rate as high as 4 000 b/d, but the decline rate the first year is as much as 75 percent. To fully exploit the Eagle Ford, some 4 000 ad additional wells are expected to be drilled beyond the more than 500 wells already completed.

The redeeming economic feature of fracked shale oil production is that the production curve 'tail' is quite long at a low rate of production. However, we do not have the years of experience to determine how long the 'tail' is, its ultimate oil production, and the actual decline rate (now estimated to be only two percent).

Some shales prove to be oil rich with modest amounts of associated gas. Other shales produce only gas. Gas occurs in a greater variety of geological settings than does oil, so it is more widespread and abundant than oil in its distribution.

3. Will the U.S. become an oil Exporter?

The decline rate of conventional oil fields worldwide is about five percent annually, or about four million barrels a day/year. The United States currently uses nearly 20 million barrels of oil a day. As of October 19, 2012, we imported 11.16 million barrels per day of oil and oil products. Therefore to eliminate our dependence on foreign oil, we would have to add production from fracked wells of more than 11 million b/d, plus around five percent of existing production from conventional oil fields to replace their production decline, an unlikely total quantity given high decline rates in fracked wells. Other factors, including environmental considerations such as the need for huge volumes of water with added chemicals in the process, and their safe disposal, mitigate against achieving this production. And in these calculations we have ignored increased oil demand, which, despite minor inroads from electric cars, will almost certainly occur.

In regard to the statement that the United States might exceed Saudi oil production by 2020, by the Saudis own statement they expect to peak in oil production at 12.5 Mb/d. If the U.S., by some magic, produced say two million barrels a day more than Saudi Arabia at its peak, that would mean U.S. production of 14.5 Mb/d, and would still be far short of the approximately 20 Mb/d we use today and even farther short of U.S. expected demand by 2020.

4. Reserves vs. Resources

Oil and gas volumes are commonly reported by industry as *reserves* and *resources*. The distinction between the two is very important but is frequently not understood. Reserves are the amount of oil or gas that may be recovered economically by known existing technology and at current prices. Resources are the amount of given commodity in total that exists in the Earth. An example of reserves versus resources is the vast amount of gold in the oceans. It is a huge resource, but none of it is a reserve as none of it can be economically recovered.

Technology may improve and prices may rise, and this combination may make more of a given resource move into the category of reserves over time. History suggests that price is at least as important as technology. History also shows that over time the easily won reserves have already largely been exploited, and remaining resources are converted to reserves only with higher prices. The recovery of both oil and gas from fracking technology is dependent on consistently high prices. This determines the 'recovery factor', which is commonly stated as a percentage of the resource.

For example, the Monterey Shale of California is cited to have roughly 500 billion barrels of oil in place (resources). However, only about 15 billion barrels, approximately three percent, are estimated to be economically recoverable (reserves). The Eagle Ford shale has an estimated 27.0 billion barrels of oil in place, but the recovery factor is only six percent. The Athabasca oil sands of Canada are estimated to contain approximately two trillion barrels of oil, but only about 170 billion barrels are estimated to be economically recoverable at current prices. A misunderstanding of the distinction between reserves and resources may lead to an enthusiastic overestimate of what a given mineral or energy discovery may do for an economy.

Worldwide, with fracking technology, only about five percent of the oil in place, and ten percent of the gas in place, are estimated to be recoverable. The simple natural gas molecule, which is methane (CH_4), being lighter than air and much smaller than the large complex oil molecule means that more gas can be released by fracking than can oil. This fact is important in considering the future production of these two energy sources. (Note: In energy equivalent, 6 000 cubic feet of gas is taken to be equal to a barrel of oil. A more precise equivalent is 5 600 feet, but 6 000 is used as a convenient round figure).

5. Global Prospects

Whereas the fracking technology was developed and is now extensively implemented in the United States, and slightly less so in Canada, it is beginning to be used in many places around the world, and has geopolitical implications as it relates to energy dependency. Poland, for example, would like to be independent of Russia for its gas supply and has already leased tracts in the Baltic basin for gas development. ExxonMobil was an early entrant, but after two unsuccessful wells has abandoned further exploration plans. Other companies continue to explore.

France has banned all fracking, fearing excessive environmental impacts from the technology. Germany is considering fracking as are other European countries, along with Great Britain. The concerns largely are in regard to possible groundwater contamination, proper disposal of waste water that occurs in large volumes, and small earthquakes that have been noted in some areas of fracking.

China is moving slowly in using this technology, but with greatly increasing demand for energy and the intent to try to decrease its dependence on coal to improve its currently very bad air quality, is gradually embracing fracking. China's potential for technically recovering gas from fracking is the largest of any country with 1 275 trillion cubic feet, exceeding even the United States, which is in second place with 862 trillion cubic feet. (Note: Gas is commonly sold in the United States in units of 1,000 cubic feet, written: Mcf).

Regionally, the estimated technically recoverable natural gas in trillions of cubic feet (Tcf) is: Americas 3 143 (Argentina with 774 is next to the United States), Asia-Pacific 1 625; Africa 1 059; Europe 989; Australia, 396 (Chevron has already invested $349 million in shale gas there), and Middle East with 141 Tcf. Note that these are *technically recoverable* figures and ignore the economics. We are finding that at least some technically recoverable oil and gas from fracking are not currently economic. How much will be economic in the future, as elsewhere stated, is dependent considerably on price.

World economies already are being negatively impacted by the high price of oil, and a probable future much higher price may be the most vulnerable part of our industrial civilization. Without affordable oil, industrial civilization as we know it now will gradually disappear.

The most suggested energy alternatives, wind and solar, are unlikely to completely replace oil in its myriad end uses, including energy in our current high energy intensive economies.

6. Conclusions

In summary, the fracking of source beds for both oil and gas will likely continue to expand and then mature as an industry for several decades. It will, to some degree, alter the current energy balance for various countries, and for a time reduce but not eliminate the need for Middle East oil and Russian gas.

For the United States, oil from fracking shales will reduce, but not eliminate, the need to import oil. We will be independent from foreign oil imports only when the last barrel of oil available to import is imported. Shale oil fracking won't make us oil independent (and therefore not energy independent), but it will, for a time, help a bit on the import bill, the largest single item in our current negative balance of trade. Our gas supply situation, however, is greatly improved and will favourably impact our industrial complex and may even provide gas for export, improving our balance of trade.

Fracking will for a time change the world geopolitical scene regarding oil and gas supplies, and will provide some countries with relatively cheap fuel for many years. Producing oil and gas by fracking from shales around the world will take considerable time to be fully implemented. Rates of developments will differ depending on the political and economic circumstances; how fast the technology can be transferred; and the necessary equipment provided and put on site. But for all that fracking might do for oil supplies, the countries that are now oil importers will probably continue to be net importers, but perhaps for a time to a lesser extent.

OPEC will not become obsolete and is very likely to still be the last oil man standing. In the meantime, the oil and gas industry will have a new if transient lease on life, providing many jobs and opportunities for a variety of industrial developments in many regions for several decades to come.

The Author

Walter Youngquist is an Emeritus member American Association of Petroleum Geologists, and is based in Eugene, Oregon. His many publication includes the book *GeoDestinies*, which takes a broad look at the link between mineral availability and civilisation, from the Stone Age to the present day, and provides detailed observations of current mineral supply sources and issues, including those relating to oil and gas.

Editor's Note

As Editor, I take the opportunity here of adding a recent forecast relating to U.S. oil production. This is from Wood Mackenzie, and covers US Lower-48 onshore oil production, split by category, out to 2035; see Figure 1. As this shows, total production of Lower-48 onshore oil is forecast to ramp up rapidly over the next five or so years, to reach a rough plateau at around 12 Mb/d, which lasts from 2024 out to the forecast horizon.

If this comes about this is indeed a significant increase. And it should not be forgotten that the U.S. has considerable production of liquids in addition to 'crude oil including lease condensate'. As classified by the EIA, these liquids are: NGPLs, 'other liquids' (such as biofuels), and refinery gain; in 2015 contributing 3.3, 1.3, and 1.0 Mb/d, respectively. Even so, and in line with the view given in the paper above, a predicted Lower-48 onshore production plateau of 12 Mb/d, coupled with U.S. oil production from offshore fields and from Alaska, plus the three 'liquids' categories just listed, will still not be enough in total to meet U.S. demand if the latter stays in the region of 20 Mb/d (or indeed increases). It thus seems that the U.S. will likely remain an oil importer, despite its production gains from fracking, unless it can significantly reduce its demand for oil.

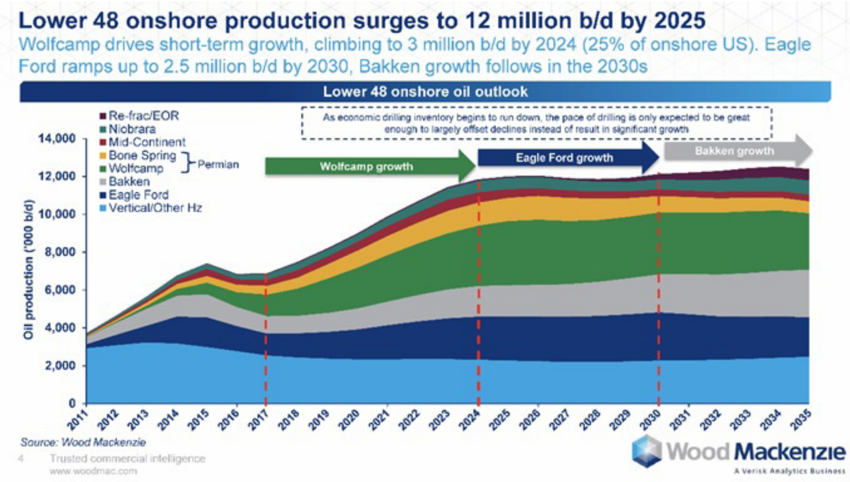

Figure 1. Forecast of U.S. Lower-48 States' Onshore Oil Production, Split by type.
Source: Wood Mackenzie.

The Importance of Peak Oil: An Open Letter to BP and *The Economist*

R. W. BENTLEY

Abstract

This 'open letter' is based on an e-mail sent in December 2016 to the oil company BP and to *The Economist* newspaper. The purpose was to raise the understanding within these organisations of past and future 'peak oil' dates, to help clarify the significance of peak oil.

For perhaps twenty years I had been in communication with both organisations about this topic, but with little traction. This was in part perhaps because my communications were rather long and technical; and more recently perhaps because 'peak oil' is no longer seen as likely from the supply side; the concept being apparently holed below the waterline by the rise of shale oil production in the U.S.

It therefore occurred to me that a short questionnaire asking when specific countries would see their *resource-limited* peaks in oil production might be a more effective way to get the ideas across; in particular if giving examples of countries with large populations, high oil revenue dependencies, and relatively near-term dates of peak. This questionnaire is given in this paper.

1. Introduction

As mentioned in the Abstract, this paper results from numerous efforts over a number of years to persuade successive chief economists within the oil company BP, and also staff at *The Economist* newspaper, to consider the risks posed by resource-limited peaks in oil production. (For a description of some of the efforts by members of the *ad hoc* 'Oil

Group' at Reading University, including myself, to communicate with BP on this issue see Chapter 4 of Campbell, 2011.)

Thinking, finally, that a short communication might be more effective, concentrating on when specific countries expect to see their resource-limited peaks in oil production (in particular, in their production of *conventional* oil), in December 2016 I sent the e-mail outlined below to the two organisations. With no response to date, I take the opportunity of publishing the questionnaire here.

2. E-Mail to BP and *The Economist*

The e-mail in question, somewhat amended, was as follows:

Subject: ***When will Nigeria reach its peak in oil production? - And related questions.***

Dear BP and *The Economist*,

I have previously communicated with your organisations concerning the misleading conclusions to be drawn by examining *changes* in global proved ('1P') oil reserves data. Recently I sent a 'letter to the Editor' of *The Economist* on this topic, and here wish to amplify this briefly. In particular, I suggest that the questions below on the global oil supply risks may help illuminate the topic.

3. The Questionnaire

Section A: Years to Peak Production

Q1. The US is a major oil producer. If 'light-tight' oil (oil from 'fracking') is classed as non-conventional oil, when does US production of conventional oil reach its peak?

Q2. The UK is a significant oil producer. When does its oil production peak?

Q3. Norway is a significant oil producer. When does its oil production peak?

Q4. Nigeria is a significant oil producer, and its government depends on oil revenues for an important fraction of its budget. When does Nigeria's oil production peak?

Q5. Russia is a major oil producer. When does its production of conventional oil peak?

Q6. China is a significant oil producer. When does its oil production peak?

Q7. Iran is a significant oil producer. When does its oil production peak?

Q8. Saudi Arabia is a major oil producer. When does its oil production peak?

Country & Oil type	**Years to peak**	**R/P ratio (years)**	**Difference (years)**
US - Conventional			
UK – All oil			
Norway – All oil			
Nigeria – All oil			
Russia – Conventional			
China – All oil			
Iran – All oil			
Saudi Arabia – All oil			

Table 1. Comparing 'Years to peak' with R/P ratios. (Note: If a country's peak in oil production was in the past, please enter a negative number in 'years to peak'.)

Section B: Comparing 'Years-to-peak' with R/P ratios

Q9. Based on the answers above, please fill in table 1.

Section C: Increases in Proved Oil Reserves

Q10. From 1980 to 1995 global proved oil reserves increased by about 445 billion barrels (from 683 to 1126 Gb). Which group of oil exporting countries contributed over 80% of this increase?

Q11. How much of this 445 Gb increase would count as 'proved oil reserves' under SEC rules?

Q12. From 1995 to 2016 global proved oil reserves increased by some 580 billion barrels (from 1126 to 1706 Gb). Which two countries together contributed over 60% of this increase?

Q13. How much of this 580 Gb increase would count as 'proved oil reserves' under SEC rules?

Section D: Economics

Q14. Sketch up a rough plot of the contribution oil imports and exports made to UK balance of payments flows, from 1965 to 2015.

Q15. Global production of 'all-oil' in 2016 was over 90 Mb/d. How much of an imbalance between supply and demand (in Mb/d) is judged necessary to move the price of oil significantly (by, say, >20%)? Hence, to what extent do current oil prices reflect the supply situation in 3 years' time; and in 10 years' time?

How to answer these questions:

Some of the answers are in the BP *Statistical Review of World Energy*.

For calculation of 'years to peak production', some analysts will have access to the generally very expensive oil-industry proved-plus-probable ('2P') oil discovery data, and so will to be able to answer these questions.

For analysts that have access only to the very poor proved ('1P') oil reserves data, such as those given by the US EIA, or in the BP *Stats. Review*, please look at Bentley (2015) to see how, despite the unreliability of these 1P data, they can be used to estimate the dates of peak production by country with at least reasonable precision.

Alternatively, two public sources of information that do provide '2P' data can be used to answer these 'years to peak' questions. These are: (a). the Globalshift Ltd. website, www.globalshift.co.uk (select a region, then a country, then click: 'E and P' to see the relevant chart); and (b). *Campbell's Atlas of Oil and Gas Depletion*, published by Springer in 2013. For details of the Globalshift Ltd. oil forecast model see Smith (2015), and for the forecast model of Colin Campbell see the *Atlas*, or Campbell (2015).

I hope these questions help in understanding some of the relatively near-term oil supply constraints that society faces.

Yours sincerely, etc.

4. Some Answers

To help readers of this present paper a little, should they wish to answer the questions above, Table 2 gives expected dates of peak oil production for three countries, where the data are drawn from two of the sources listed above. Note that these sources report peak production dates for very different classes of oil. Table 2 gives also the corresponding R/P ratios, drawn from the 2017 BP *Stats. Review*

Dates of Peak production	**Globalshift Ltd.**	***Campbell's Atlas***	***R/P ratio***
Type of oil:	Total fossil oil	Regular Conventional oil	(years)
Russia	~1980 & ~2016	1983 (&~2013)	*27*
Nigeria	~2025	2005	*49*
Brazil	~2026	1990	*13*

Table 2. Approximates Dates of Peak Oil Production; and corresponding R/P ratios.

Notes

- Globalshift Ltd. data are from www.globalshift.co.uk. Data refer to production of 'Total fossil oil', defined as: "fossil oil produced from on and offshore reservoirs, including tight sands/shales; and liquids extracted from gas." This category thus includes the very heavy oils, including tar sands and Orinoco oil, as well as NGLs.
- '*Campbell's Atlas*' data are from '*Campbell's Atlas of Oil and Gas Depletion*', Second edition, by C.J. Campbell; published by Springer, 2013. Data refer to the production only of '*Regular Conventional*' oil. This is defined as conventional oil less oil from ultra-deepwater (>500 m water depth) fields, and from oil fields in the Arctic. Conventional oil, in turn, broadly here refers to light- and medium-density oil produced from oil fields by primary or secondary recovery; and hence excludes the non-

conventional oils such as light-tight oil produced by fracking, very heavy oils, NGLs, and oil produced from kerogen.

- The significant differences in estimated dates of peak production for both Nigeria and Brazil from these two sources are primarily down to inclusion in the Globalshift data of oil from deepwater offshore fields.
- Both sources of data predict these dates of peak based on their evaluation of limitations to production-rate / resource availability; i.e., these dates *do not* reflect estimates of limits to oil *demand*.
- The R/P ratio is a country's proved ('1P') reserves divided by its annual production. This gives the notional life in years that these reserves would take to become exhausted provided production does not change. Though widely used, this ratio is wholly misleading in terms of security of supply. This is for two reasons: In many countries proved ('1P') reserves are a very poor indicator of the country's likely (i.e., proved-plus-probable, '2P'), reserves. Secondly, and more importantly, reserves give no indication of when a country's production will reach its *resource-limited* peak and then decline. A country can have relatively large oil reserves and have this production peak well in the future, or for the peak to be very close, or for it to be long in the past. In general, quoting R/P ratios is very misleading, and should be avoided.

In a future issue of this journal we will give the full set of what we regard as the likely answers.

5. Conclusions

The questions above are intended to help analysts think in a more focussed manner about future global oil supply, and hence the near-term constraints that we likely face.

In the main, only three concepts are needed to understand peak oil, either for a country, or globally. These are:

- For conventional oil, production in a region typically reaches its resource-limited peak when roughly half the total recoverable conventional oil in the region (the region's URR) has been produced; i.e., at a date when a considerable quantity of reserves still remains. These reserves may well see production, but at a declining rate.

- In calculating the date of peak, use should generally be made of a country's proved-plus-probable ('2P') oil reserves, not its proved ('1P') reserves.
- The world contains very large quantities of recoverable non-conventional oil (likely in the region of at least 4 500 billion barrels; see Chart 2, page 78 of The Oil Age vol. 1, no. 1). But in general these oils are more difficult and expensive to produce than most conventional oils, and tend to have significantly lower energy return (EROI) ratios. At least in some cases also, these non-conventional oils may come on-stream only relatively slowly, due to technical and investment constraints.

The Annex lists research papers that have led to the above questions being posed, and hence to the conclusions drawn.

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Unresolved Questions on Oil, other Energies, and Economics: Providing Insight into the Coming Energy Problems

R. W. BENTLEY AND C. J. CAMPBELL

Abstract

This paper lists a number of questions for which the authors currently have no satisfactory answers, and where answers would help illuminate the energy problems we see ahead.

Many of the questions are to do with oil supply. These include, for example, asking:

- Why have data on *proved* oil reserves (particularly for the USA, UK and OPEC) been so poor?
- Why, given their dubious nature, are these data so widely relied upon?
- Why was President Carter wrong on oil supply in his 1977 '*Moral Equivalent of War'* speech?
- How close is peak oil demand?

Questions cover other energies also, including gas, coal and the renewables, as well as minerals in general. They include:

- Whether lack of energy contributed to the fall of the Roman Empire?
- Whether anyone has adequately reliable data on the global recoverable quantities of coal?

- Whether, to-date, the global supply of any mineral has become exhausted?

In addition, we list somewhat more theoretical questions. These are mainly to do with the linkage between energy and economics. They ask, for example:

- If any energy or economic model is yet properly accounting for the generally falling energy-returns (EROIs) of nearly all energies?
- If any economic model is properly accounting for the impacts of the high energy prices that seem to us likely in future?

We raise these questions with the aim of improving society's understanding of the current and prospective global energy situation. Many of the questions might make useful student projects. We seek help from whomever has full or partial answers to these questions.

1. Introduction

In our view, the world faces a number of serious upcoming energy problems, many of which are under-recognised, and some of which seem scarcely recognised at all. These problems include:

(i). The *resource-limited* peak in the global production of *Regular Conventional* oil, defined by Campbell as *all-conventional* oil less very deepwater (>500m) and Arctic oil; see Campbell (2015).

The resource-limited global production peak of this category of oil seems to have occurred in 2005, and was almost certainly a key contributor to the generally high oil prices (up to $145/bbl) since, see Figure 1. These oil prices resulted primarily from the need to meet the world's increased 'all-liquids' demand from the increased production of generally more expensive oils, including deepwater and Arctic conventional oil; non-conventional oils such as shale oil and oil from tar sands; and from production of 'other liquids', such as NGLs and biofuels.

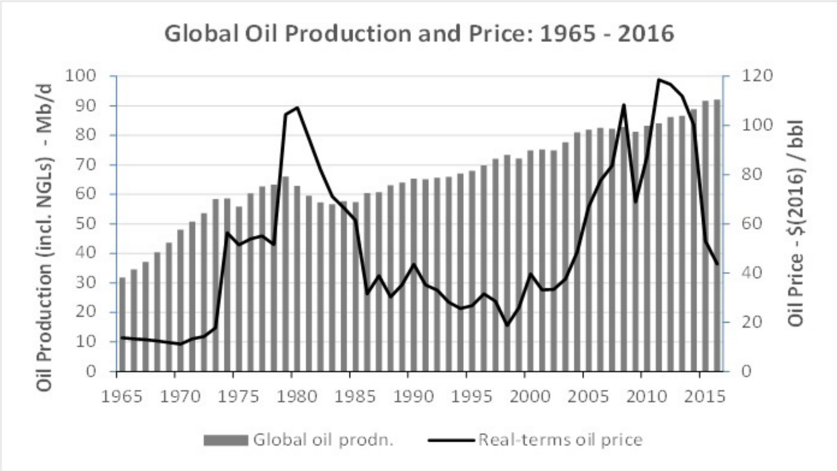

Figure 1. Global Oil Production, and Oil Price: 1965 – 2016.
Price averaged >$80/bbl for most of 2007 to 2014 (and >$100/bbl for much of this period).
- Vertical bars (left-hand scale): Global 'all-oil' production, in millions of barrels/day.
- Solid line (right-hand scale): Annual-average real-terms oil price, in 2016$/bbl.
Source: BP Statistical Review 2017; based on an original plot by E. Mearns.

(ii). The almost-certainly near-term *resource-limited* peak in global production of *all-conventional* oil; i.e., of *Regular Conventional* oil plus very deepwater (>500m) and Arctic oil.

Predictions of the date of this global 'all-conventional' oil peak vary considerably, ranging from about now (Laherrère *et al.*, Part-1, 2016), out to ~2025 (see www.globalshift.co.uk), and to "*before 2030 appears likely and there is a significant risk of a peak before 2020.*" (Sorrell *et al.*, 2009). Some other forecasts do not foresee a peak of this class of oil within their forecast horizon, but do forecast its production to remain on-plateau over this period (for example, the forecasts of IEA 2011, BP 2015, and ExxonMobil 2015). As Figure 2 shows, global production of 'all-conventional' oil has been on-plateau since 2005.

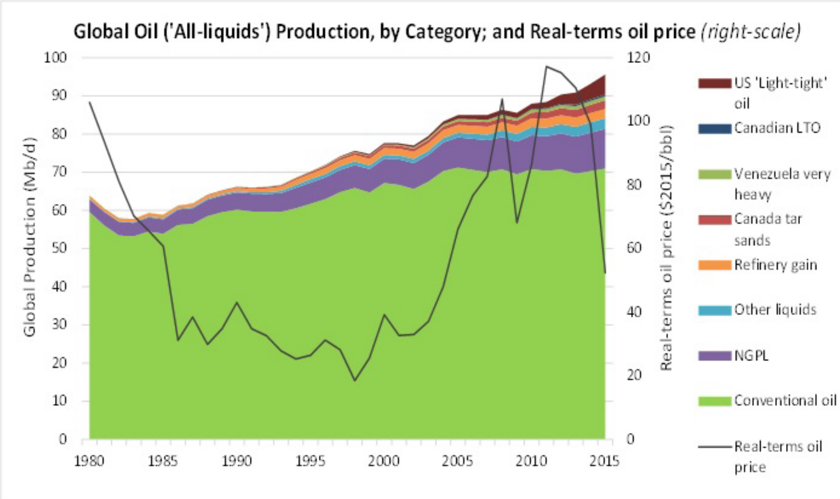

Figure 2. Global Production of 'All-liquids', 1980 – 2015.
Note: Global production of *'all-conventional'* oil has been on-plateau since 2005, despite an on-average high oil price.
Data are from US EIA for crude-plus-condensate, NGPLs, other liquids, and refinery gain; data for other categories are from Laherrère et al. *'Oil Forecasting – Data Sources*

(iii). The likely near- or medium-term *resource-limited* peak in global production of *all-oil*; i.e., *all-conventional* oil, plus 'light-tight' and very heavy oil (such as tar sands and Orinoco oil); plus oil produced by retorting kerogen, and that from GTL and CTL processes.

We recognise that there are very large remaining quantities of technically-recoverable non-conventional oils, see Figure 3. But our modelling and that of others suggests that these may not be able to come on-stream fast enough once production of 'all-conventional' oil is in decline.

(iv). The possible near- or medium-term *resource-limited* peak in global production of *all-liquids*; i.e., *all-oil*, plus liquids such as NGLs and biofuels, plus refinery gain. Once again, the modelling of one of us (Campbell), and by Laherrère and a number of others, suggests that the various components of 'all-liquids' may not be able to come on-stream fast enough, once production of 'all-conventional' oil is in decline.

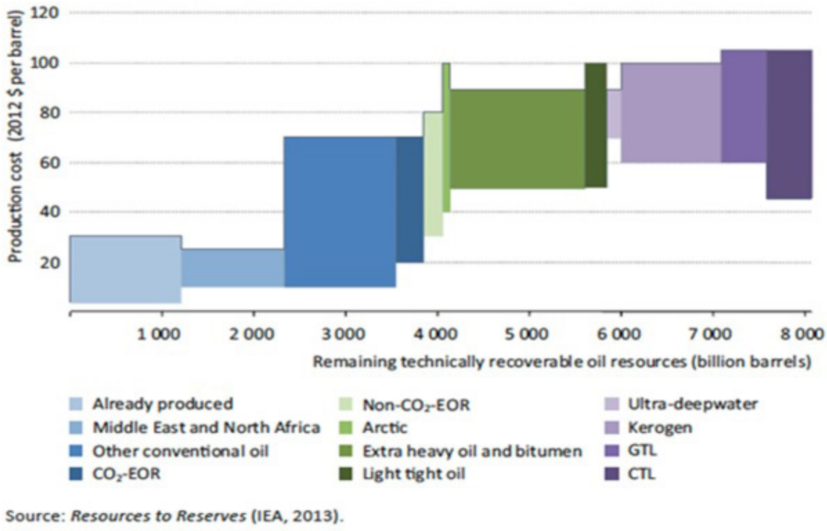

Figure 3. Typical Recoverable Resource Estimates as used in 'Resource-based' Oil Forecasts: Estimated global remaining technically recoverable volumes of oil by category (in Gb) vs. production cost range (in $2012/bbl).
EOR: Enhanced oil recovery; CO2-EOR: EOR using CO2; GTL: Gas to liquids; CTL: Coal to liquids.
Note: Conventional oil is represented by the first three 'blocks' at the left of this chart.
Source: IEA. Resources into Reserves, 2013 edition.

(v). We recognise, however, that there is a potential caveat with these predictions of a global *resource-limited* peak in the production of these various classes of oil, and of liquids.

This is that an increasing number of organisations do not foresee a global oil production peak caused by limits to *supply*, but instead a peak occurring in global oil *demand*; often in the relatively near future; e.g. the recent forecast from DNV GL (2017) which sees global oil *demand* as reaching a maximum by 2022.

This is therefore an important question to raise, and is listed later in this paper. But from the oil and liquids forecasts known to us (see Campbell, 2015; Smith, 2015; Laherrère, 2015; Miller, 2015; McGlade, 2015; Wold, 2015; Voudouris, 2016; as well as the forecasting of the IEA, 2016), we judge that at least some of the global oil and liquids production peaks, when they occur, will indeed be *supply-limited*, rather than *demand-limited*; with these peaks falling either in the past (that of *Regular Conventional* oil), or in the relatively near-term future, for example, for 'all-conventional' oil, and possibly for 'all-oil', and 'all-liquids', as indicated above.

(vi). The likely medium-term *resource-limited* peak in global production of *conventional gas*. Modelling suggests that this will occur in around 10, perhaps15, years; see, e.g., *Campbell's Atlas of Oil and Gas Depletion* (2013).

(vii). We recognise that there is less likely to be a near- or medium-term *resource-limited* peak in global production of *all-gas*, because it is known that the potentially recoverable resource is very large and access can sometimes be fairly rapid. The recoverable resource has been significantly increased in recent years by the advent of hydraulic fracking of tight-gas reservoirs; adding to the other various classes of non-conventional gas that exist, such as in deep brine aquifers; and possibly in methane hydrate deposits, which may be extensive.

(viii). The possible medium-term *resource-limited* global production peak of *hard coal*; and maybe even of *all-coal*. Here the data are too uncertain to know for sure, but see Wang *et al.* (2017), and question Q4.2-1, below.

(ix). The energy return (EROI) ratios of many current energy sources are lower (and sometimes significantly lower) than many of the fuels used in the past (see, e.g., Hall, 2016). This issue has lately received some recognition, but in our view needs to be far more widely recognised; and also needs much new modelling; and specifically for EROI ratios to be included in energy models in general, as in done for example in Campbell's oil forecast model (Campbell, 2015).

(x). A separate - and still less recognised problem - associated with energy return is that it sets a limit on the *useful rate* that any new energy source (or energy-saving approach) can be introduced.

The prime example here is that of the introduction of photovoltaic systems, where an acceptable but modest EROI ratio for fully-installed PV systems, coupled with the rapid rate in which they have been installed globally, has meant that no net energy has so far been returned to humankind (see Dale and Benson, 2013). This is because, in any given year the total energy generated by such systems already installed has been insufficient to construct and install the systems in the following year. Once the rate of installation slows, then net energy does return to society. But the general principle applies to all energy systems, such that simple calculations of the energy they will yield (or will save) can be very misleading during the system's growth phase. (Note that the above calculation of 'no net energy return from PV to-date' is based on accounting for energy directly. The picture is significantly better if the calculation is based on primary energy, where the electricity out of a PV system can be more valuable if measured in primary energy terms. Nevertheless, even on this basis, the world's PV systems, while growing, are delivering far less useful energy than virtually all current energy models calculate.)

(xi). The impact of high energy price on the performance of economies.

We are not experts here, but understand that standard economic theory is poor at handling the crucial part that energy plays in economic activity. As a result it is often still widely said that because the cost of energy is only small fraction of a region's GDP, an increase in the price of energy will have only a correspondingly small impact on the level of economic activity.

We understand that a number of independent economists take issue with this latter view; and given the likely high oil and other energy prices we see ahead, there would seem to be a need for a more 'physics-based' approach to modelling the role that energy plays within economic activity. We would be fairly sure that high oil prices, for example, will lead to economic slowdowns, or even recessions, as has frequently been the case in the past; most notably in 1978, and 2008.

(xii). Climate change: The need to 'keep the fossil fuels in the ground' (or to combine their combustion with carbon capture and storage).

This is a big topic, which we intend to return to in future issues of *The Oil Age*. Suffice to say here that understanding the linkage between global fossil fuel production and climate change is important, and all sides of the discussion will be helped by a better understanding of the likely fossil fuel CO_2 emissions ahead.

The above is a daunting list of serious, near-certain, likely and possible near- and medium-term energy problems that the world may have to face. There is an urgent need for better knowledge to remove some of the uncertainty about these problems, and to this end we set out below a number of questions known to us that bear on these issues, and for which currently we have no satisfactory answers.

2. The List of Unresolved Questions

The questions below are - to our knowledge - unresolved. But if answers or partial answers already exist, or are subsequently found, please let us know; see Section 7.

The questions are categorised into sections on ‘oil’, ‘other energies and minerals’, and ‘energy modelling / energy-economics linkages’. In each case these are further categorised into ‘past’, ‘current’, and ‘future’ questions. (These latter categories apply fairly loosely, and sometimes overlap.) In each case the individual sequence of questions is fairly arbitrary, though we have tried to gather similar questions together.

In general a question is asked; its context is given; a suggestion is made for what might be an answer (or partial answer) if we have thoughts on this; and an indication given - if known - of where one might look for an answer.

3. Questions on Oil Supply

3.1 Oil supply - Questions about the past

Q3.1-1: Why have proved reserves for US and Canadian oil fields grown so much in the past?

Context

(- Taken in part from Bentley, 2016a;, pp 109-110.)

In the past in the U.S. (and also Canada) the apparent size of individual oil fields, if measured using *proved* ('1P') reserves data, has generally grown very significantly.

Attanasi and Root (1994), for example, found that the aggregate size of US oil fields, as measured by cumulative production plus proved reserves at a given date, appeared to grow by seven-fold after 20 years of production, and by thirteen-fold after 90 years. Other approximations put US average field growth at about six-fold for onshore fields, and three-fold for offshore; while for Western Canadian fields Odell found apparent growth in proved field volumes to be nine-fold over field lifetimes.

Attanasi and Root said there was insufficient US data to consider individual fields (and hence find detailed explanations), in part because US field data are proprietary. They raised a number of possible explanations for this 'enigma of field growth', and mentioned new pools, new reservoirs, and the renaming of fields; but did not explicitly discuss 'drilling-up' in terms of communication of wells to the oil (see below).

The significance of this question should not be under-estimated. Because apparent field size always kept growing (at least in the past) many US analysts took the gains to be largely real, reflecting improvements in knowledge and in technology, rather than - as we suspect in most cases - just changes over time in how the already-discovered oil was booked. In this regards, Attanasi and Root noted that: "*... from 1978 through 1991, growth of old discoveries accounted for more than 90% of additions to* [US] *proved reserves.*"

Tentative answer

There are many possible explanations for the very large increases in the apparent size of US and Canadian oil fields, if measured by changes over time in their cumulative production plus *proved* reserves.

These explanations include, initially, ignorance of the true size of fields, and later for reasons of US and Canadian tax regimes. And we accept that some of field 'reserve growth' can be real, driven by better knowledge of a field, or better recovery rates (where, for example, US data showed large reserves growth in old heavy-oil Californian fields, such as Kern River, due to later use of steam injection).

And for all reserves reporting, including outside of the US and Canada, there are important psychological issues at play, as discussed in Campbell and Gilbert (2017). Exploration geologists are largely motivated by the quest for information about the geology of the area being explored, much of which can only come from drilling wells. They often therefore exaggerated the potential of a prospect to persuade management to drill. Engineers, by contrast, invest huge amounts of money, and are dedicated to making reasonable profits. They have an incentive therefore to understate the size of a discovery to minimise investment risks, and perhaps get credit from management if they extract more than first estimated. Management, for its part, faces many competing claims on limited budgets; and there are still further pressures from governments that influence exploration and production decisions. It is understandable therefore that reserves, as reported, evolve over time, and may not be true scientific estimates of the size of a discovery.

But despite these uncertainties, our main tentative answer for the apparent many-fold growth in US and Canadian oil field volumes is simply the 'drilling-up' of large early fields. This allowed ever larger volumes of oil to be reported as 'proved', as under SEC rules proved reserves could mainly only refer to oil *in communication with existing* wells; and where, for a large field, companies at any point in time drilled only the minimum number of wells sufficient to provide adequate profits, with uncertain oil price forecasts being a critical factor in these calculations.

Given that this apparent US and Canadian 'reserves growth' phenomenon has misled many on the true amounts of conventional oil likely to be recovered, and the long shadow that this confusion has cast over the 'peak oil' debate, there is still much that needs to be elucidated about exactly why US and Canadian proved oil reserves data were historically so extraordinarily conservative.

Where to look for the answer

The answer must necessarily lie in historical data on individual US and Canadian fields. Possibly these data have already been assembled and properly analysed to answer this 'reserves growth' question, but if so, this analysis is not known to us. If such analysis does not exist, then historical data on individual fields will need analysis from this perspective, at least for a representative sample of fields.

Q3.1-2: Why was President Carter wrong on oil supply in his 1977 'Moral Equivalent of War' speech?

Context

(- Taken in part from Bentley, 2016a, pp 179-183.)

President Carter's '*Moral Equivalent of War*' speech on 18th April 1977 was quite wrong on the anticipated date of global oil supply difficulties, albeit addressing a valid subject. Wikisource (accessed 17th Sept 2014) has Carter saying:

> *"Tonight I want to have an unpleasant talk with you about a problem unprecedented in our history. … We simply must balance our demand for energy with our rapidly shrinking resources. By acting now, we can control our future instead of letting the future control us. … Unless profound changes are made to lower* [global] *oil consumption, we now believe that early in the 1980s the world will be demanding more oil than it can produce."*

The trouble is that scientists, engineers, and certainly some policy makers knew at the date of this speech that only about 400 billion barrels (Gb) of oil had been produced globally, out of estimates at the time of the initial global recoverable quantity of conventional oil (the global URR) ranging from about 1800 Gb to 2500 Gb. Thus, it was known in 1977 that roughly only a fifth of this initial *conventional* oil had been used, and that there was enough remaining for its production to keep increasing quite rapidly until reaching a peak around the year 2000 or so, before declining.

Correct forecasts using these data were available quite widely, for example from ESSO (1972), a study for the UN (Ward and Dubois, 1972), a study for the UK government (Marshall, 1976), and from analysis published by Hubbert (1977); see: Bentley (2016a, p60); the extensive list in the Appendix of Andrews and Udall (2015);

and the list in Bentley and Boyle (2008).

Moreover, it was also well known at that time that there were very large quantities of *non-conventional* oil potentially available; for example in 1956 Hubbert had given estimates for these quantities as: ~225 Gb for NGLs, 400 - 800 Gb for oil from tar sands, and 1300 - 3000 Gb for oil from kerogen in shale rocks, (Bentley, 2016b, p67).

So the question is, why, with only some 400 Gb of oil in total produced globally by 1977, and hence with known estimates at the time of perhaps 1600 Gb of conventional oil *remaining*, and a further 2000 Gb or more of non-conventional oil potentially available, did Carter's speech get it so wrong?

We raise this question not as some footnote to history, but because it is one of the pillars of the still very-widely held view among many senior energy analysts that 'all past oil forecasts were wrong', and hence that current oil forecasts are likely to be wrong also.

But as indicated above, it is simply not true that 'all past oil forecasts were wrong'. As already listed for oil forecasts available in 1977, and in Bentley (2016a) Chapter 3 and Andrews and Udall (2015) for forecasts subsequently, oil forecasts of *conventional* oil production if *resource-based* (i.e., based on assessments of the total of such oil likely to be recoverable) have been extraordinarily accurate on the dates of peak of this class oil. This is true both for oil production forecasts for individual countries (e.g., Hubbert, 1956, for the US; or Marshall, 1976, for the UK); and from about 1970 onwards for global forecasts produced by many companies and individuals, including Shell, Esso, Petroconsultants, Hubbert and Ivanhoe; as well as forecasts produced for organisations such as the US, UN and the World Bank.

It is because of its part in the incorrect 'all oil forecasts were wrong' view that it is important to get a satisfactory answer if possible to this question about the error in President Carter's speech.

Tentative answers

Currently, three potential answers to this question are known to us:

(a). In line with the gist of previous questions on misleading US proved oil reserves, in 1977 *global proved* oil reserves were 650

Gb or so, resulting in a global R/P ratio (the number of years to exhaustion of these reserves at the then-current production rate) of about 28 years. So, it is perhaps not surprising that some might have expected global oil supply difficulties well before these 28 years were up. A problem here is that President Carter in his speech seemed to at least partly recognise the poor nature of the proved reserves data, saying:

> *"World consumption of oil is still going up. If it were possible to keep it rising during the 1970s and 1980s by 5 percent a year as it has in the past, we could use up all the proven reserves of oil in the entire world by the end of the next decade. … I know that many of you have suspected that some supplies of oil and gas are being withheld. You may be right, but suspicions about oil companies cannot change the fact that we are running out of petroleum."*

(b). A second reason for the misplaced alarm in the speech may have been a report produced by the CIA (which subsequently President Carter succeeded in getting made public) which predicted a near-term collapse in Soviet oil production. A fascinating discussion of this topic (which may well be correct, but which we have not yet looked at in detail) is by Stern (2012). In this account, Stern has Secretary of Defense at the time, Harold Brown, as saying:

> *"The present deficiency of assured energy resources is the single surest threat that the future poses to our security and to that of our allies."*

Stern goes on to make the case that much of the military tension, and indeed military action, that followed was based at least in part on this misconception. He also makes the more general point that many of the military conflicts and standoffs over the last century or so were the result of fundamental misunderstandings by one or both sides of the true nature of the situation.

(c). Finally, in this list of possible reasons for President Carter's pessimism on future global oil supply, it is worth mentioning the possible influence of Admiral Rickover. When at the ASPO-6 conference in Ireland, one us (Bentley) asked James Schlesinger, America's first Secretary of Energy and appointed by Carter, about the latter's views on oil.

Schlesinger replied in effect: '*Always look to see who was a fellow's boss*.' Asked for clarification, Schlesinger pointed out that President Carter had worked under Admiral Rickover, and since the latter had been Director of Naval Reactors in the US Navy, it seems likely that Rickover had impressed on Carter the Navy's vulnerability to interruptions in Middle East oil supply (and possibly also of the wider issues of future oil supply), and hence the need for the US to have a nuclear navy. This view on Carter's possible thinking is supported by Wikipedia reporting that: *"Carter later said that, next to his parents, Rickover had the greatest influence on him."*

Where to look for the answer

In seeking to answer this question, we suggest reading President Carter's speech in full; it is surprisingly clear on the dangers it identifies, and on the solutions suggested (see '*Perspective*', below); and also Stern's (2012) paper on '*Oil Scarcity Ideology in US National Security Policy, 1909-1980*'; including also some of the key sources he quotes.

If people can be found who were staffers or analysts close to the topic at the time, talking to them may well shed useful light on the topic.

And of course, asking President Carter himself is also potentially useful. One of us (Bentley) recently wrote to ask him if he might write an article setting out his reminiscences of 'how he saw the oil supply debate develop over the years'. (With hindsight, a request about the specific question raised here might have been more sensible.) President Carter kindly replied, saying:

> "*I don't have time to write an article for you* [see above]. *You can read my official documents and books. I emphasized energy conservation, the development of renewable energy plus natural gas, etc., and more efficiency of autos, homes and equipment. – Best wishes."*

Perspective

This reply leads in turn to an important perspective:

Most of us in the energy field are well aware of the many crucial initiatives on new energy supplies, including the renewables such as wind and solar, but also on far better use of energy via tighter

CAFE and building codes etc., which resulted from research and legislation initiated while President Carter was in office. Given the long time-lags of introducing new energy technologies, it is in significant part as a result of these initiatives that today we have many of the tools required to respond to both the underlying question of providing sufficient energy globally to support society, as well as to climate change concerns.

The situation envisaged by President Carter - of a near-term risk of declining global oil production of some or all categories of oil - now looks near certain, despite scope for significant production increases from the non-conventional oils.

Thus an updated version of President Carter's original 'Energy Plan', now adapted for CO_2 concerns also, is warranted. In essence, Carter was not wrong on the plan, but wrong on its timing. And in terms of seeking to establish the facts, in May 1977 Carter commissioned the landmark *The Global 2000 Report to the President*, which when finalised in 1980 (Barney, 1980) correctly quantified many of the anticipated problems ahead, including that of global peak conventional oil.

(Incidentally on one of these problems, that of CO_2, it was under Schlesinger that the US DoE launched its then-innovative 'Carbon Dioxide Effects and Assessment' Program which has likewise placed humankind in a much better position than would have otherwise been the case.)

In closing this 'perspective', it is worth noting that there were numerous other examples from the late 1970s and early 1980s of those who thought global oil would soon become in ever shorter supply: in effect, *'oil would soon to run out'* was a zeitgeist of the time.

A notable example was *'Energy Future'*, a report of the Energy Project at the Harvard Business School (Stobaugh and Yergin, 1979). This had (p4): "… *higher real oil prices seem assured for the future, with the only questions being how soon and how high*"; and (p13): *"The easy days of easy and cheap oil are truly over ….*" This was not just the views of the authors, as in the acknowledgments they write: "*In the course of researching and writing this book, we two communicated with over three hundred business executives,* *government officials, labor union leaders, analysts, academics, and other specialists … Our co-authors had similar exchanges with many hundreds more."*

Overall, therefore, a solid explanation still awaits for the large 1970s/early-80s disconnect between the general expectation at that time of global oil supply 'running out soon', versus the view, resulting from the technical forecasts from a range of recognised authorities and based on estimates for the global URR of conventional oil being in the region of 2000 Gb, which showed no peak in conventional oil supply until around the year 2000; and with large resources of non-conventional oil potentially available after that.

If readers have insight into this conundrum, we would be very pleased to hear.

Q3.1-3: Why have UK proved-plus-probable ('2P') oil reserves data, as published by the UK Government, been typically only half the value published in oil-industry databases, for example, that of IHS Energy?

Context

The UK has what are regarded as some of the best government-provided data on its oil industry. But in at least four cases, the data provided have been very poor. The first case is discussed in this question, and the other three in the questions below.

The question here is: Why have UK proved-plus-probable ('2P') oil reserves data, as published by the UK Government, been typically only about half the value published in oil-industry databases, for example, that of IHS Energy?

The importance of this question is that evolution over time of the UK Government 2P oil reserves data, in a rather similar manner to the lower-still 1P reserves data, fed into the widely-held narrative of UK oil being produced, but reserves always being replaced as a result of improving skills and technology; such that the UK oil production peak when it came (in 1999) was a surprise to many, despite being accurately predicted since at least 1976.

Tentative answer

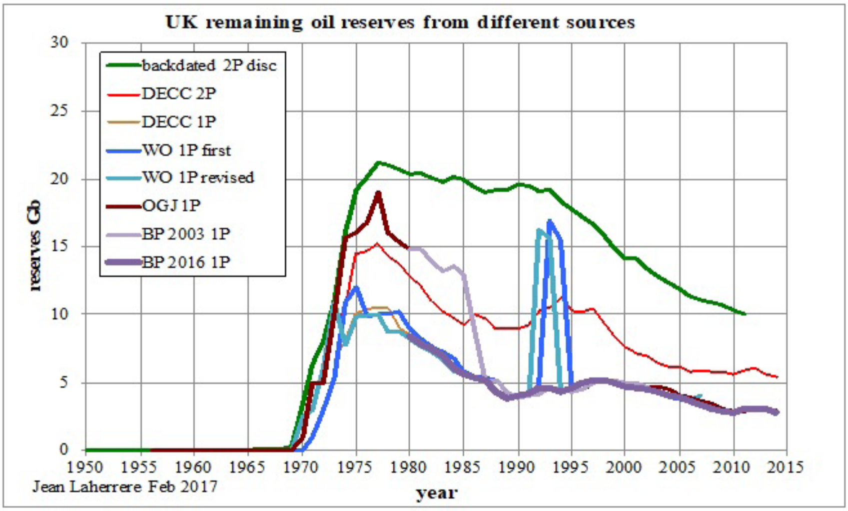

Figure 4. Comparison of Changes over time in Reported UK Oil Reserves: Data from various sources; including oil-industry 'scout' 2P backdated oil reserves.
- Top line: Oil-industry 'scout' backdated proved-plus-probable ('2P') oil reserves data. These reflect the rapid early finds of the major UK oil fields from 1970 to 1975; with the smaller, later finds not being enough to prevent the 2P reserves from falling as production rose.
- Roughly middle (fairly steady) line: UK govt. 2P reserves data. Though these roughly match the profile of the oil-industry 'scout' backdated data, they are mostly at about half the latter values.
- Bottom line: UK govt. proved ('1P') oil reserves data.
- Other lines:
- UK oil reserves as reported in the *Oil & Gas Journal* (line 'OGJ'). These are notionally 1P data, but clearly switched from 2P to 1P after 1985.
- UK oil reserves as reported in the BP *Stats. Review* as of 2003. These are again notionally 1P, and track the *O&GJ* data.
- UK oil reserves as reported in the BP *Stats. Review* as of 2016. Unlike the BP *Stats. Review* 2003 data, these track the UK govt.1P data.
- UK oil reserves as reported in *World Oil* (line 'WO'). These are notionally 1P oil reserves, and generally track the UK govt. 1P data, but with a short excursion in the early 1990s to roughly oil-industry backdated 2P reserves values.
Source of chart: J. Laherrère

The tentative answer for why UK Government 2P data have been roughly half the oil-industry data is two-fold:

- Certainly the oil-industry data as shown here are backdated, i.e., *today's* view of the size of fields set against the date they were discovered; whereas the UK Government's 2P oil reserves data are 'current basis' i.e., the view that was reported at the date shown.
- But we are fairly certain that this is only part of the problem. Almost certainly the UK Government 2P reserves only included reserves for either fields in production, or also for fields approved ('sanctioned') for production; whereas the oil-industry 'scout' data certainly include the reserves of *all fields discovered* at the dates shown, whether approved for production or not.

Note that the proved ('1P') UK oil reserves are lower still is almost certainly simply because they correspond to proved oil reserves as reported by field operators under the conservative SEC rules.

Where to look for answers

The answers have to come by comparing reserves by field in both the oil-industry data, and as was recorded by BEIS. We have recently asked BEIS if they can provide clarity on this question, and on the three following:

Q3.1-4: Significant errors in the oil statistics data presented in the UK government's publication: 'UK Energy in Brief'.

There are three questions here:

Q3.1-4(a): Why 'UK Energy in Brief', in its plots of 'Oil and gas production and reserves', plotted first 1P, then 3P, and finally 2P oil reserves?

Context

The generally excellent small annual UK Government publication '*UK Energy in Brief*', carries plots of 'Oil and gas production and reserves', showing the changes from 1980 to the current year. (The plot was earlier titled: 'Remaining oil and gas reserves'.) For a long time this plot showed cumulative production plus proved ('1P') reserves; later it showed cumulative production plus proved-plus-probable-plus possible ('3P') reserves; and most recently cumulative production plus proved-plus-probable ('2P') reserves.

Tentative answer

The tentative answer for why these different classes of reserves were used in the plot is simply that BEIS did not initially understand what categories of oil were included in these reserves, but slowly became more knowledgeable, moving finally to using 2P reserves (though with these being still only roughly half the volume indicated in the oil industry 2P reserves data, as discussed above).

Where to look for answers

Discussion with analysts who at the time supplied these data.

Q3.1-4(b): Why did the 'UK Energy in Brief', in its plots of 'Oil and gas production and reserves', explain the apparent 'replacement of reserves' as being largely due to the application of improved technology?

Context

More important than the change from 1P to 3P to 2P reserves in this plot mentioned above, was the wholly misleading narrative that accompanied it. By adding cumulative production to reserves the plot had consistently shown that the UK quantity of 'known oil' had apparently always steadily increased; from around 2500 Mt in 1980 to nearly 4500 Mt currently. This narrative was spelled out explicitly; for example the 2004 edition writing:

> *"In earlier years, estimates of remaining reserves in present discoveries stayed at broadly similar levels despite the large increase in oil and gas extracted. This was due to newfound discoveries and new technology allowing exploitation of discoveries being made and new technology allowing exploitation of discoveries that previously regarded as not viable."*

The problem here was that, as the oil-industry data show, by and large new discoveries were *not* very large, and improved technology *was not* what was allowing reserves to be replaced as fast as they were being produced; it was simply that reserves already-known to the oil industry were being successively included in the data shown in these plots.

This problem caused by this erroneous 'reserves are always getting replaced' view was significant. For example, a number of us from the University of Reading's *ad hoc* 'Oil Group' went to the DTI in perhaps 1997 to say that using the oil-industry backdated 2P oil discovery data we expected *global* oil resource-limited supply constraints to occur reasonably soon. To help make our case we pointed out that the causes for this coming global constraint were the same as would soon produce the UK oil production peak. But the DTI said in effect: 'Oh no, your analysis is quite wrong; we don't expect a UK oil peak anytime soon, because for years now oil reserves get replaced due to technology gain'.

Tentative answer

We do not have a tentative answer to this. But we do accept that the view of 'reserves are always being replaced' was widespread among nearly all energy analysts at the time (a false zeitgeist that in itself was a reaction to the earlier false zeitgeist that 'global oil would soon run out'). That the DTI (now BEIS) accepted this view, without looking deeper, is disappointing.

Where to look for answers

Discussion with analysts who at the time supplied, and commented on, these data.

Q3.1-4(c): Why does 'UK Energy in Brief' get the definition of EUR so wrong?

Context

Our third and final '*UK Energy in Brief*' error is in some ways perhaps the most serious, as well as most surprising; and in essence continues the 'reserves always get replaced' narrative.

Since perhaps about 2011, the plot of 'Oil and gas production and reserves' has been accompanied by a table showing evolution over time of the UK's 'Estimated Ultimate Recovery (EUR)', with an accompanying text (2016 version) as follows:

> *"The Estimated Ultimate Recovery (EUR) shows the cumulative total of production to the end of the years given*

> *and* [meaning 'plus'] *the total of proven plus probable reserves as estimated at the end of those years. For both oil and gas, EUR has grown substantially since 1980, increasing by 116% for oil and 93% for gas. This reflects increased new discoveries and the effect of new technology allowing exploitation of resources that were previously regarded as uncommercial. Total cumulative production of oil and gas are 87% and 70% respectively greater than the estimated EUR in 1980."*

The serious error here is that the EUR of a region at a given date is *not* defined as cumulative production plus the 2P reserves of fields found by that date, but as the estimated ultimate recovery from the region, *including anticipated future discoveries*.

What makes this *UK Energy in Brief* error so extraordinary is that the UK government's own 'Brown Books' (the main government publications on the UK's oil and gas) have been reporting sensible values for the UK's proper EUR since 1974, i.e., from even before offshore production had started - but after all the initial major offshore fields had been discovered.

The 1974 Brown Book oil EUR estimate was 4500 million tonnes. By 1977 more fields had been discovered, and the government now gave a range for the EUR, of between 3000 and 4500 Mt. Subsequently this EUR range widened, but the average stayed roughly in the 4000 to 5000 Mt range, and where the current value is not so very different from that estimated back in 1974.

Thus rather than being misled by apparent 'reserves replacement', and identification of technology gains as the cause, the most striking lesson from these proper UK 'Brown Book' EUR estimates is how accurate they have been, and hence how easy it has been to make a reasonable estimate for the date of the UK oil production peak. For example if the original 1974 estimate for the UK's ultimate of 4500 Mt is combined with the 'mid-point peaking' rule, then the UK's oil resource-limited peak would be expected when cumulative production reached ~2250 Mt. This was not in 1984, the first apparent peak, as by then cumulative production had reached only 730 Mt, but in 1997; and where the actual date of peak was 1999.

Tentative answer

We do not know why the '*UK Energy in Brief*' booklets have the calculation of EUR incorrect (and ignore the excellent EUR data long available in the 'Brown Books'); and as a result effectively perpetuate the 'reserves always get replaced' view.

We have recently learned that the group that puts together '*UK Energy in Brief*' gets its data and text on oil and gas from the UK's Oil and Gas Authority, an independent authority created April 2015 (and which became a 'government company' in October 2016). Since this 'EUR' error has existed since at least 2011, its origins must lie within DECC (BEIS' forerunner) or even earlier.

Where to look for the answer

We are currently in the process of getting help from BEIS to try and elicit an answer to this question from the OGA.

Q3.1-5: Why have OPEC proved oil reserves data been so extraordinarily poor?

Context

This is a very important question. But we will not write much about it here, as it is covered in detail in Laherrère *et al.* Part-2 (2017). Primarily the issues are:

- How much of the large 'step' increases in proved reserves reported for OPEC countries in the 1980s reflected justified corrections to their *proved* reserves, and how much were over-statements of these proved reserves?
- How much of these increases then correctly reflected these OPEC countries' *proved-plus-probable* ('2P') reserves, and how much were over-statements of even 2P reserves? (The concern here is that for the Middle East OPEC countries, their declared *1P* total reserves *exceed* the value held in industry databases for their *2P* reserves by some 300 Gb!)
- The same two questions refer to step increases in proved reserves that occurred for OPEC countries after the year 2000, most notably that for Venezuela.
- And finally, why for many OPEC countries have their declared proved reserves remained static, often for very long periods of time, despite relatively small quantities of new oil being discovered in these countries, and significant production having

taken place?

Tentative answers

Tentative answers are given in Laherrère *et al.* Part-2 (2016). The 1980s step changes are almost certainly to do with 'quota wars' jockeying for production after the oil price had fallen; the post-2000 increases due perhaps to similar manoeuvring; while the static data reflect in part reserves surveys to OPEC counties getting no reply, and hence previous-year proved reserves continuing to be reported. Campbell suspects that many of these countries are now simply reporting their *initial* 2P reserves (i.e., current estimates of the countries' 2P reserves before production started), and do not change their data for this reason.

Where to look for answers

Although the data are sensitive, there must be individuals who know the answers. Given the importance to global oil supply of having realistic estimates of OPEC reserves, it is hoped that in time such information will be forthcoming.

3.2 Oil supply - Current questions

Q3.2-1: Why, given their atrocious nature, are proved oil reserves still so widely relied upon?

Context

Many have fallen into the trap of thinking proved reserves give a reasonably valid estimate of the oil that has been discovered but not yet produced. Hubbert fell into this trap in a publication in 1938, as did Campbell in his '*Golden Century of Oil*' in 1991. But given the extensive amount that has been written on the issue, especially since the OPEC 'step-increases' of the 1980s, it is extraordinarily disappointing to see 'proved' oil reserves still being widely cited as reliable data, not only by journalists and academics, but even by senior people in major oil companies.

Tentative answer

That the accuracy of proved oil reserves data is not questioned more widely is probably due to the fact that they are quoted by apparently reputable sources, including the US' EIA, OPEC, the *Oil & Gas Journal*, *World Oil*, and BP in its *Statistical Review*. And the definition usually quoted, of being those quantities that *"with reasonable certainty can be recovered in future under existing economic and operating conditions"* sounds all too reassuring, such that still most analysts treat proved reserves as a reasonably accurate measure of the amount of oil likely to be available. It is long past time that this view is changed.

Where to look for answers

The simplest approach is to directly ask those that quote these data.

3.3 Oil supply - Questions about the future

Q3.3-1: How close is peak oil demand?

Context

As indicated in the Introduction under point (v), a relatively new question about future oil supply is whether a peak in global demand for oil will come earlier than significant constraints in its supply. The question is being raised by DNV GL as mentioned, but also by Shell, Citi Bank, Bloomberg Energy, the World Energy Council and a number of others.

We suspect that at least some of those proposing this 'peak oil demand' view do not know that the post-2005 high oil prices resulted from a global resource-limited oil supply peak that is already past, that of Regular Conventional oil; nor that global production of 'all-conventional' oil is on-plateau, and will probably soon decline.

Nevertheless, it is true that there is a wide range of developments, either underway or envisaged soon, that could indeed help move transport away from oil. These include:

- Road fuels that use biofuel as a mandated percentage of fossil fuel.
- Increasingly tight vehicle efficiency standards, leading to the use of more efficient internal combustion engines; with significant

engine efficiency increases still possible.

- Current and predicted moves to hybrid-electric and all-electric cars, and to a lesser extent, vans.
- Development of heavy goods road vehicles that use compressed or liquefied natural gas.
- Development of ships that use electricity (mainly, so far, ferries), or compressed or liquefied natural gas (including, in the latter case, the special case of LNG carriers).
- Aircraft approved for part or full biofuel use; small aircraft with electric propulsion; and a few demonstrator aircraft using compressed or liquefied hydrogen.
- Development of potential transport solutions (such as 'hyperloop') that potentially could have very low energy use per passenger- or kg-km.
- Other transport developments aimed at reduction of CO_2 emissions (including walking, cycling, ride-sharing, and 'home-work' rezoning).

The key question then being: Will these oil-saving developments be sufficient to reverse the continual growth in demand for liquids for transport that we have seen since about 1900, in turn driven by an ever-increasing global population, rising income levels, and the increased economic benefits that result from increased use of oil-powered transport?

Tentative answer

We just do not know. We know however that the IEA, which has long done excellent demand-side modelling, seems not convinced about at least a near-term peak in global oil demand. Though we have not done any detailed demand modelling ourselves, we are inclined to share this view.

Where to look for answers

The answers will come from:

Detailed examination of the models of those that predict a near- or medium-term global peak in oil demand, examining these for possible errors or oversimplifications. (Once Issue-12 of *The Oil*

Age is put to bed, we hope to carry out at least some investigations along these lines ourselves, at least for organisations geographically close to London.)

Modelling global oil demand for oneself.

This is not in principle a difficult exercise, requiring making reasonable assumptions on vehicle growth by category (cars, trucks, ships and planes) in countries like India, China and in Africa, and anticipated vehicle use changes in OECD countries; and offsetting these against data or assumptions on the various trends for moves away from oil-powered transport as listed above. An assumption will also be required on future oil demand for other uses of oil, primarily that for petrochemicals.

In the first instance probably an Excel model should be sufficient. Start with a simple model, but aim if possible to include calculations (often overlooked even in professional studies!) on the *extra quantities* of non-oil energy that will then be required (either directly, if for example biofuel or gas is the substitute fuel; or indirectly, if an energy carrier such as electricity or hydrogen is the alternative fuel); and paying attention to the availability of these alternatives, their EROI ratios, and their EROI rate-limit constraints.

Note that, at least for a student project, getting a correct answer is less important than demonstrating a reasonable methodology and set of assumptions.

4. Questions on Other Energies

(Note: For convenience, the questions in this category include minerals generally, in addition to ‘other energies’.)

4.1 Other energies - Questions about the past

Q4.1-1: Did the Roman Empire collapse because it ran out of energy?

Context

At least one author (though we forget who) suggested that at least a partial reason for the collapse of the Roman civilisation was the difficulty in accessing the energy required to sustain it; possibly in terms of not being able to distribute sufficient food to feed the slaves whose labour underpinned society.

The significance of course is, might a similar lack of accessible energy lead to the collapse of our current civilisation, as envisaged as a possible development path - in terms of total resources - in the still badly misunderstood '*Limits to Growth*' studies?; see Meadows *et al.* (1972 *et seq*.). In effect the question is: We know that many civilisations collapsed due to climate change (often those involving fragile large water or farming infrastructures, such as the Khmer), but have any civilisations collapsed due to lack of energy?

Where to look for answers

There are we understand a number of very good recent books on the collapse of civilisations, see Trainer, Diamond etc.; and see also Vaclav Smil's excellent wide-ranging book on energy and civilisation. But by-and-large - and reprehensibly! - we have not read these books, so do not know what light they shed on the question.

Tentative answer

We just don't know; probably someone does.

Q4.1-2: Has humankind ever run out of any mineral source?

Context

Some critics of the concept of peak oil say that humankind has never run out of any mineral resource, so it seems unlikely to them that this will apply to oil.

The first thing to say here, as explained in the Introduction, is that it has long been known that the world contains very large resources of all types of oils, and near-oils (such as kerogen); and even when these quantities are restricted to estimates of the remaining recoverable quantities, these are still very large indeed. 'Peak oil' is thus not about 'running out' of anything, but of getting to the point where production of the oil in question reaches a peak due to pragmatic constraints – geology, economic, energetic and technical - on the rate that this oil can be produced.

But having said this, it is still an interesting question as to whether humankind has ever run out of any mineral source.

Tentative answer

We do not know.

Where to look for answers

We judge that somewhere the literature is likely to say.

4.2 Other energies - Current questions

Q4.2-1: Does anyone have reliably accurate global data on recoverable quantities of coal?

Context

This is an important question, and may be one that needs answering fairly soon.

Wang *et al.* (2017) model global production of all fossil fuels, oil, gas and coal, both conventional and non-conventional, and find that in their 'best guess' scenario global production of all fossil fuels combined is likely to reach its resource-limited peak around 2025, at 570 EJ/yr. As they state: "*This date of peak is much earlier than many analysts suppose.*"

The reason for this surprisingly early date of peak lies primarily in the conservative values they assume for coal availability, given in terms of the coal URR's assumed for the coal-producing countries modelled. The authors discuss in their Section 5.2 (i) the uncertainty over these URRs for coal, and indicate how such uncertainty can be reduced. Moreover, they accept that:

> "… *it may become possible in future to access the world's significant quantities of thin and deep coal seams* … [where, if] *combined with carbon capture and storage, these may make scenarios of higher energy production from coal plausible.*

But, nevertheless, the paper points to a potentially serious concern over coal availability; an uncertainty that needs resolution by better data.

Tentative answer

The tentative answer is that some countries have good estimates of their economically and technically recoverable quantities of coal (and often split by hard and 'brown' coal), but a number of countries do not. It is these latter countries that need to bring in geologically-based, agreed, reporting standards for coal, to enable more solid assessments of global energy production to be made.

(We of course accept here that climate change considerations say 'keep the fossil fuels in the ground', but would respond by saying that part of the solution is adequately quantifying the problem. Moreover, given the coal dependence of some of the world's most populous, and at- or below-average per capita energy use, countries, it would be a brave person who would say that demand for coal in these countries is likely to fall significantly anytime soon.)

Where to look for answers

As far as we understand, and noting that coal is outside our expertise, we gather that the data required are not available, at least not in any consolidated form. The key countries in question will have to put in sufficient technical effort if the question is to be resolved.

Q4.2-2: Did the current programme of closure of UK coal mines consider CCS; or where the replacement energy will come from?

Context

The UK has recently been closing many of its coal-fired electricity plants, mainly we gather to meet EU pollution requirements. Such closures are both legally required, and laudatory in terms of the UK reaching its mandatory self-imposed CO_2 reduction targets.

But we do ask, if in requiring these closures, the companies in question, or the UK government as a whole, have adequately considered two related questions:

Whether, in terms of anticipated long-run cost of electricity, to supply that foregone by these coal plant closures was the alternative of keeping the plants open and using carbon capture and storage (CCS) adequately considered?

In making these closures, was adequate analysis carried out of where the foregone electricity will be sourced?

Tentative answer

We do not know the answers. We know that some UK energy experts have raised concerns about the thin safety margin that now, and in the future, may exist between UK electricity supply and demand; and know that the UK Government has brought in financial incentives to electricity companies (the 'capacity market') to address this risk. But our concern is that, in the absence of 'whole system' energy and economic modelling, and taking into account the 12 global energy concerns set out in the Introduction, perhaps inadequate analysis has been carried out.

Where to look for answers

We assume that available publications, the companies in question, or BEIS may be able to answer these two questions.

4.3 Other Energies - Questions about the Future

There are many such questions; we will return to these in a future issue.

5. Questions on Energy Modelling, and Energy-economics Linkages

5.1 Energy / economic modelling - Questions about the past

Again, there are a number of these questions, which we intend to return to another time.

5.2 Energy / economic modelling - Current questions

Q5.2-1: Is any energy/economic model properly yet accounting for the generally falling energy-return (EROI) ratios of most energies?

Context

See section (ix) of the Introduction for a statement of the problem.

Tentative answer

Our tentative answer is 'no'. As mentioned, Campbell's oil forecast model (2015) does include allowance for lower EROI ratios of some non-conventional oils; and we know that the IEA is at least aware of the issue. But in general we think no-one is properly modelling national or global energy where this includes accounting for current and expected EROI ratios of the various fuels modelled.

Where to look for answers

By examination of the energy forecasting models of organisations. Certainly as far as we know, most (or all?) models that foresee a large or total transition to renewable energies neither factor in EROI ratios, nor EROI rate-limits (see the next question).

Q5.2-2: Is any energy/economic model properly yet accounting for the energy-return (EROI) rate-limits of introducing new energy sources (or energy-saving technologies)?

Context

See section (x) of the Introduction for a statement of the problem.

Tentative answer, and where to look for answers

As in the question above, our tentative answer is 'no'; and likewise the answer can come by examination of current energy forecasts from the organisations that make such forecasts.

Q5.2-3: Do any of current economic models correctly solve the energy / economy nexus?

Context

See section (xi) of the Introduction for a statement of this problem. This is a much deeper question than the two above, and where possibly entirely new theory, and hence theory-testing also, may be required.

Tentative answer

A number of authorities have suggested various approaches aimed at addressing this issue; see the partial list, below. But to our very limited and inexpert knowledge we think there is no fully accepted new paradigm for this area.

Where to look for answers

Read the papers and books of proponents of approaches that deal with aspects of this issue (e.g., those of Slessor, Odum, Hawker, Lovins & Lovins, Kümmel, Ayers, Hall, Klitgaard, and almost certainly others); and then make your own judgements. And by all means develop a new 'physics plus economics plus common-sense' model, if one occurs to you; and check this against data, and also against simple simulation modelling, as far as possible. This topic would seem probably to be research at a PhD level, and if fully successful would indeed be important.

5.3 Energy / Economy modelling - Questions about the future

There are many of these questions, such as what is better to solve the global energy problems envisaged: free market, or government edict? But such issues are too big to cover here. We may raise some of these in future issues of *The Oil Age*, or on the website.

6. Some of the above questions might make useful student projects

We recognise that some of the questions listed above might make good student projects at various levels (undergraduate, masters, or part or all of a PhD). Unfortunately, we cannot guarantee that the research required would necessarily count as 'novel', as is often required for masters' projects, and, as far as we know, for all PhD projects. So, if originality of topic is a necessary requirement, the student (or their supervisor) may need to do some preliminary research to resolve this issue. Outside of this caveat, and where we have time and ability, we will gladly provide assistance to supervisors and students, if required, on the questions raised here.

7. We seek help in getting answers to these questions

We would be pleased to receive help in answering these questions. Answers known to you, or developed by you, can be communicated to the Administrator of The Petroleum Analysis Centre ('PAC'), Noreen Dalton, at: theoilage@gmail.com; or sent to either of us (for example, to r.w.bentley@reading.ac.uk); or to other founders of PAC, as listed on the website: www.petroleumanalysiscentre.org.

Over time we intend issuing updated versions of this list, to reflect new questions, and answers to questions that we or others have been able to answer (and of course in the latter case, giving due acknowledgment).

8. Conclusions

The questions above are raised as they seem to us important in understanding the current and prospective global energy situation. They relate to specific energy, and energy-economic, issues that we judge can help illuminate some of the energy problems that society will likely need to address in the near- and medium-term.

Some of the questions may make useful undergraduate or graduate student projects. We aim to include revisions to questions, answers where available, and new questions either in future issues of 'The Oil Age', or on the website: www.petroleumanalysiscentre.org.

Any help in answering these questions will be much appreciated.

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Hubbert took Nehring's "best estimate" for the ultimate from this range, of 2000 Gb, and matched global historical production up to 1974 to two possible production curves representing this volume. One was an unconstrained derivative logistic curve, which peaked at about 100 Mb/d in 1996. The second curve examined how long the recoverable resource base would last if production were held at the 1974 level. This showed that production could stay flat until about 2035, after which it would decline quite steeply, reaching near-zero by 2080. For more detail see Bentley (2016a) p148. [Note that Wikipedia (accessed 25 Oct. 2017) states: "*The Global 2000 Report to the President was … commissioned by President Jimmy Carter on May 23, 1977,* [and] *released … July 24, 1980*.]

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See also the sequels:

- Meadows, D. H., Meadows, D. L., & Randers, J. (1992). *Beyond the Limits*. Chelsea Green Publishing;

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