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Forum

The status of conventional world oil reserves—Hype or cause for concern?

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ABSTRACT

The status of world oil reserves is a contentious issue, polarised between advocates of peak oil who believe production will soon decline, and major oil companies that say there is enough oil to last for decades.

In reality, much of the disagreement can be resolved through clear definition of the grade, type, and reporting framework used to estimate oil reserve volumes. While there is certainly vast amounts of fossil fuel resources left in the ground, the volume of oil that can be commercially exploited at prices the global economy has become accustomed to is limited and will soon decline. The result is that oil may soon shift from a demand-led market to a supply constrained market.

The capacity to meet the services provided by future liquid fuel demand is contingent upon the rapid and immediate diversification of the liquid fuel mix, the transition to alternative energy carriers where appropriate, and demand side measures such as behavioural change and adaptation. The successful transition to a poly-fuel economy will also be judged on the adequate mitigation of environmental and social costs.

1. Introduction

Fossil fuels have been at the centre of growth and trade since industrialisation re-organised economies for the purpose of manufacturing goods (O'Sullivan and Sheffrin, 2003). In many applications, energy dense crude oil-derived fuels displaced coal and have long since dominated as a transport fuel. In recent years, however, concerns have grown over the environmental consequences of burning large volumes of oil, and whether reserves have the capacity to service growing demand (Alekkett, 2007; Campbell and Laherrere, 1998; Laherrére, 2009a; Robelius, 2007; Sperling and Gordon, 2007; USGAO, 2007).

Here we review the status of conventional crude oil reserves. As crude oil is a finite non-renewable resource, by definition it cannot continue to meet ongoing demand. Of particular interest is the point at which oil production becomes limited by the capacity of extraction technology, causing supply and demand curves to diverge. To determine when this may occur requires access to a number of contentious and inherently uncertain data sets.

Although it is not the intention of this report to discuss motivations for reserve misreporting, it is necessary to investigate ambiguities and sources of error that are broadly acknowledged but not taken into account in public data[1] due to the politically sensitive nature of reserve information.

It was found that the failure to report according to guidelines set out by the Society of Petroleum Engineers (SPE) and the World Petroleum Council (WPC) together with intentional false reporting, could go a long way to explaining the polarised views on the status of conventional oil reserves.

Evidence suggests that conventional oil production has a limited capacity to meet growing demand, and most additional demand will have to be met by unconventional sources (IEA, 2008). Unconventional resources are abundant and may meet supply deficits, although the capacity for substitution is also contingent upon the effective mitigation of environmental, social, and technical challenges associated with the production of

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Select terms and abbreviations: API, American petroleum institute gravity (141.5/specific gravity—131.5); BPSR, BP statistical review; Conventional oil, Oil that is less dense than water (above 10° API); Gb, giga barrel (one billion barrels); Giant oil field, contains 0.5 Gb of 2P conventional oil reserves; IEA, international energy outlook; Information agencies, organisations that republish data from reporting agencies (some times with small amendments); NGL, natural gas liquids, the liquid or liquefied hydrocarbons produced in the manufacture, purification and stabilisation of natural gas; OGJ, oil and gas journal; OPEC, organisation of the petroleum exporting countries; Reporting agencies, organisations that gather oil reserve data from producers; Reserves, commercially exploitable oil that is in-situ; Super-giant oil field, contains 5 Gb of 2P conventional oil reserves; Unconventional oil, oil that is below 10° API; Ultimate recoverable reserves (URR), The total volume of reserves expected to be recovered, past and present; WEO 2008, world energy outlook 2008; WO, world oil; 1P, 'proven reserves+P90'; 2P, 'proven+probable reserves'=P50; 3P, 'proven+probable+possible'=P10

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[1] Includes data presented in the BP Statistical Review (BPSR), Energy Information Administration (EIA), Oil and Gas Journal (OGJ), World Oil (WO), and the International Energy Agency (IEA).

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Table 1
'Proved[a]' world oil reserve estimates from select sources and information agencies.

	OGJ Jan 2009	WO Year end 2007	IEA WEO 2008	BPSR June 2009	Independent authors
Billion barrels (Gb)	1342[b]	1184[c]	1241	1258[d]	903

[a] In this case 'proved' is defined as 'reserves that can be recovered with reasonable certainty from known reservoirs under existing economic conditions' (EIA, 2009b). Correct reporting protocol also demands that 'proved' reserves must be defined by a stipulated probability of achieving estimated volumes, hence the term 'proved' in this table is somewhat obscure.

[b] Includes tar sands (172.7 Gb), crude oil, condensate.

[c] Includes tar sands (4.9 Gb), crude oil, gas condensate, and natural gas liquids.

[d] BPSR figure includes tar sands (22 Gb), crude oil, gas condensate, and natural gas liquids.

unconventional resources (Bergerson and Keith, 2006; NEBC, 2006).

2. Literature survey

A literature review reveals that opinion is divided over the volume and grade of oil remaining in reserves. Data available in the public domain originates from surveys conducted by the OGJ and WO magazine, and the OPEC Secretariat (Haider, 2000; Laherrére, 2009a). In general, these sources give more optimistic estimates compared to independent parties that assess reporting methodology. They do not question surveyed reserve estimates, and probably regard such queries as being outside their jurisdiction and politically sensitive; to question them could be interpreted as a diplomatically offensive. For example, data published by the OPEC secretariat has never been subject to independent audit (Simmons, 2007) and is widely considered inaccurate but is still included in public data (Bentley et al., 2007; Campbell and Laherrere, 1998; IEA, 2008; Leggett, 2005).

A second tier of reporting is carried out by information agencies (including IEA, EIA, and BP Statistical Review). In some cases, information agencies acknowledge sources of reporting error described by independent authors as a caveat to published figures. For example, the WEO 2008 stated 'the world is far from running out of oil; remaining oil and natural gas liquid proven reserves totaled 1200–1300 Gb by the end of 2007 (including about 200 Gb of Canadian oil sands) … though most of this increase has come from revisions made in the 1980s in OPEC countries rather than new discoveries' (IEA, 2008). In general, information agencies reproduce data referenced from reporting agencies, sometimes with small amendments that attempt to account for different oil grades.

Data on individual fields may also be purchased from scouting companies, such as the IHS. It is generally considered the most accurate by independent authors and academic institutions, and was relied upon by Robelius (2007) from Uppsala University to compile a database of giant oil fields to study production.

A literature survey of independent authors revealed consensus that reserve estimates published by reporting and information agencies are likely to be over-inflated. Publications by separate authors (Alekkett, 2007; Bakhtiari, 2004; de Almeida and Silva, 2009; IEA, 2008; Laherrére, 2009a; Robelius, 2007) were reviewed and showed that on average, conventional oil reserves should be revised downwards to 903 Gb, and production is expected to decline between 2010 and 2015[2]. A summary of published oil reserve estimates is given in Table 1.

3. Sources of ambiguity

Ambiguity in public data mostly arises from: (1) a lack of binding international standards to report oil reserve volume and grade (Alekkett, 2007; Bentley et al., 2007; Laherrére, 2009a; Robelius, 2007; Society of Petroleum Engineers (SPE), 2007); (2) the point at which resources may be classified as commercially exploitable reserves (Hirsch, 2005); (3) intentional mis-reporting to further a financial or political agenda (Alekkett, 2007; IEA, 2008; Laherrére, 2009a, 2009b; Robelius, 2007; USGAO, 2007); and (4) inherent technical assessment uncertainty (Laherrére, 2009a; Meng and Bentley, 2008; Mitchell, 2004).

The following section discusses the main flaws in reserve reporting. In doing so it defines conventional crude oil grade and best practice reporting methodology.

3.1. A question of cost: resources vs reserves

To address technical assessment uncertainty, the SPE and WPC has set out a best practice oil reserve assessment methodology framework. The framework uses a probability based system that classifies resources into prospective (undiscovered), contingent (sub-commercial), and reserves (commercial) categories (Society of Petroleum Engineers (SPE), 2007; SPEE et al., 2007). It is significant to note that 'reserves' are defined as volumes that are commercially exploitable irrespective of grade, and may include conventional or unconventional oils.

As oil prices rise and extraction technology improves, unconventional resources become reclassified as commercial reserves. This is commonly referred to as the price-reserve relationship (Hirsch, 2005). There is no consistency regarding when reclassification should occur, as evident by the range of estimates given for commercially exploitable Canadian tar sand volumes in the most recent reporting agency estimates that range from 4.9 Gb (WO) to 172.7 Gb (OGJ). These figures represent 20% and 660% of current annual global oil demand, respectively.

3.2. A question of chance: reserves vs production

The SPE and WPC further subdivide reserve estimates into categories that describe the probability of extracting an estimated volume. This system was developed to address inherent evaluation and production uncertainty, and considers three categories: 1P, 2P, and 3P (see selected terms and abbreviations). The number assigned to each category is the probability of successfully producing an estimated volume. For example, proven reserve estimates should be recognised with 90% certainty.

Assuming estimates are accurate, 1P reserves would be expected to be revised upwards over time and 3P reserves downwards to converge at the estimated 2P volume. For this reason, 2P reporting should represent actual reserve volumes most accurately (Bentley et al., 2007; Meng and Bentley, 2008; Mitchell, 2004). Confusion between 1P and 2P data sets is

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[2] Authors commonly gave URR estimates that were used to approximate reserves by subtracting 1128 Gb of cumulative oil production according to IEA (2008). Authors include Alekkett (2007); Bakhtiari (2004); Campbell and Laherrere (1998); de Almeida and Silva, 2009; Deffeyes, 2009; Laherrére (2009a); Leggett (2005); Robelius (2007); Skrebowski (2009).

widespread and has fuelled nearly every aspect of the oil reserves debate (Bentley et al., 2007). 1P estimates more closely represent oil that can be extracted using the infrastructure in place, rather than volumes of accessible oil in the ground. For this reason, 1P reporting has given the false illusion that reserves have been increasing when in reality estimates have just been converging at the 2P estimate as expected. The relevance of the '2P effect' on current reserve estimates is shown by using backdated 2P reserve data in Figs. 2 and 3. To add further complication, some countries report a mixture of 1P, 2P and 3P reserves and data presented in the public domain does not adequately explain discrepancies between reporting methodologies (Alekkett, 2007; EIA, 2009a; IEA, 2008; Laherrére, 2009a). Although information agencies qualify reserves as 'proven', such statements lack credibility without specifying the probability of attaining quoted production volumes (Graefe, 2009).

3.3. *A question of grade: conventional reserves vs unconventional resources*

Conventional oil reserves are the most accessible and least technically challenging to bring into production. In contrast, unconventional oils cease to flow at surface temperatures and pressures (Mommer, 2004) and are not readily recovered because production is capital intensive (Hirsch, 2005) and requires supplementary energy (Brecha, 2008). These factors also increase the carbon footprint of such resources.

To avoid grade ambiguity, conventional oil is defined as oil that is less dense than water (above 10°API) in accordance with Mommer (2004) and Laherrére (2009a, 2009b) who subtract extra-heavy oil from reserve calculations. This definition includes heavy oil (10–20°API), medium oil (20–30°API), light oil (above 30°API), and condensates (Robelius, 2007). Data from reporting agencies does not distinguish between oil grades according to density and commonly includes a range of 'conventional liquids' including extra heavy oil (0–10°API), tar sands, and natural gas liquids (NGLs).

3.4. *Intentional mis-reporting and withheld information*

Political and financial objectives are known to encourage reserve misreporting. The most well known example of this occurred in the 1980s during the OPEC 'fight for quotas'. The IEA now acknowledges that misreporting occurred because OPEC countries agreed to set export quotas in proportion to reserve volumes, which provided a strong incentive to inflate reported reserve figures to gain market share (IEA, 2008; Leggett, 2005). Most sources estimate such additions to have contributed between 287 Gb (Campbell and Laherrere, 1998) and 300 Gb (Salameh, 2004) to world oil reserve figures, which is not accounted for in public data.

3.5. *Caution: reserve–production ratio (R/P)*

Oil field production rates averaged over a large region follow an approximate bell-shaped curve, as first identified by Hubbert who accurately predicted US peak production in 1970 (Deffeyes, 2009), and has since been observed in a large number of post peak fields (Robelius, 2007). Production does not stay constant until resources are exhausted because geological constraints confer a characteristic extended tapering off period.

For this reason statements such as 'proved oil reserves are sufficient to match production levels for 42 years' (BP, 2009b) that were made at the June 2009 BP Statistical Review are misleading. With closer consideration it was found this figure was calculated by dividing reserve and production figures given in the same report (BP, 2009a)[3]. Reserve-production ratios are not sensitive to increasing demand and declining production rates. While the net amount produced over an extended period should reflect reserve estimates, engineers cannot access reserves on demand.

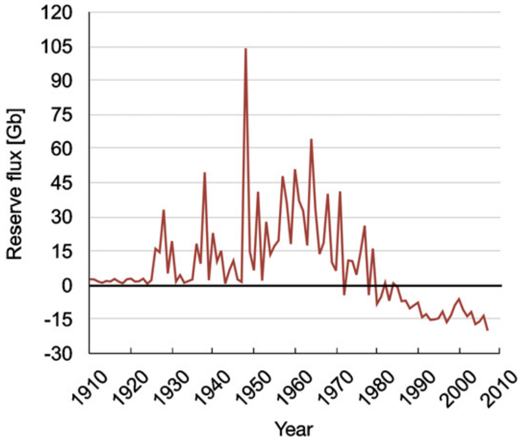

Fig. 1. World 2P conventional oil reserve flux: additional volumes discovered less volumes consumed. *Source*: Data provided by Laherrére (2009b).

3.6. *Caution: contradictory figures*

Data in the public domain consistently reports increases in annual reserves despite simultaneously reporting that consumption has exceeded additional discovery volumes of conventional oil. Such discrepancy in reporting is mostly due to the volatile price-reserve relationship described above, and reflects the addition of unconventional sub-commercial resources into reserve estimates. The WEO 2008 states 'in the last two decades, volume discovered has fallen well below volume produced' (IEA, 2008), indirectly acknowledging these inconsistencies.

Fig. 1 shows additional 2P conventional oil discoveries less demand, which gives the flux of oil into, or out of, the world conventional oil reserve inventory. Data below the zero flux axis indicates periods of net withdrawal from reserves. This first occurred in 1972 and has consistently occurred since 1980, indicating that conventional oil reserves have been in decline since then.

The turning point of conventional oil reserve status is also illustrated in Fig. 3, together with contrasting public data that shows reserves increasing. Since 2007, the volume produced exceeded volume discovered by a factor of three according to data provided (Laherrére, 2009b), which was used to construct Fig. 1. It should also be noted that the trend is for this relationship to widen.

4. Global oil reserves

Until now, the widening gulf between discoveries and production can be almost entirely attributed to reduced discovery rates as shown in Fig. 2. In the near future, however, this rift could be driven further apart by forecasted declines in production from the relatively few fields that support supply.

World oil reserves are unevenly distributed between 70,000 fields (IEA, 2008). In total 507 fields are classified as 'giant' and account for 60% of conventional oil production (Robelius, 2007).

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[3] The June 2009 BPSR stated global reserves (R) of 1258 Gb and production (P) of 29.7 Gb in 2008, giving an R/P value of 42 years.

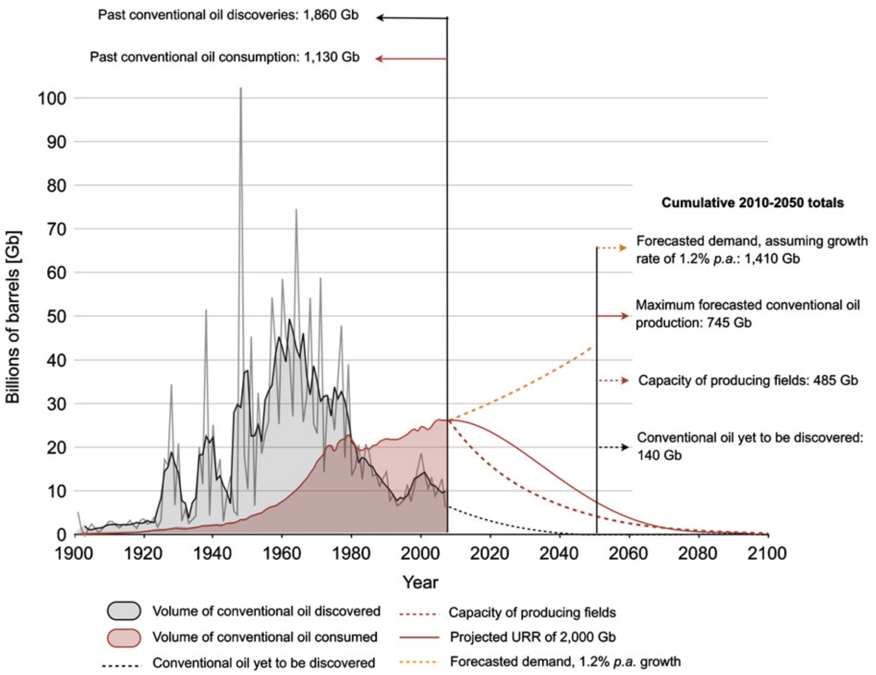

Fig. 2. Annual backdated 2P conventional oil discovery, conventional oil consumption, and forecasted production and discovery. *Sources*: (Campbell and Laherrere, 1998; EIA, 2009b; IEA, 2008; Laherrére, 2009b).

The top 110 producing fields constitute over 50% of global supply, the top 20 contribute 27%, and the most productive 10 fields contribute 20% (IEA, 2008).

Of the 507 giant oil fields, 430 are in production (Robelius, 2007) of which 261 are in decline (Höök et al., 2009a). In 2007, production from 16 of the top 20 producing fields was also in terminal decline (IEA, 2008). The average post-peak decline rate of giant fields is critical to determine future productivity, and has been estimated by several studies at 4.5% (CERA, 2008), 5.5% (Höök et al., 2009b), and 6.7% (IEA, 2008). This rate would result in a cumulative gap between BAU demand and declining production rates of approximately 925 Gb over the period 2010 to 2050. The average decline rate for all producing fields was extrapolated from Fig. 4 at 4.07% *p.a.*

According to the WEO 2008, the world's 20 most productive fields were discovered in 1959 (IEA, 2008), which suggests that the chance of finding fields of similar size is remote. Fig. 2 shows the peak of conventional oil discovery occurred in the early 1960s. 1948 was the most successful year for discoveries, with finds totaling 107 Gb including the Ghawar field (world's largest and most productive field ever discovered) in Saudi Arabia. Very few giant oil fields have been found since the early 1980s, and the last of the super-giants was found in the 1960s (Hirsch, 2005).

The following section will examine the status of conventional oil reserves through two independent methods. The first will review backdated 2P conventional oil data, and the second will amend public data to account for speculative and false additions.

4.1. *Review of corrected 2P discovery data*

The first approach uses corrected 2P conventional oil discovery data provided by Laherrére (2009b). Laherrére used the Hubbert linearisation methodology to forecast a URR of 2000 Gb, which is close to the average found in the literature survey of independent authors of 2030 Gb. This methodology is deemed accurate, though not completely without difficulties, in publications by Bently and Boyle (2008) and Robelius (2007).

The discovered volume of 2P conventional oil is given by the area under the 'world discoveries' line in Fig. 2 and totaled approximately 1860 Gb in 2007. If the assumed URR is 2000 Gb, conventional oil discoveries after 2007 should total approximately 140 Gb.

The forecasted production line was constructed using an equal area approximation with the discoveries curve in Fig. 2. Given that the total volume of conventional oil produced to date is approximately 1130 Gb (IEA, 2008) by deduction 870 Gb of conventional oil remains *in-situ*. As the volume produced exceeds half (55%) the URR, conventional oil production may have already plateaued, although the equal area curve may exhibit an asymmetrical profile allowing for higher production rates before a steeper decline.

4.2. *Published reserves less acknowledged error*

The second method approximates conventional oil reserves by amending public data to account for reporting inconsistencies acknowledged by the WEO 2008 and independent authors.

Fig. 3 gives a history of cumulative backdated 2P conventional reserve data together with data from the OGJ. OGJ data shows two distinct jumps in reserve estimates in the 1980s and again in 2004. The first reflects false additions during the OPEC fight-for-quotas years (which contributes 287–300 Gb) and the second shows the inclusion of tar sands into reserve estimates. The adjusted line accounts for these false and unconventional additions.

It is important to note that simply accounting for these large distortions in public data does not accommodate detail in reporting error. For example, convergence of 1P estimates to more correct 2P volumes over time explains why the adjusted line incorrectly shows reserves increasing. It does, however, validate present conventional 2P reserve estimations provided by Laherrére (2009a) and average reserve estimates from independent institutions. Table 2 gives amended reserve estimates for values presented in Table 1, which account for these false additions.

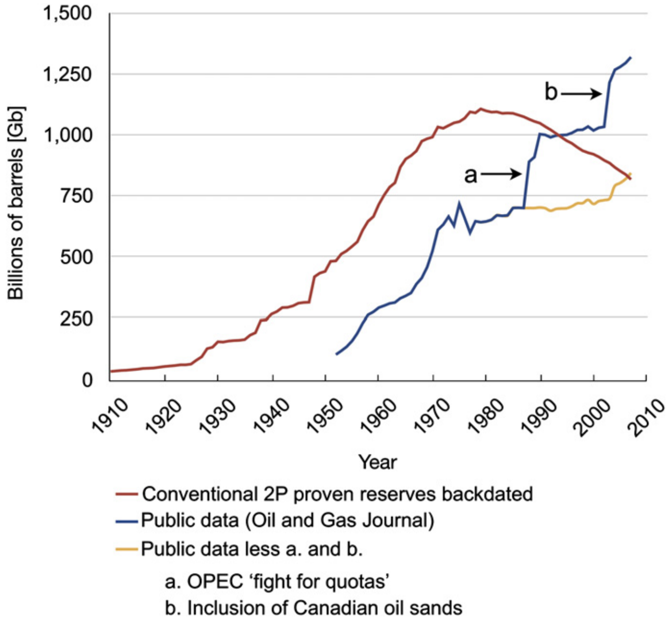

Fig. 3. World cumulative crude oil reserves: backdated 2P data, OGJ data, and amended OGJ data. *Sources*: Constructed from data provided by Laherrére (2009b).

The two methods presented independently show that 2P conventional world oil reserves should be revised downwards to between 850–900 Gb.

A third method that was developed by Campbell and Heapes (2008) considers oil depletion in the context of production, whereby avoiding the difficulties associated with estimating world URR. Although still subject to uncertainty, it estimates that the peak production of conventional oil passed in 2005, and that the peak of all liquids (excluding gas) will follow around 2010 (Campbell and Heapes, 2008). These results also support the evidence provided in this report.

4.3. *Liquid fuels demand and production forecast*

Having established that conventional oil reserves are probably less than previously thought, it is necessary to discuss what the future may hold for liquid fuels production. Fig. 4, published by the IEA, shows that the capacity to meet demand is contingent upon rapid and immediate diversification of the liquid fuels mix.

Total liquid fuel consumption in 2008 averaged 85.41 Mb/day (IEA, 2008), which is equivalent to 31.2 Gb over the year. Since 1985 consumption has grown at an average rate of 1.42% p.a (BAU) according to EIA figures (EIA, 2009c). At this rate, Fig. 4 shows that by 2030 the world will consume 42.5 Gb per year.

It is expected that almost all additional demand will come from China and India (IEA, 2008) and be met by non-conventional oil, enhanced oil recovery (EOR), and natural gas liquids. However, it remains unclear why the IEA expects near zero demand growth in industrialised countries, especially since previous IEA forecasts predict much higher demand growth.

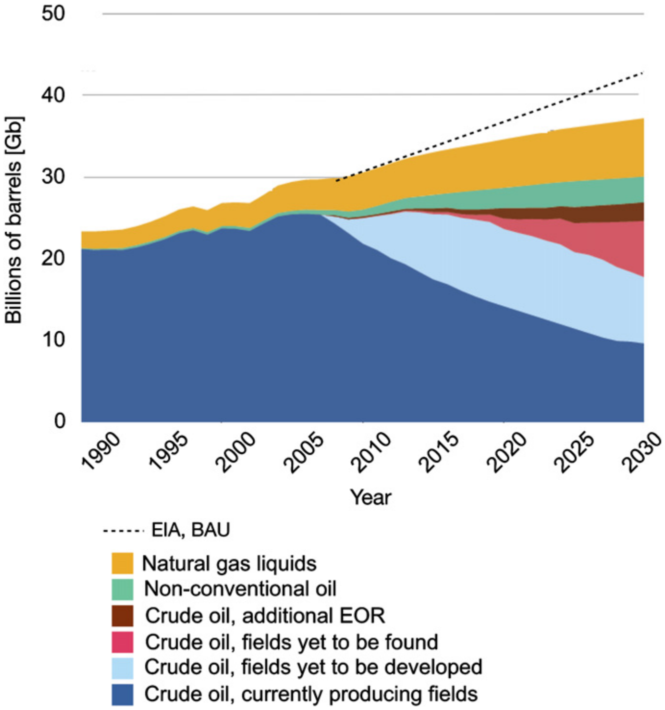

Fig. 4. Projected world liquid fuels demand and supply. *Sources*: IEA (2008).

According to Fig. 4, conventional oil production rates will maintain current capacity (not grow) until 2030, though it is critical to note this is dependent upon the development of known crude oil reserves, the discovery and development of new crude oil fields, and EOR. Conventional oil from producing fields currently constitutes approximately 85% of the global liquid fuel mix and is expected to decline at a rate of 4.07% per year after 2010.

At this rate, current sources of liquid fuel (crude oil from producing fields, non-conventional oil, natural gas liquids) will only have the capacity to service just over 50% of BAU demand by 2020. The implication is that the remaining 50% (approximately 18 Gb) will have to be met by sources that are not in production today.

5. Oil price and future resources

Restricted crude oil production will obviously affect crude oil price. Fig. 5 shows a history of the nominal crude oil price and price adjusted to 2009 dollars. Oil prices reached record highs in both measures in 2008.

Prominent price fluctuations in Fig. 5 are labeled. Past surges have been abrupt and commonly reflect a single event; either supply shortages from conflict or deliberate restrictions on production to inflate prices. The most recent price escalation that began in 2002, however, has been more gradual indicating a number of contributing factors. Although speculation in futures

Table 2
Amended conventional world oil reserve estimates that account for OPEC false additions and the inclusion of Canadian tar sands.

Liquids	OGJ Jan 2009 Crude oil, condensate	WO Year end 2007 Crude oil, condensate	BPSR June 2009 Conv. crude[a]	Independent authors Conv. crude	Independent authors Conv. crude
Billion barrels (Gb)	882	892	830	903	872

[a] This figure was further reduced by 12.5% to account for Natural Gas Liquids according to the WEO 2008.

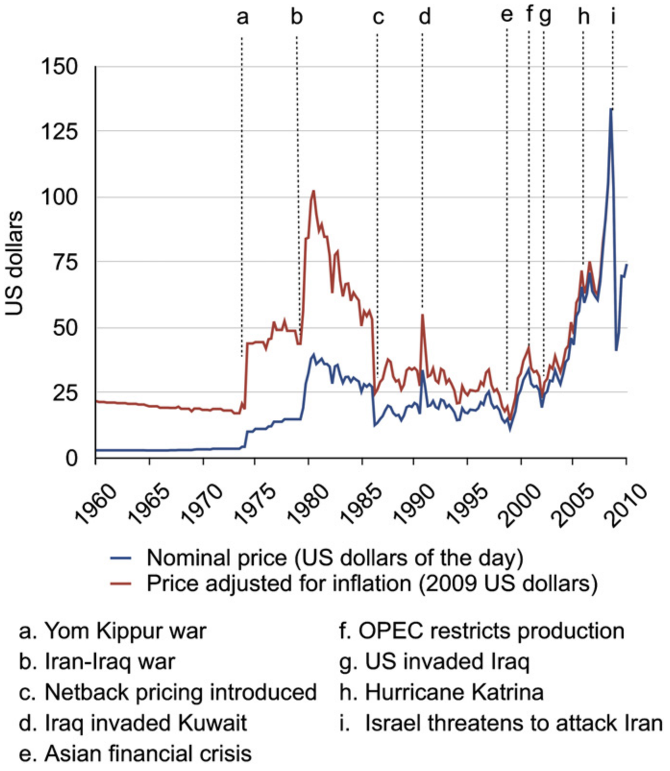

Fig. 5. A history of world oil prices. *Sources*: (BP, 2009a; Lopez-Bassols et al., 2007; Louis, 2009).

markets is likely to have played a significant part (Engdahl, 2008), the speculative bubble experienced recently is superimposed on an upward trend in oil prices due to fundamental demand and supply factors (Soros, 2008).

The WEO 2008 forecasts an oil price of US $200 per barrel by 2030, which is an increase of $135 on the WEO 2007 estimate of $65 per barrel. While such broad predictions give little confidence in quantitative forecasts, all qualitative indicators suggest there will be considerable price rises in the future.

Forecasted price rises are inevitable according to the law of diminishing returns. Although new extraction technologies may delay the period and severity of price increases, there is no escaping the problem of using up a limited non-renewable resources (Taylor, 2008). As prices rise, the business case for developing unconventional, lower grade, resources improves. This is the main reason why Canadian tar sand and deep-sea resources have come into production over the past decade.[4] Saving the best (conventional oil) until last works in opposition of the free market, and part of the reason why such resources have come into production is because the best reserves are in rapid decline. Therefore, pursuing oil for energy security is pursuing a policy of diminishing returns–except that the diminished returns are not just economic, but also affect the environmental and energy security pillars of a functioning energy market.

A second school of thought, based on the observation that oil is inextricably linked to global economic activity, should also be considered. It contends that a sustained oil price of greater than $100 per barrel could induce global recession (Rubin, 2009) driving oil prices downwards and paradoxically reducing investment in alternative fuels. The exact price threshold is difficult to estimate, however, as volatile oil prices cannot adequately be described by traditional linear and aggregate economic models (Jones et al., 2004). Rather a systems approach is required to quantify the asymmetrical effects of price fluctuations, with particular emphasis on the physical work it delivers (Ayres and Warr, 2005). Although rising oil prices are associated with a loss of economic growth, declining oil prices tend to have a disproportionally small effect on stimulating growth (Awerbuch and Sauter, 2005; Mork, 1989). Sources of asymmetry derive from inter-sectoral resource reallocation costs (e.g. retraining labour forces, sourcing interchangeable materials), demand composition (demand for durable goods, e.g., large automobiles), and the investment pause effect (e.g. households and firms that defer major investment in the face of uncertainty) (Jones et al., 2004).

The magnitude of a rise in oil price on GDP is described by oil price–GDP elasticity, which is defined as the percentage change in GDP divided by the percentage change in oil price. World average oil price–GDP elasticity is estimated at -0.055 (± 0.005) (Awerbuch and Sauter, 2005; Birol, 2004; Jones et al., 2004; Mork et al., 1994). This would mean a 10% rise in oil price would translate to 0.55% GDP loss. Considering that real oil prices are now stable at more than 300% of pre-2000 levels, and forecasted to rise further, absolute losses are significant. Additionally developing economies that rely heavily on imported oil that is often used in inefficient manufacturing processes are characterised by higher oil price–GDP elasticities (Birol, 2004), and will therefore suffer disproportionally more than developed countries from high oil prices.

It follows that effective and co-ordinated international policy mechanisms have to be devised with a tacit understanding of oil price–GDP elasticity in the context of an oil supply constrained economy. Such policies would recognize the business case of reducing consumption, and operate with a sense of urgency to introduce alternative energy carriers and effective demand side measures. Hesitation will risk high oil price induced negative macroeconomic consequences in the future, which will demand even more drastic policy measures to reduce oil-price GDP elasticity. The self regulating relationship between oil price and economic activity will have to be broken to promote investment in alternative fuels and demand side measures, which could complicate and extend the transition away from conventional fuels.

6. Key conclusions

This paper supports the contention held by many independent institutions that conventional oil production may soon go into decline (Alekkett, 2007; Campbell and Laherrere, 1998; IEA, 2008; Laherrére, 2009a; Robelius, 2007; Sperling and Gordon, 2007; USGAO, 2007) and it is likely that the 'era of plentiful, low cost petroleum is coming to an end' (Hirsch, 2005). Significant supply challenges in the near future are compounded against a backdrop of rising demand and strengthening environmental policy. Key conclusions include:

- The age of cheap liquid fuels is over. A condition of meeting additional demand is to develop unconventional resources, which translates to an increase in the price of petroleum products.
- Oil reserve data that is available in the public domain is often contradictory in nature and should be interpreted with caution.
- World oil reserve estimates are best described by 2P reporting. This means public reserve figures should be revised downwards from 1150–1350 Gb to 850–900 Gb.

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[4] At present tar sands require 1 GJ (in-situ extraction phase) +0.25 GJ (mining extraction phase) +0.01 GJ (electricity)+X GJ (site construction and operation, upstream products, material support) =1.26 GJ per barrel of synthetic oil produced, which contains 6.12 GJ (21%) (Bergerson and Keith, 2006).

- Supply and demand is likely to diverge between 2010 and 2015, unless demand falls in parallel with supply constrained induced recession.
- Reserves that provide liquid fuels today will only have the capacity to service just over half of BAU demand by 2023.
- The capacity to meet liquid fuel demand is contingent upon the rapid and immediate diversification of the liquid fuel mix, the transition to alternative energy carriers where appropriate, and demand side measures such as behavioural change and adaptation.
- The negative effect of oil price on the macro-economy is significant, and should be used to build the business case to invest in alternative energy carriers. Many alternative fuel carriers also present the double dividend of improving energy security (i.e. utilize local resources) and reducing emissions (i.e. electricity, hydrogen).

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