The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Article Review: Depletion and the Future Availability of Petroleum Resources

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In the last edition of the Energy Journal of the International Association of Energy Economists an article was published that concluded that the recent high oil price spike was just an aberration, as there is plenty of low cost oil out there waiting to be produced. This claim was made by a group of scientists from the Catholic University of Chili and Colorado School of mines, R. Aguilera, R. Eggert, C. Gustavo Lagos and J. Tilton. In this post I critically review this study showing that many important factors have not been taken into account by Aguilera et al. (2009), making it highly probable that their conclusion is incorrect.

Abstract of Aguilera et al. (2009)

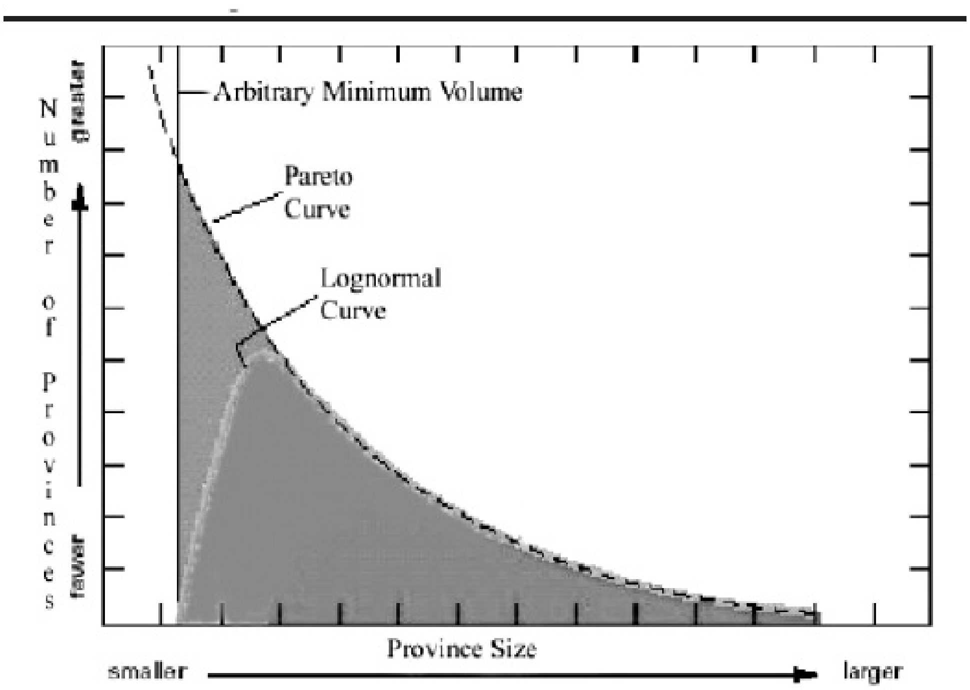
"This study assesses the threat that depletion poses to the availability of petroleum resources. It does so by estimating cumulative availability curves for conventional petroleum (oil, gas, and natural gas liquids) and for three unconventional sources of liquids (heavy oil, oil sands, and oil shale). The analysis extends the important study conducted by the U.S. Geological Survey (2000) on this topic by taking account of (1) conventional petroleum resources from provinces not assessed by the Survey or other organizations, (2) future reserve growth, (3) unconventional sources of liquids, and (4) production costs. The results indicate that large quantities of conventional and unconventional petroleum resources are available and can be produced at costs substantially below current market prices of around US$120 per barrel. These findings suggest that petroleum resources are likely to last far longer than many are now predicting and that depletion need not drive market prices above the relatively high levels prevailing over the past several years.(Aguilera et al. 2009, page 141)"

Expected oil discoveries in Aguilera et al. (2009)

In the year 2000 the United States Geological Survey conducted a study in which expected discoveries and reserve growth have been analyzed. In this study 102 out of the total 937 geological provinces on the planet were assessed. This selection was made on the basis of historic oil discoveries in these provinces or because it is likely that they contain oil. The conclusion made by USGS (2000) was that potentially 939 billion barrels of oil could be discovered between 1996 and 2025 and an estimated 730 billion barrels added to reserves through reserve growth. This study has been extensively discussed at The Oil Drum in four earlier posts of mine (1,2,3,4)

In Aguilera et al. (2009) a model has been made to estimate the oil yet to be discovered in the 835 geological provinces not assessed by the USGS (2000). This was done by looking at the relationship between the cumulative number of oil provinces and the volumes contained in these provinces. The rationale in this case is that the big oil provinces are found first and oil province size declines by time as exploration continues. The authors assume that many smaller oil provinces are out there and that they oil in these provinces can be produced at low costs, as explained later in this post. To calculate the size of these provinces a new distribution called variable form was used. This distribution lies in between the Pareto distribution and the Lognormal distribution of province size versus number of provinces which are both shown in figure 1 below.

Figure 1 - Pareto Distribution and Lognormal distribution of the size of oil provinces versus the number of provinces



The variable form distribution has been selected based on the following reasoning:

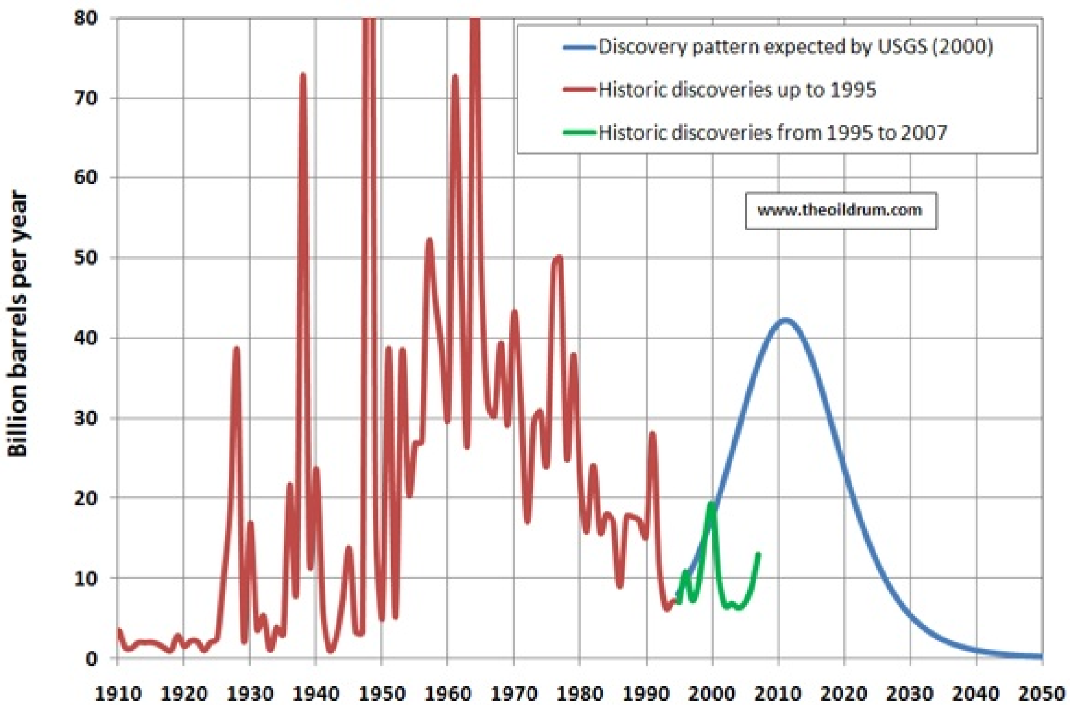
> "Previous size distribution models used to estimate the volumes of energy resources have assumed that the relationship between a given volume size and the number of areas that contain or exceed that volume follows either the log-normal or the Pareto distributions. The earliest efforts used the log-normal distribution (Kaufman, 1962). Subsequently, however, researchers at the USGS (Drew, 1997) observed that the lognormal distribution provides overly pessimistic results, and concluded that the Pareto distribution was superior. The difference between the two distributions can be seen in Figure 7, where they are shown as density distributions. While it is now generally acknowledged that the lognormal distribution underestimates petroleum resources, for various reasons the Pareto distribution may overestimate them. Historically, all the methods used to forecast petroleum volumes have been "based on an assumed form of the size-frequency distribution of the natural population of oil and gas accumulations" (Barton, 1995). The Variable Shape Distribution (VSD) model is different in that it allows the data to determine the size distribution relationship rather than specifying this relationship ex ante (Aguilera et al. 2009, pp. 161)."

The methodology employed, which led to an estimated 593 billion barrels to be found in the 835 provinces not assessed by the USGS, is explained as follows:

> "Specifically, we start by observing the curvature given by the USGS (2000) data points on a log-log plot. We then estimate the VSD model whose predicted values for the relationship between size and number of petroleum provinces mostly closely match the actual data. As with all size distribution models, the original sample used to estimate the parameters contains most of the largest and promising data. This allows one to estimate the slope and intercepts, on log-log coordinates, of the straight line given by the largest data (these parameters remain constant during the forecasting stage). The previously unassessed data will then generally contain smaller volumes than the assessed (Aguilera et al. 2009, p.162)."

The first assumption made by Aguilera et al. (2009) is the decision to take the USGS (2000) estimate at face value, by using it as input for the calculation of future discoveries in the 835 geological provinces. That is, they assume that the 939 billion barrels for potential oil discoveries between 1996 and 2025 in the 102 geological provinces is correct. In my opinion, USGS (2000) discovery estimates are too optimistic as it would imply a radical change from the 4 decades of declining discovery cycles since the 1960s, shown in figure 2 below.

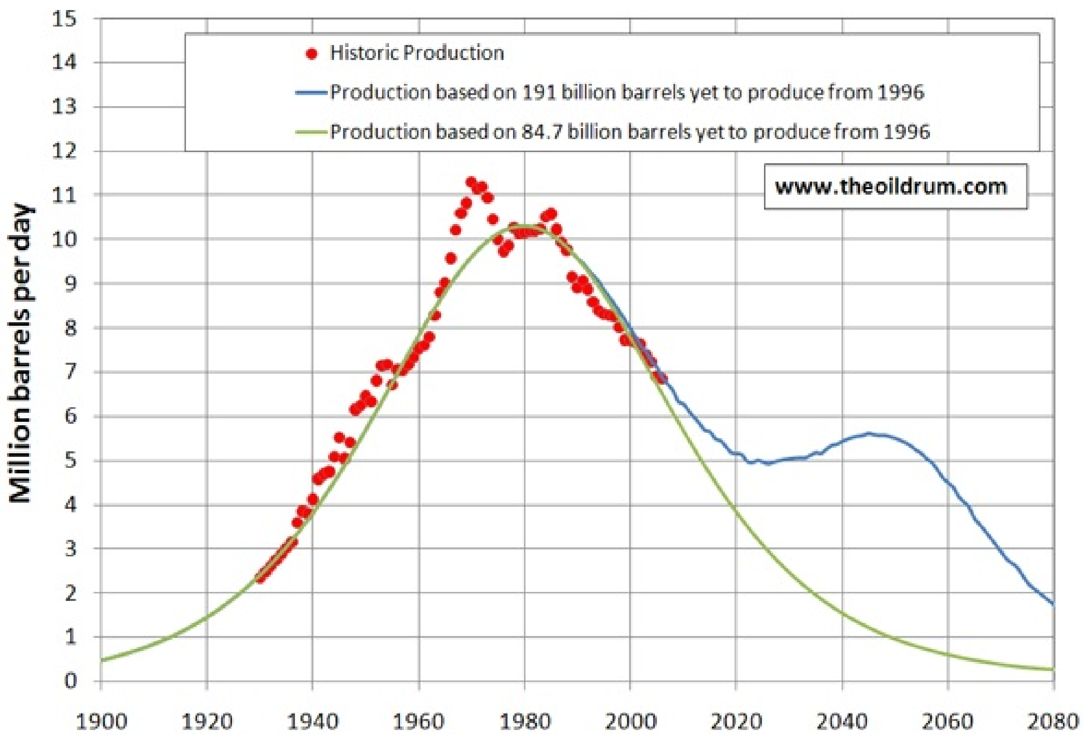
Figure 2 - Historic discovery data from IHS Energy up to 1995 in red and from 1996 to 2007 in green. In blue expected discoveries of 939 billion barrels from USGS (2000), shown by means of a Hubbert curved discovery pattern.



An example of the production implications of the discovery estimate by USGS (2000) is made here for the United States. According to the USGS (2000), a total potential of 83 billion barrels of conventional oil plus natural gas liquids could be found between 1996 and 2025 in the US. In addition it was expected that technological innovation could lead to reserve growth of 76 billion barrels. If this is add up to US reserves of 32 billion barrels at the time, a number taken from the IHS Energy (formerly Petroconsultants) raw input data used in the USGS 2000 study, this would yield a total of 191 billion yet to be produced from 1 January 1996. Based on this number a production scenario has been constructed shown in blue in figure 3 below. The scenario implies that US oil production, which has been declining since the 1970s, will stabilize around 2020 and slightly increase from there on until 2045 after which a new phase of decline sets in.

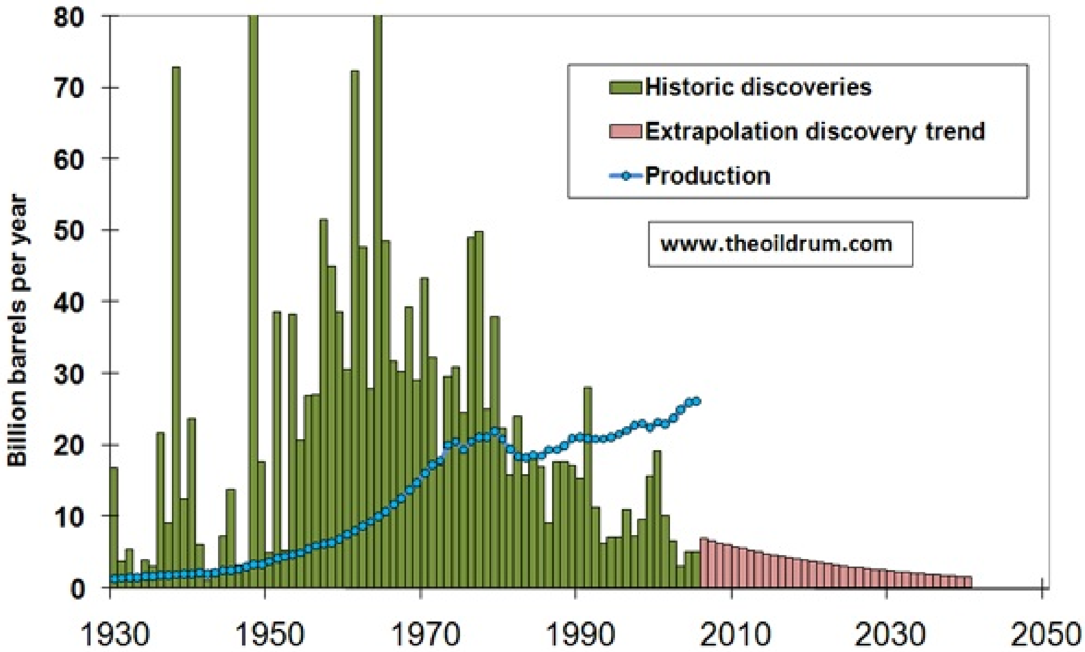
Next to the USGS (2000) figures I have prepared a Hubbert Linearisation analysis based on production data from 1974 to 1996. This yields an estimated yet to be produced amount from 1 January 1996 of 84.7 billion barrels. Based on this number I have made a Hubbert based production scenario shown in figure 3 as the green curve. If one compares these scenarios, I think it is much more probable that the production decline in the US will continue as per the green curve, since the US is one of the most mature oil regions in the world, with respect to both exploration and production.

Figure 3 - Historic oil production in the US in red dots, a production scenario in green based on Hubbert Linearisation based on US production data from 1974 to 1996 resulting in 84.7 billion barrels remaining to be produced from 1996, and a production scenario based on the estimated 191 billion barrels yet to be produced as of 1 January 1996 according to USGS (2000).



Instead of taking the USGS (2000) assumption for oil discovery, it would be better to assume that the historic discovery pattern will continue as most of the big fields have already been found, and only some smaller cats are remaining. If we extrapolate the declining discovery trend and calculate the future amount, this results in another 250 billion barrels yet to be discovered in the future. This estimate is shown in figure 4 along side the historic data.

Figure 4 - Extrapolation of the historic oil discovery pattern. Historic data from IHS Energy shown in green and extrapolation shown in pink. Chart adapted from Colin Campbell of ASPO Ireland.



The second assumption made by Aguilera et al. (2009) is that the estimated volumes in the remaining provinces will be producible. This view can be contested as these areas lie in remote regions and the expected fields will on average be quite small. The costs of producing these oil fields is hence not favorable and perhaps prohibitive.

Expected reserve growth in Aguilera et al. (2009)
This issue will only be covered here briefly. For a more detailed coverage on reserve growth I refer to my earlier posts on this topic (1,2,3).

Aguilera et al. (2009) attempted to estimate reserve growth based on the percentage increase of reserve growth between 1996 and 2025 as estimated by USGS (2000). This was calculated by taking the USGS estimate of reserve growth and dividing it by the sum of historic production and reserves as per 1 January 1996. This percentage, 42.97%, was taken and multiplied by: 1) the historic discovery data of 939 billion barrels of yet to be discovered in the 102 geological provinces asessed, 2) The 939 billion barrels of remaining world reserves as per 1 January 1996 from the USGS (2000), 3) the estimated 593 billion to be found in the 835 geological provinces assessed in Aguilera et al. (2009). By doing this procedure, a total number for future reserve growth of 1070 billion barrels was estimated.

Again, similar to the discovery estimate, the assumption was made that that USGS (2000) had made a good estimate of reserve growth, which could be taken at face value. The issue of reserve growth is so complicated, however, and the errors in making these estimates so large, that the USGS estimate cannot be relied upon. I have outlined many of the problems in my earlier posts (1,2,3). Besides the general problems of estimating reserve growth, Aguilera et al. (2009) have made a wrong assumption in thinking that the USGS (2000) did not incorporate a reserve growth function in their estimate for potential discoveries in the 102 geological provinces. The USGS (2000) states:

> "Growth functions were applied for two different types of analyses (1) to aid in estimating grown sizes of undiscovered fields and (2) to determine the contribution of reserve growth of existing fields to world resources (USGS 2000, DS-8)."

Hence Aguilera et al. (2009) double count reserve growth of the 939 billion barrels discovery estimate made by the USGS (2000) in making this assumption.

Calculating economic costs of producing the technical recoverable estimate for conventional oil

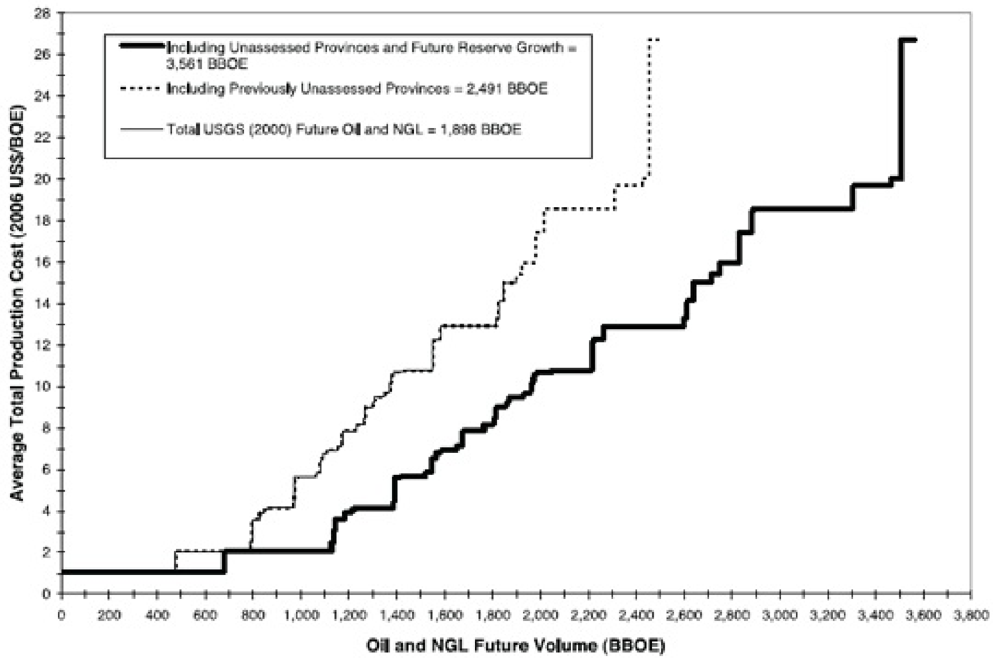
After estimating a total of 1532 (939 + 539) billion barrels as yet to be discovered oil and 1070 billion barrels for reserve growth, as per 1 January 1996, Aguilera et al. (2009) proceed to estimate the costs of production. Total costs were estimated based on historical capital costs and operating costs from one to a couple of years for as many geological provinces as possible. Data came from a dozen sources including Bloomberg, Center for Global Energy Studies, and Goldman Sachs. These figures have been averaged by province over the number of produced barrels in case of operating costs and over the total amount recoverable in the case of investment costs. As a unit of analysis the inflation corrected value of a dollar in 2006 was taken. The calculation thus uses a static view of costs of one to a number of years which is extrapolated into the future, assuming that no fundamental cost increases or reductions will take place. "Our estimates of production costs are static, and therefore do not take into account the tendency of technological advancement and other factors to reduce costs over time. Nor do they take account of cost increases (Aguilera et al. 2009, p.150-151)."

To estimate the production costs of oil in the 835 geological provinces for which no data is available, as no oil has been found in these regions so far, Aguilera et al. (2009) have used a formula in which the production costs are estimated based on the costs in the region in which these provinces lie such as Europe, Middle-East, and North Africa. However, a further assumption was needed as the yet to be found estimate by Aguilera et al. (2009) only yields the aggregate over the 835 provinces, and not the regional distribution. Therefore it was assumed that the yet to be discovered number of 539 billion barrels, plus the 254.8 billion barrels of estimated reserve growth in these provinces, will be similarly distributed over Europe, Middle East and so forth as the percentual distribution of the known amount of oil in these regions. "While the model provides future volumes for all 937 provinces, it does not indicate which volumes correspond to which provinces. As Table 4 shows, we have allocated the future volumes from previously unassessed USGS provinces, for both oil and NGL and for gas, among the eight regions of the world on the basis of each region's share of the future volumes in the assessed provinces. This is consistent with the idea that regions with high amounts of future volumes in previously assessed provinces will have unassessed provinces with generally proportional amounts of future volumes (Aguilera et al. 2009, p. 148-149)." After this calculation, production costs have been calculated by taking the highest costs in the region and multiplying this figure by 1 plus the total expected amount of yet to be found crude oil from Aguilera et al. (2009) divided by the estimated number of oil in this region by the USGS (2000).

The rationale here is that the average production costs in the areas estimated by Aguilera et al. (2009) will be higher than in the already known areas, as high quality crude oil with low production costs will be produced first and lower quality oil later. "This procedure presumes that within a region the average production costs for all the unassessed provinces are higher than those for all the assessed provinces including the assessed province with the highest costs. This is consistent with the notion that the highest quality, least costly resources are usually extracted first. The procedure also presumes that the difference between the production costs for the unassessed provinces and the highest cost assessed province increases as the volumes for unassessed provinces rise relative to assessed provinces (Aguilera et al. 2009, p. 167)" These assumptions are logical but it is not clear on what basis the multiplication factor has been chosen. It appears to me when reading the text by Aguilera et al. (2009) that there is no empirical basis whatsoever in selecting the chosen multiplication factor.

The calculation of Aguilera et al. (2009) leads to an average production cost below 20 dollars per barrel for the vast majority of estimated technically recoverable conventional crude oil, as shown in figure 5 below.

Figure 3. Global Cumulative Long Run Availability Curves for Conventional Oil and NGL



The employed methodology solely rests on the assumption that one or a few static points of production costs from the past can be extrapolated to the entire future. The shortcoming lies in the few data points used as well as the assumption of static costs. Costs are likely to change permanently in the future, as cost decreases due to technological innovation have largely played out, and cost increases are going to play a bigger role, because of declining quality of the remaining oil, more remote and politically difficult locations of extraction, and smaller and smaller fields in these locations. Furthermore, it is implausible to expect that cost premiums in areas such as Nigeria and Iraq will dissapear in the near to mid term future as stabilization of these regions are unlikely. The method employed by Aguilera et al. (2009) is hence limited in its scope and does not provide reliable estimates for future production costs.

Also the input figures as used in Aguilera et al. (2009) are not comparable to other sources. The International Energy Agency (IEA) in the World Energy Outlook 2008 incorporated a study of the production costs in the oil industry, obtained through a survey of oil companies. The average production cost for the world for the years 2003 to 2005 was found to be 12 dollars per barrel in 2006 dollars, and 16 dollars per barrel on average between 2004 and 2006. The average cost in Aguilera et al. (2009) worldwide is estimated to be 6 dollars per barrel in 2006 inflation adjusted dollars. The reason for the difference is perhaps found in the methodology used to calculate costs in areas for which no data was available. The authors have for instance derived average production costs in the US of 10.77 dollars per barrel. The offshore production costs in the US, according to the IEA, are much higher at 45 dollars per barrel, an estimate similar to that of the US department of Energy.

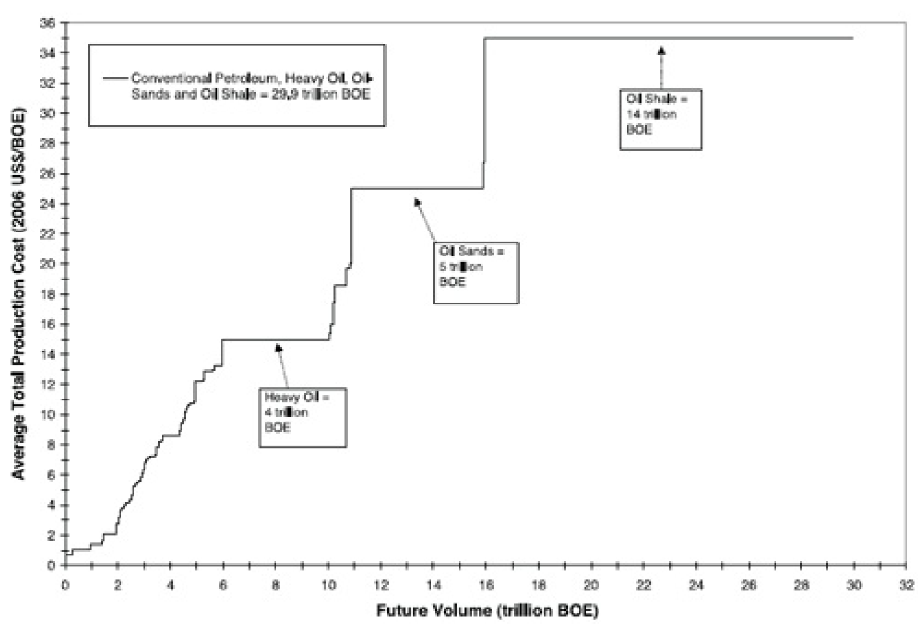
Estimates for unconventional oil production by Aguilera et al. (2009)

As a last step, an estimate of the total number and production costs of unconventional oil was made, including tar sands, extra heavy oil, and oil shale. A direct comparison was made between conventional and unconventional oil by Aguilera et al. (2009) which leads to comparing apples with pears as the production mechanism for both oil types differs considerably. Unconventional oil is of much lower quality and the production procedure to a large extent resembles mining. A large number of inputs are needed to produce unconventional crude in the form of energy and water which is an important limiting factor to production, not taken into account by Aguilera et al. (2009). Production speed of unconventional oil is much lower as well. In Bengt et al. (2007) it was estimated that the production of tar sands in Canada will be at its maximum around 5 to 6 million barrels per day, as the required amount of natural gas for production can no longer be supplied.

Not incorporating limits to the inputs needed for producing unconventional oil leads to incorrect results. The error introduced will be especially large if an aggregation of estimated numbers of unconventional crude oil on a very broad basis is made, as done by Aguilera et al. (2009). Costs for unconventional oil will not remain stable as assumed by Aguilera et al. (2009) but rise quickly in the mid term future as the limits to required inputs permanently are reached--a situation which could already occur within 10 to 15 years in case of the Canadian tar sands.

Although the limits to the employed methodology for unconventional oil is recognized by Aguilera et al. (2009), they have still chosen to ignore these limits which resulted in the graph shown in figure 6. "In addition, the life expectancies shown in Table 6 implicitly assume that the future volumes for an energy resource represent the fixed stock of that resource available over all time to society. Particularly for heavy oil, oil sands, and oil shale, this is unlikely to be the case. As Tilton (2002) has argued, the fixed stock paradigm for assessing the future availability of resources can be misleading (Aguilera et al. 2009, p. 158)."

Figure 6. Global Cumulative Long Run Availability Curve for Conventional Petroleum and Unconventional Sources of Liquids Including Heavy Oil, Oil Sands and Oil Shale



Conclusions

The conclusion by Aguilera et al. (2009), 'that large quantities of conventional and unconventional petroleum resources are available and can be produced at costs substantially below current market prices of around US$120 per barrel', is not valid for the following five reasons:

1) The data from USGS (2000) of the yet to be found estimate in 102 geological provinces has been used to estimate the future potential in 835 geological provinces which were not assessed in USGS (2000), resulting in an additional 539 billion barrels of expected discoveries by Aguilera et al. (2009) in addition to the 939 billion barrels estimated by the USGS (2000). The original USGS

(2000) is too optimistic as it implies that the declining discovery curve which has been declining since the 1960s will turn around. This methodology produces an estimate of 539 billion barrels, which is also too optimistic.

2) Aguilera et al. (2009) have double counted reserve growth because they made the incorrect assumption that the USGS (2000) did not apply a reserve growth function for the estimate of yet to be discovered fields.

3) A large number of factors that limit production have not been incorporated, including the availability of water and natural gas which play a large role in the production of unconventional crude oil.

4) A direct comparison between the production of conventional and unconventional oil has been made while production mechanisms for these types of oil differ significantly, leading to a comparison between apples and pears.

5) It is incorrect to take historic production costs from a single to a set of years in a given oil province and extrapolate them into the future to obtain future costs. Costs are likely to change permanently in the future as cost decreases due to technological innovation have largely played out, and cost increases are expected to play a bigger role. These changes are expected because of declining quality of the remaining oil, more remote and politically difficult locations of extraction, and smaller and smaller fields in these locations.

References

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