Information concerning oil extrapolation curves

Abstract:

This paper describes background information, approach and detailed methodology used by The Shift Project in the elaboration of an extrapolation tool for conventional oil production scenarios. The tool (so called "module") is conceived to provide a pedagogical insight on stocks and flows analysis associated to oil production issues. Global oil production is composed of different types of liquids. The scope here is to focus on conventional oil which is only a part of the total oil production. After a presentation of the module and its main purposes, the paper focuses on the sources and scenarios used in the tool. A long and precise presentation of the calculation of the extrapolation curves is proposed, with some words concerning the URR range.

Note: *This document is a "work in progress paper". It is subject to changes and improvements. As The Shift Project intends to be fully transparent on its work, we hope this document contains all the relevant information explained in an understandable way.*

Foreword:

The author clearly wants to highlight that this module is intended to deliver a **pedagogical analysis** of oil production forecasts. **The main objective is to let the user play with the curves, compare and discuss them, and use the graph to support and illustrate ideas or studies.**

This module definitely does not claim to predict precisely future oil production. It is rather intended to make the user understand what is implied with the different oil production scenarios published by international organizations, in terms of constitency with conventional oil resources published. Moreover, the author did not intend to display in details the different scenarios taken from the sources quoted in the following sections.

The author wants to clarify that:

- All the scenarios have been initialized at 80 Mb/d in 2008 to have a proper continuity with the curves displaying: **this value is not the value given by the scenarios**.
- Scenarios have been interpolated between values given for different years.
- The URR range is wide and exhaustive on purpose. Then, the user is able to design whatever future oil production he wishes.
- The extrapolation curves proposed have been designed to give an idea of what could be the future oil production. They do not come from a detailed study of oil production forecasts, but meet the main specification to display the right URR selected.

I. Story:

Predict oil production future on your own

This section presents a graphic module for oil production until 2250. From the script you can select the type of extrapolation and the Ultimate Recoverable Resources (URR) you want to assign. URR is considered to be the sum in Gb of (UKERC, 2009):

- The current cumulative conventional oil production
- The remaining 2P reserves, i.e. the proven and probable reserves
- The reserve growth, corresponding to the extra oil produced by fields that were supposed to produce less
- The undiscovered resources, the quantity estimated to be contained within accumulations yet to be discovered.

For time scales associated to human being, oil stock can be considered as given, it is a physical limit, oil is available in a finite quantity. The proposed tool has indeed a special feature, i.e. it respects the Ultimate Recoverable Resources (URR) selected by the user. Therefore the URR are visible directly on the graph since they represent the area under a given curve. Through this module, the user is able to see and find out through different ways what is implied by a given oil production scenario. This might reveal some inconsistencies in these scenarios which trends can be designed with little consideration of the resources' limitations.

This module is composed of three modes to enable different analysis:

- The Source and Scenario mode, where you can compare scenarios in the long term perspectives
- The Extrapolation mode, where you can plot different type of extrapolation curves for a given scenario and given URR
- The URR mode, where you can select different URR to compare the future physical limits implied by a given scenario.

How to play with this module

1 – Select a scenario to prolong historical data until 2030 (OPEC, Uppsala) or 2035 (IEA and EIA)

2 – Choose the way to extrapolate the scenario until 2250

3 – Assign a URR (Ultimate Recoverable Resources)

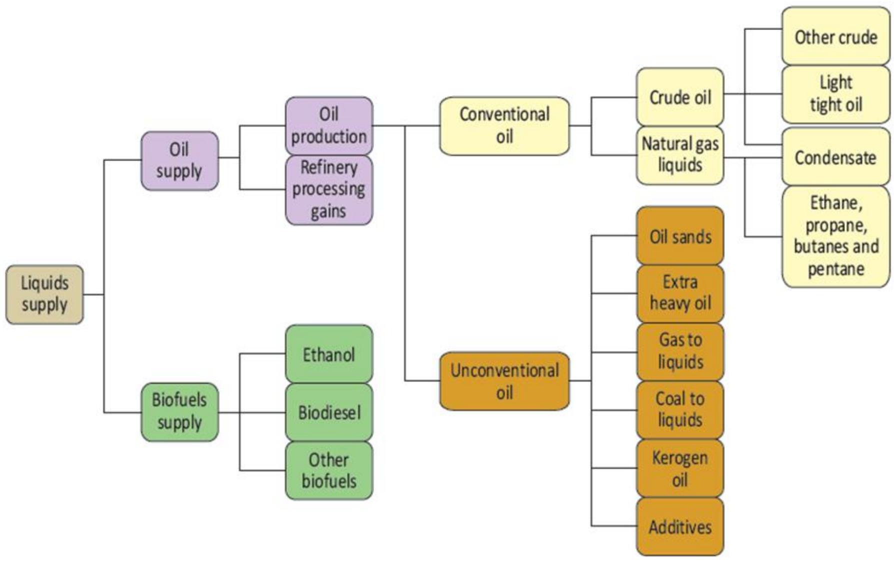
4 – Interpret the graph you built.

Conventional and Unconventional Oil

This module takes into account only conventional oil in terms of curves design and proposed URR. When it comes to conventional oil, we do consider the following assumption:

Conventional Oil = Crude Oil + Natural Gas Liquid

In addition to that, we consider Processing Gains which values are included in the oil production scenarios or sometimes given apart.



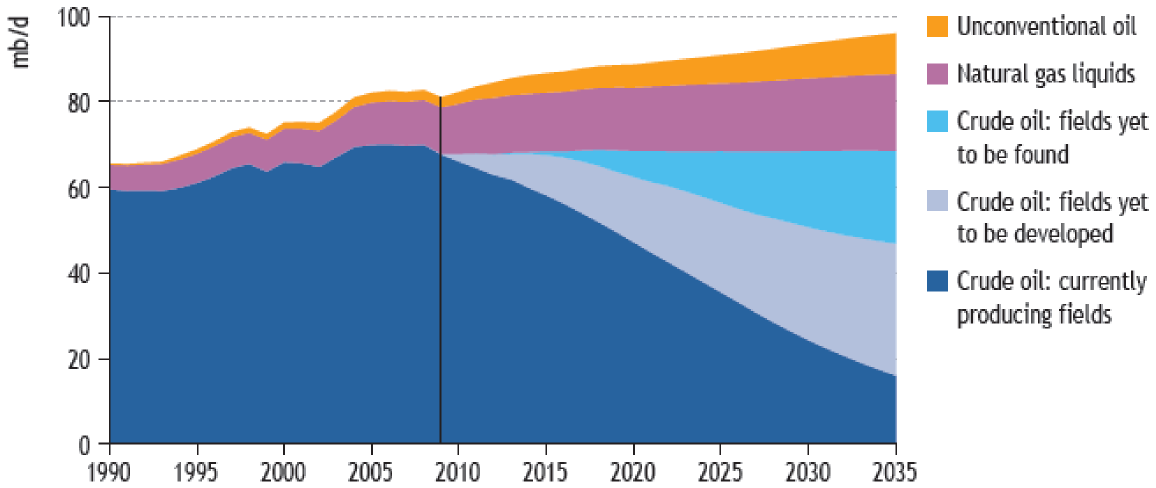
Liquid Fuel Schematic, (IEA, World Energy Outlook, 2011)

Unconventional oil is not considered in this module as the resource base associated is much more difficult to define. In the *World Energy Outlook 2010* from IEA unconventional oil is defined as hydrocarbons requiring *"production technologies significantly different from those used in the mainstream reservoirs exploited today".* The graph above clearly identifies the different categories when it comes to liquid fuels. Therefore, unconventional oil currently gathers the following categories of oil:

"

- *Bitumen and extra-heavy oil from Canadian oil sands.*
- *Extra-heavy oil from the Venezuelan Orinoco belt.*
- *Oil obtained from kerogen contained in oil shales.*
- *Oil obtained from coal through coal-to-liquids technologies.*
- *Oil obtained from natural gas through gas-to-liquids technologies, as well as refinery additives and gasoline blending additives originating primarily from gas or coal, such as methyl tertiary butyl ether (MTBE), or methanol for blending. "*

(IEA, World Energy Outlook, 2010)



World oil production by type in the New Policies Scenario (IEA, World Energy Outlook, 2010)

This figure published in the *World Energy Outlook 2010* by IEA shows that the case of unconventional oil is different from the one of conventional oil (all the other categories) since production perspectives could be much more optimistic.

II. The method

Basically what we did is clear and simple. We collected historical data concerning conventional oil production, extended them with different scenarios provided by international organizations or academic entities, and finally extrapolated them using four kind of extrapolation curves. You will find a "scenario" called *History – Extension of Historical Data* which is a simple prolongation of historical data using extrapolation curves.

III. Data Sources:

For conventional oil, historical data from 1900 to 2008 are taken from:

- **Etemad & Luciani (1900 – 1979)**

Bouda Etemad and Jean Luciani, World Energy Production 1800 – 1985, ISBN 2-600-56007-6, Data digitalized and published with agreement of B. Etemad

- **US EIA Historical Statistics (1980 – 1989)**

U.S. Energy Information Administration, International Energy Statistics, **Go to EIA database** data accessed 15th of December 2010

- **IEA (1990 – 2008)**

International Energy Agency, Data Services, **Go to IEA database.** 2010 data has been used

From year 2009 to year 2030 or 2035, the following scenarios can be displayed:

- *From IEA* (IEA, World Energy Outlook, 2010)
    - Current Policies Scenario

  - New Policies Scenario
  - 450 Scenario
- *From EIA* (EIA, 2011)
  - Reference
  - Traditional High Oil Price
  - High Oil Price
  - Traditional Low Oil Price
  - Low Oil Price
- *From OPEC* (OPEC, 2010)
  - Reference Case
- *From University of Uppsala* (Kjell Aleklett, 2010)
  - World Oil Outlook 2008

A special work has been done on Univ. of Uppsala's Data, to adjust the Scenario to the other ones. Firstly, processing gains from IEA's *World Energy Outlook 2008* (Reference Scenario - oil supply forecast) have been added since Uppsala did not consider them while comparing their Scenario to the IEA's Reference Scenario from 2008. Nevertheless, it seems that they just used the same figures as IEA for processing gains when they compared the whole production (see p 25 of the *The Peak of the Oil Age - analyzing the world oil production Reference Scenario in World Energy Outlook 2008* document published in Energy Policy, (Kjell Aleklett, 2010)). Therefore, we have just assumed that the processing gains were the same as those of IEA Reference Scenario for the global time range considered (2008 – 2030). Secondly, Uppsala used a factor to convert Mb/d of NGL into Mb/d oil equivalents of NGL: 0, 75. As the other scenarios did not do this conversion, we just convert back the NGL values for Uppsala scenario.

Sources

EIA. (2011). *International Energy Outlook.* Retrieved from http://www.eia.gov/forecasts/aeo/

IEA. (2008). *World Energy Outlook.* Retrieved from http://www.iea.org/weo/2008.asp

IEA. (2010). *World Energy Outlook.* IEA.

IEA. (2011). *World Energy Outlook.* IEA.

Jancovici, J.-M. (2011, August). *When does the world oil production peak ?* Retrieved October 2011, from Manicore.com: http://www.manicore.com/anglais/documentation_a/oil/oil_future_peak.html

Kjell Aleklett, M. H. (2010, March). The Peak of the Oil Age - analyzing the world oil production Reference Scenario in World Energy Outlook 2008. *Energy Policy*, pp. 1398 - 1414.

OPEC. (2010). *World Oil Outlook.* Retrieved from http://www.opec.org/opec_web/en/publications/340.htm

UKERC. (2009, August). *The Global Oil Depletion Report.* Retrieved from http://www.ukerc.ac.uk/support/Global%20Oil%20Depletion

IV. Extrapolation

Type of curves

The module proposes different kind of extrapolation curves. They model in different ways the future oil production evolution, and therefore highlight different specific points.

Hubbert logistic curves (UKERC, 2009)

Hubbert curves are well known among fossil fuels specialists. They have a bell shape, displaying a maximum which represents a peak-oil. The general equation of that kind of curves is the following one:

$$Production = \frac{a \times URR \times \exp(-a \times (t - tm))}{\left(1 + \exp\left(-a \times (t - tm)\right)\right)^2}$$

Given

- t – the considered year
- URR – Ultimate Recoverable Resources

- $a = \frac{URR \times (Production(t_0) + production\ slope(t_0 - 5; t_0))}{Cumulated\ Production(t_0)^2 \times (\frac{URR}{Cumulated\ Production(t_0)} - 1)}$

  Constant depending on historical data

- $tm = \frac{1}{a} \times \ln\left(\frac{URR}{Production\ cumulée(t_0)} - 1\right) + t_0$
  year at which half of the URR has been extracted

Asymmetric Hubbert curves with plateau

From a mere Hubbert curve, it's possible to assign a non-equal share of extracted oil before and after the peak oil. The obtained asymmetric curve is more realistic. In addition a plateau of 15 years maximum (Jancovici, 2011) is modeled.

Before the plateau:

$$Production = \frac{a_1 \times 2 \times \mathrm{URR}_1 \times \exp(-a_1 \times (t - tm_1))}{(1 + \exp(-a_1 \times (t - tm_1)))^2}$$

Given

- t – the considered year
- $\mathrm{URR}_1 = bp \times URR$
  Ultimate Recoverable Resources extracted before the plateau
- 20% < bp < 58% – the share in % of URR extracted before the beginning of the plateau (UKERC, 2009).
- $a_1 = \frac{2 \times \mathrm{URR}_1 \times (Production(t_0) + production\ slope(t_0 - 5; t_0))}{Cumulated\ Production(t_0)^2 \times (\frac{2 \times \mathrm{URR}_1}{Cumulated\ Production(t_0)} - 1)}$
  Constant depending on historical data
- $tm_1 = \frac{1}{a_1} \times \ln\left(\frac{2 \times \mathrm{URR}_1}{Cumulated\ Production(t_0)} - 1\right) + t_0$
  Year at which URR_1 has been extracted, i.e. year at which we reach the plateau

The plateau:

$Production_{plateau} = Production(tm_1)$ If $tm_1 > t_0$

$Production_{plateau} = Production(t_0)$ If $tm_1 < t_0$

And with

- $t_{plateau}$ = plateau's duration
  The plateau lasts while $t - tm_1 < t_{plateau}$ (max 15 years)
- $URR_{plateau} = t_{plateau} \times Production(tm_1)$

After the plateau:

$$Production = \frac{a_2 \times 2 \times \mathrm{URR}_2 \times \exp(-a_2 \times (t - tm_2))}{(1 + \exp(-a_2 \times (t - tm_2)))^2}$$

Given

- t – the considered year
- $\mathrm{URR}_2 = URR - \mathrm{URR}_1 - URR_{plateau}$
  Ultimate Recoverable Resources extracted after the plateau
- $a_2 = 2 \times \frac{Production_{plateau}}{\mathrm{URR}_2}$
  Constant verifying continuity condition

- $tm_2 = tm_1 + t_{plateau}$
  Year at which $\mathrm{URR}_1 + URR_{plateau}$ has been extracted, i.e. year at which we leave the plateau

How is bp evaluated?

For increasing production scenarios

$bp = \frac{Cumulated\ Production\ (t_0)}{URR} + 0{,}02$ If result < 58%

If the result gives *bp* > 58%, we fix it equal to 58%. It implies a shorter plateau. The extra 0, 02 in the formula are aimed at avoiding any sudden change between the growing part of the curve and the plateau.

For the scenario *"History – Extension of Historical Data"*

bp = 37 % (UKERC, 2009)

Decreasing straight lines (Triangle)

This kind of curve is aimed at highlighting the number of years remaining for oil supply, considering a decreasing production at a constant rate. This approach gives an idea about the sustainability of oil supply.

$$Production = a \times t + b$$

Given

- *t* – considered year
- $a = -\frac{Production(t_0)^2}{2 \times (URR - Cumulated\ Production(t_0))}$
- $b = Production(t_0)^2 - a \times t_0$

Constant straight lines (Square)

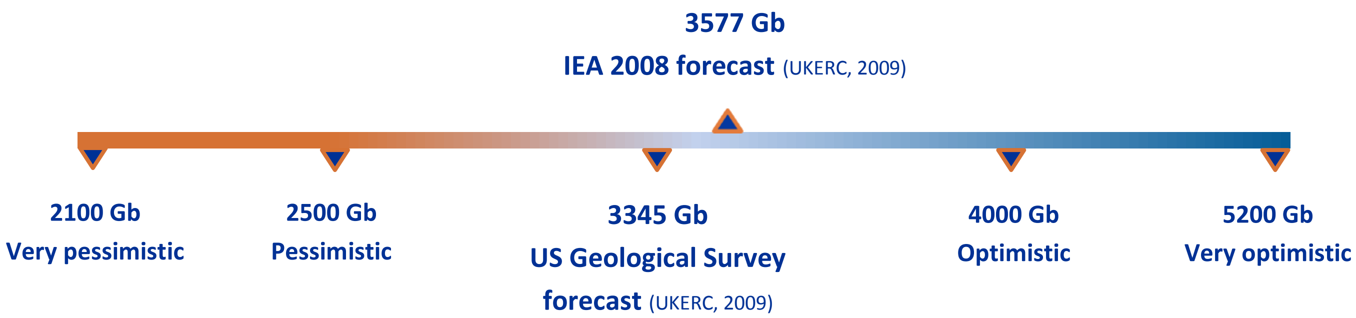
These curves are simply intended to highlight the number of years remaining for oil supply at a constant consumption given at t_0 (2008, 2030 or 2035). This approach is really relevant when it comes to show the weak sustainability of our current oil consumption.

- $\boldsymbol{Production(t) = Production(t_0)}$ for any t where Cumulated Production (t) < URR
- $\boldsymbol{Production(t) = 0}$ for any t where Cumulated Production (t) = URR

URR for conventional oil

The following scale shows the range of URR proposed in the module. Some key figures provided by international institutions are displayed to give an idea to the reader. This scale takes into account conventional oil, i.e. Crude Oil + NGL. URR forecasts gather the current cumulative production + the remaining 2P reserves + the reserve growth + the undiscovered resources (UKERC, 2009).

Range



The URR range is voluntary wide to enable the setup of various extrapolation curves to propose different kinds of comparison.

Error

As curve tracing is a sensitive task consisted of extending historical and scenarios data, the selected URR is not 100% verified with the area under the curve. A slight but nevertheless present error is made.

Note: For *"History – Extension of Historical Data"* there is barely no error made (relative error < 1%) since we do not have to cope with "scenarios' constrains".

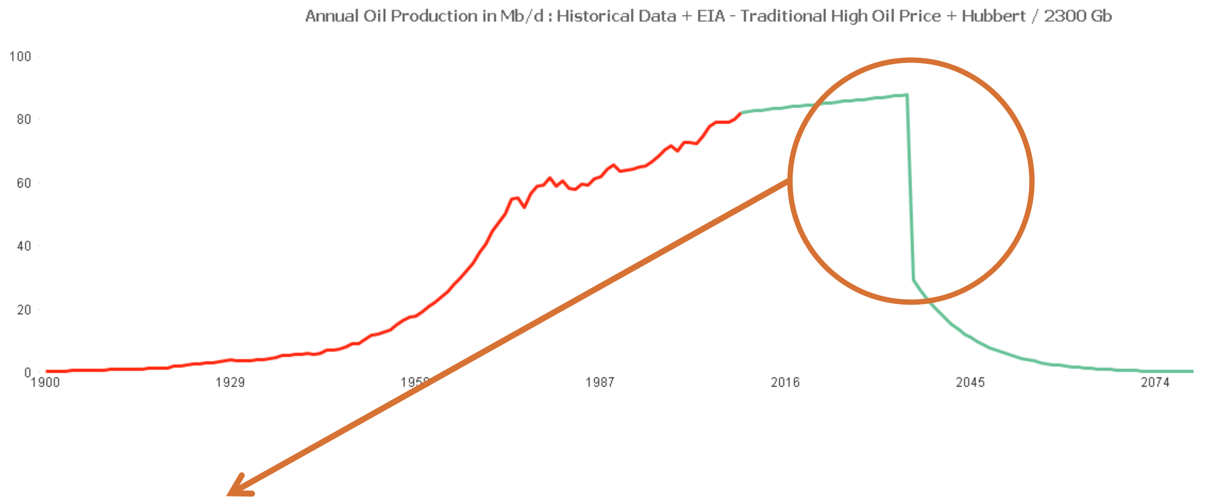
Empirical error is occurred on URR when it comes to curves displaying (historical data + scenario + extrapolation):

- The absolute error for URR below 3000 Gb might be high for instance due to the fact that more than 2000 Gb are planned to be extracted in 2035 whereas the curve constrain has to meet the selected URR inferior to 3000 Gb.

Absolute error for curve with URR <3000 GB

Mean Value: 2.67 %

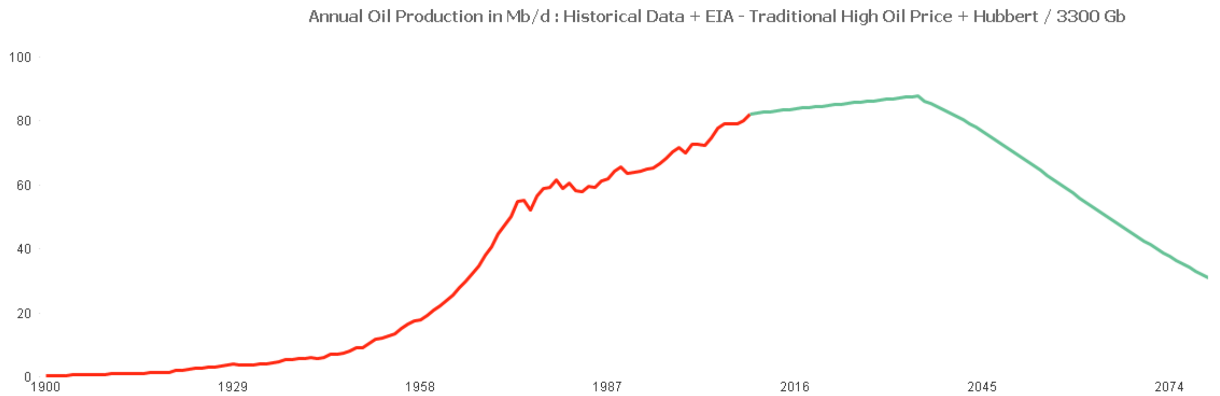
Max : 17.77 %



As you can see at the end of 2035, the production predicted by EIA in the *Traditional High Oil Price Scenario* is still high, implying a cumulated oil production of about 2000 Gb in 2035. As the selected URR is 2300, a discontinuity is unavoidable and the extrapolation Hubert curve does not fit well the requirements. It results in an error between real URR observable on the curve and the selected one.

- For URR above 3000 Gb, the absolute error is acceptable

Absolute error for curve with URR ≥ 3000 Gb
Mean Value: 0.94 %
Max: 9.98 %



Here is a more realistic URR for the given scenario. The curve manages to fit the scenario's data. The maximum error observed is less than 10%, and the mean value is very low, 0, 90%. To give you an idea, -10 % of relative error on a 3000 Gb URR selected means that the area under the overall curve is actually 2700 Gb.

Sources

Jancovici, J.-M. (2011, August). *When does the world oil production peak ?* Retrieved October 2011, from Manicore.com: http://www.manicore.com/anglais/documentation_a/oil/oil_future_peak.html

UKERC. (2009, August). *The Global Oil Depletion Report.* Retrieved from http://www.ukerc.ac.uk/support/Global%20Oil%20Depletion

Redesigning the Economy to Achieve Carbon Transition

THE SHIFT PROJECT