The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

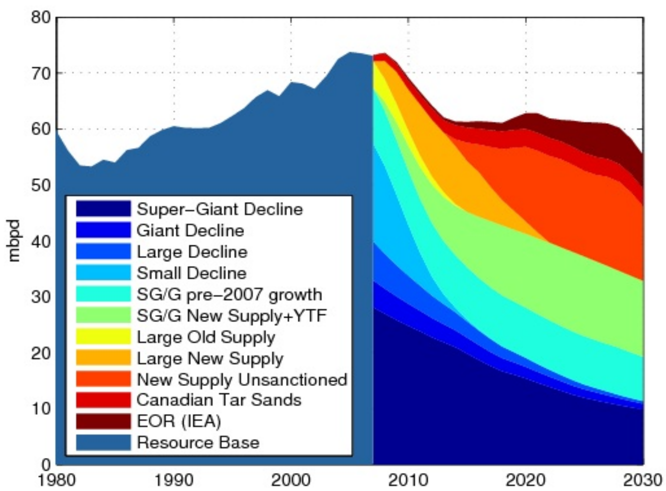
Analysis of Decline Rates

Posted by Sam Foucher on February 25, 2009 - 10:23am
Topic: Supply/Production
Tags: decline rate, iea, super-giants [list all tags]

This post offers a kind of reverse engineering of what numbers could be behind the long and detailed IEA decline analysis in their last report (2008 IEA WEO). A tentative decline structure for the post-peak Super-Giant and Giants oilfields is offered as well as a possible scenario for future production. The conclusions are:

1. It seems that the yearly decline rate of the post-peak resource base may accelerate to 10% until 2011 and then stabilize back toward 4.35%. This acceleration is due to the rapid decline rates for Large and Small oil fields (around 10%). Coincidentally, this value is the total decline rate value implicitly used by the IEA in their final forecast (see discussion here).
2. 83.0% of the 2007 conventional oil resource base (69.8 mbpd in 2007) is coming from post-peak fields.
3. The contribution from Super-Giants, Giants may have reached a broad plateau around 41 mbpd.
4. Production may slide rapidly over 3-4 years past 2009 due to a short bust in decline of the resource base then reach a gentler decline regime past 2012.

Warning, It's a long post with a lot of charts.



The IEA based its analysis of decline rates on a database of 780 world largest oil fields among which 580 are past their peak production. Fields where categorized according to their size (Super-giants > 5 Gb, Giants > 1.5 Gb and Large) and decline intensity. Three phases are considered for the decline:

- Phase 1: field is in a production plateau above 85% of peak annual production.
- Phase 2: field is past plateau and above 50% of peak production.
- Phase 3: production is below 50% of peak production.

Decline rate averages are computed for each size and decline category which give the following table:

	Decline Phase 1	**Decline Phase 2**	**Decline Phase 3**	**Total**
Super-Giants	0.8%	3.0%	4.9%	**3.4%**
Giants	3.0%	3.7%	7.6%	**6.5%**
Large	5.5%	7.2%	11.8%	**10.4%**
World	**1.4%**	**3.6%**	**6.7%**	**5.1%**

Table I. Decline rate structure according toe the IEA for the Top 580 oil fields in decline.

In addition, the following information is given for the 580 fields dataset:

1. The production-weighted average annual observed for 2007 is decline rate is 5.1% (table above).
2. They have a total initial reserves of 1,241 Giga-barrels, 101 are in a production plateau, 117 in decline phase 2, 362 in decline phase 3.
3. The total production was 40.5 mbpd in 2007 or 58% of 2007 production.

The point 3 above leads to 40.5 / 0.58= 69.8 mbpd for 2007 production (in comparison the EIA gives 73.0 mbpd for crude oil + condensate so I guess they are not considering 3.2 mbpd of condensates and unconventional oil). Even if this oil field subset covers 58% of the oil production, some large fields are missing from this 580 fields sample and are contributing to the resource base decline. They extrapolated the global decline rate bt assuming that the missing fields are large and smaller fields so they must decline at least as fast as the population of large fields above (i.e. 10.4%) which results in a total decline rate of 6.7%. They are using a production-weighted average so the calculation is the following

$$(5.1 * 40.5 + x * 10.4) / (40.5 + x) = 6.7\%$$

where x is the unknown production from small fields not in the 580 fields database with the following value

$$x = (6.7 * 40.5 - 5.1 * 40.5) / (10.4 - 6.7) = 17.5 \text{ mbpd}$$

which means that 40.5 + 17.5= 58 mbpd of 69.8 mbpd are coming from post-peak fields (i.e. 83.0%). Note that if 69.8 mbpd is the total production considered for 2007, then 69.8-58= 11.8 mbpd must come from fields that are not in decline. On their final forecast, they implicitly assumed a decline rate around 4.35% (see post here) which means that taking 81.0 mbpd for C+C+NGL in 2007 (EIA):

$$(6.7 * 58 + (81 - 58) * y) / 81.0 = 4.35\%$$

or:

$$y = (4.35 * 81 - 6.7 * 58) / (81 - 58) = -1.58\%$$

which means that 23 mbpd of crude oil + NGL that is not post peak must grow at least by 1.58% in order to get a global 4.35% decline for total production. That seems reasonable.

A Detailed View of the Decline Structure

On table I, average decline rates are given for each category. Unfortunately, the amounts used for the various production-weighted averages are not given. I propose an estimation of the 3x3 production matrix **P** behind the decline rates using the following constraints:

1. **P** must give the same average decline rates per decline phase or by size category. In all, it gives 8 equations.
2. The total production is equal to 40.5 mbpd.
3. From the list of top 20 oil fields (20 of the 45 known super-giants), we know that at least 1 field is in decline phase 1 (Ghawar), 9 are in decline phase 2 (for a total production of 7.747 mbpd in 2007) and 5 in decline phase 3 (or 3.505 mbpd).

Uisng a standard linear programming algorithm, it converges toward this solution (the residual error on the decline rates was around 0.2%):

	Decline Phase 1	**Decline Phase 2**	**Decline Phase 3**	**Total**
Super-Giants	6.204	8.794	14.400	**29.398**
Giants	0.257	0.822	2.838	**3.917**
Large	0.725	1.255	5.205	**7.185**
World	**7.186**	**10.871**	**22.443**	**40.5**

*Table II. Estimate of the production matrix **P** (in mbpd) behind the decline rates given in Table I.*

Figures 1 and 2 below are summarizing the database structure that the IEA may have considered.

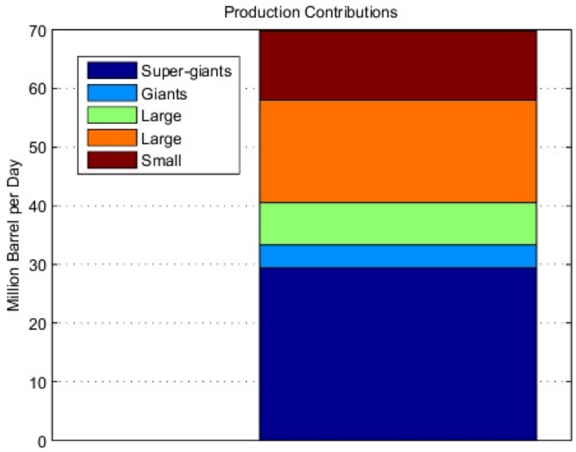


Figure 1. Amounts of post-peak production by field category used for the global decline rate calculation.

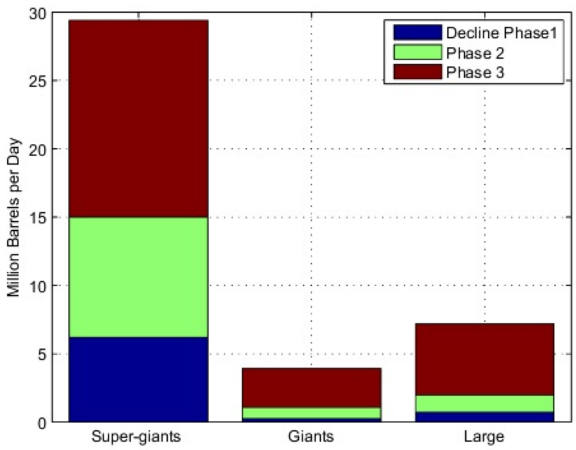


Figure 2. Repartition of decline phase per field size.

The Fate of the Super-Giants

Production from the super-giant and giant fields is the cornerstone of modern oil production. In the top 20, 16 of them are in decline.

Field	Peak Production (mbpd)	2007 Production (mbpd)	Production to Peak Ratio (%)	Decline Phase
Ghawar	5.588	5.100	91.27	1
Cantarell	2.100	1.675	79.76	2
Safaniyah	2.128	1.408	66.17	2
Rumaila N & S	1.493	1.250	83.72	2
Greater Burgan	2.415	1.170	48.45	3
Samotlor	3.435	0.903	26.29	3
Ahwaz	1.082	0.770	71.16	2
Zakum	0.795	0.674	84.78	2
Bu Hasa	0.794	0.550	69.27	2
Marun	1.345	0.510	37.92	3
Gachsaran	0.921	0.500	54.29	2
Shaybah	0.520	0.500	96.15	1
Daqing	0.633	0.470	105.85	2
Samotlor (Main)	3.027	0.464	15.33	3
Fedorovo-	1.022	0.458	44.81	2

Surguts	1.022	0.458	44.81	3
Zuluf	0.677	0.450	66.47	2

Table III. Top 16 oil fields in decline.

Using IEA decline rates (Table I), we get the following production profile for the top 16 in decline:

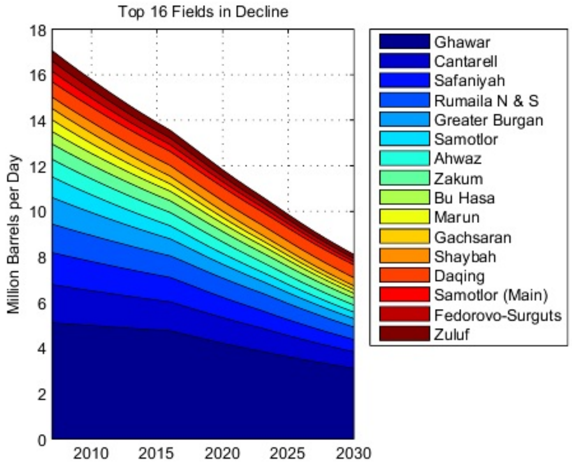


Figure 4. Field-by-field modeling for the top 16 fields using IEA average decline rates for super-giants.

We can substitute more realistic decline scenarios for Ghawar and Cantarell (see posts here and here):

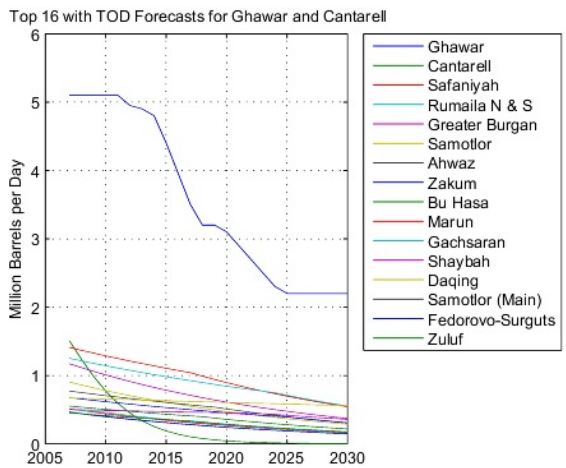


Figure 5. Field models for the top 16 in decline.

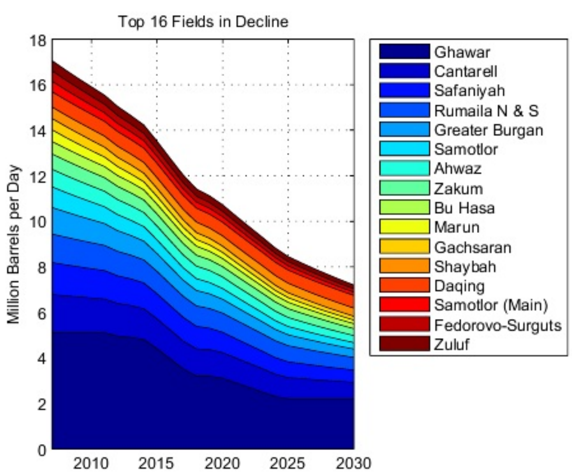


Figure 6. Field-by-field modeling for the top 16 fields and Mearns forecast for Ghawar.

The official Ultimate Recoverable Resource for the super-giants and giants is around 1.306 Tb, looking at a logistic projection we get an URR around 1.181 Tb with the official number being in the upper range.

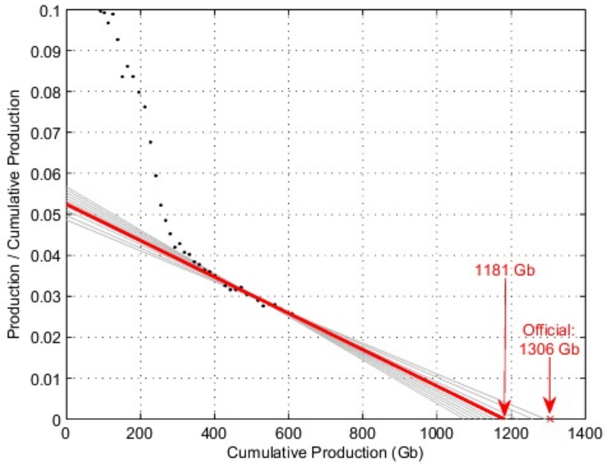


Figure 7. Hubbert Linearization technique applied on the SG/G production. Only the points between 1982 and 2007 are used for the linear fit calculation, the gray lines are the results for various starting year and the thick red line is the average.

With a cumulative production of around 600 Gb in 2007, it is likely that we have reached a kind of production plateau

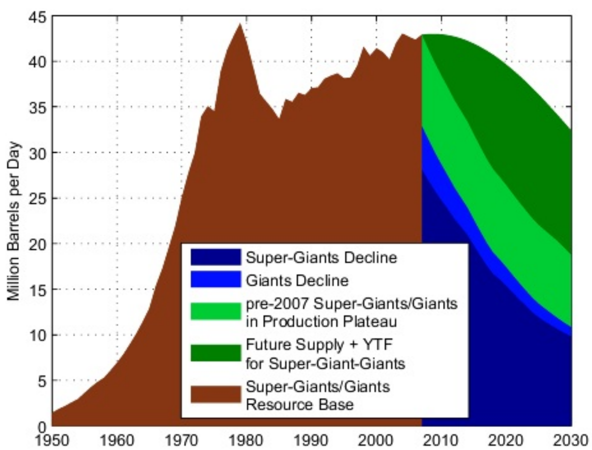


Figure 8. Logistic model for the Super-Giants\Giant group for a total recoverable resource of 1.181 Tb, production from pre-2007 fields (light green) is assuming that those fields are entering production plateau in 2007.

A Sum of Exponentials is not an Exponential

What I mean by that is the equivalent decline rate for a sum of exponentials is not the average of the individual decline rates. The resulting curve from a sum of exponentials is not necessarely an exponential with a constant decline rate.

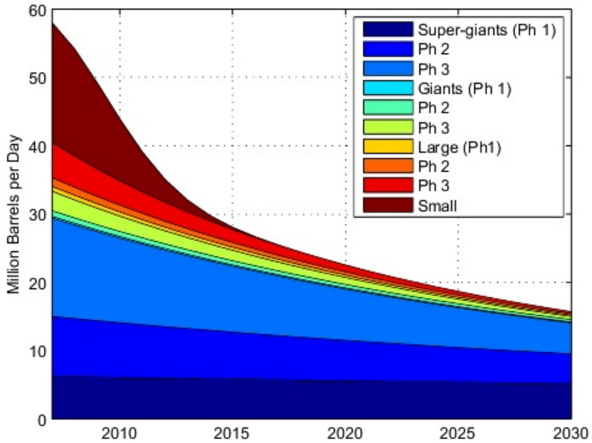


Figure 9. Projected production from post-peak fields in the resource base (derived from Table I and II).

However, the figure above offers a static view of the decline rate. Field in phase 1 will go in Phase 2 as soon as they pass the 85% threshold and then in Phase 3 as they go below 50% of peak production.

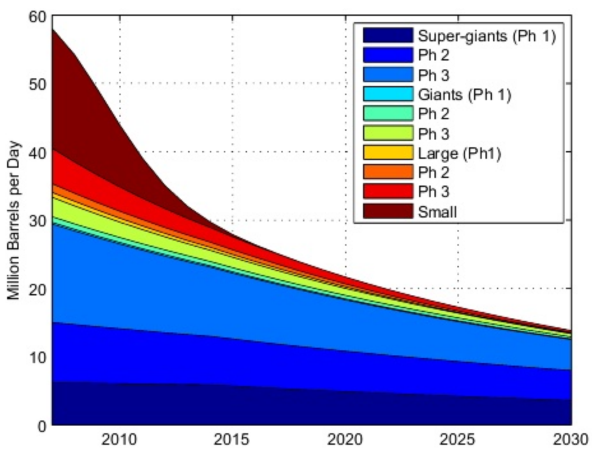


Figure 10. Post-peak components of the resource base decline with field-by-field modeling for the top 16 fields.

The resulting total decline rate has a complex behavior as shown on Figure 6, it accelerates for a few years before declining toward 4%. Interestingly, the asymptotic value for the blue curve is 4.35% which is exactly the value used by the IEA for their [forecast](#).

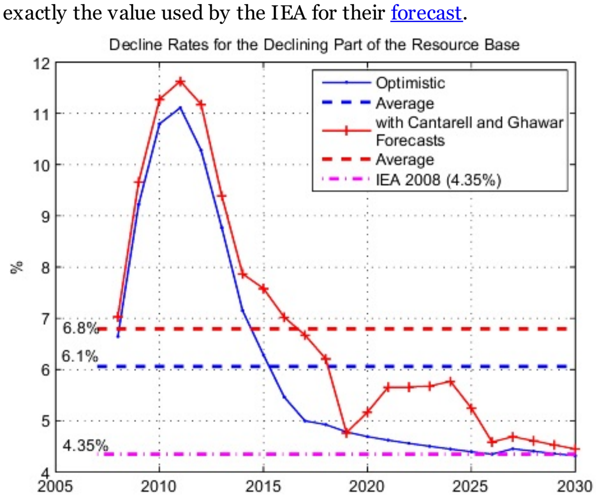


Figure 11. Decline rates for the declining portion of the resource base estimated from Figures 9 and 10.

The apparent decline rate peak in 2010 can be understood by looking at the relative contribution of each component to the total. We can see the small field component decline will have more weight at first.

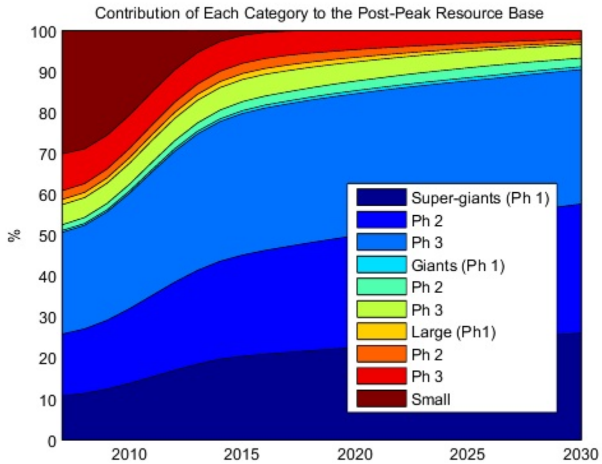


Figure 12. Contribution of each field category to post-peak resource base.

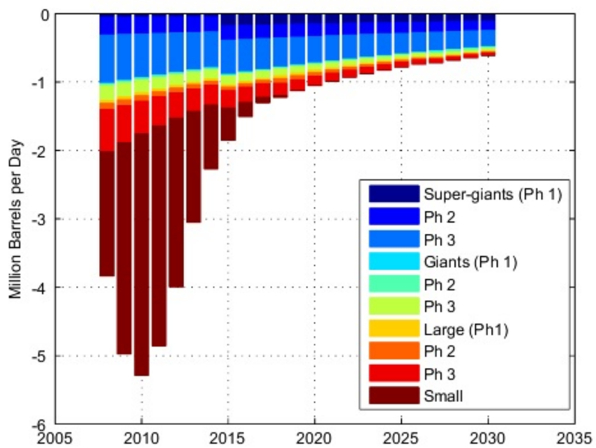


Figure 13. Annual production losses.

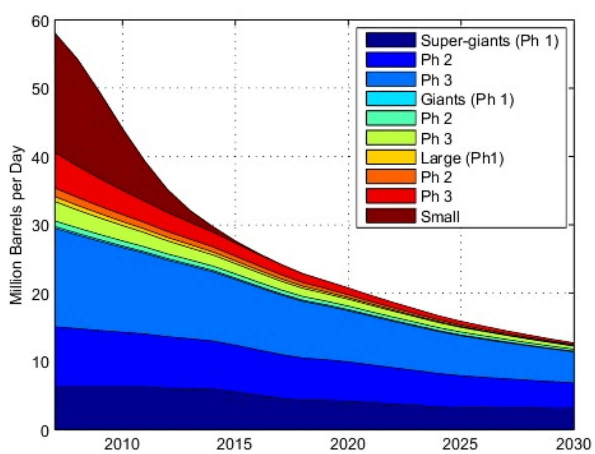


Figure 10. Post-peak components of the resource base decline with field-by-field modeling for the top 16 fields and Mearns forecast for Ghawar.

What's Missing?

Past this point, we will get even more speculative so bear with me. Figure 11 shows so project contributions from the Wikipedia database.

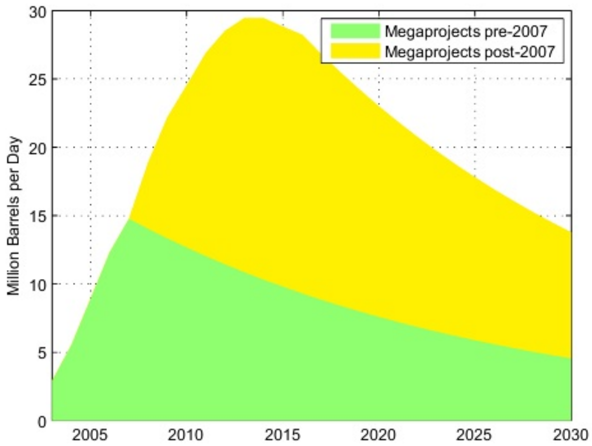


Figure 11. New supply from megaprojects derived from the Wikipedia database.

Strangely, if we use the pre-2007 portion of the Wikipedia database, it fills exactly the gap between the 2007 production level and the total amount in decline (69.8 mbpd). However, the resulting decline profile is far more bleak than the one used by the IEA for their final oil production forecast.

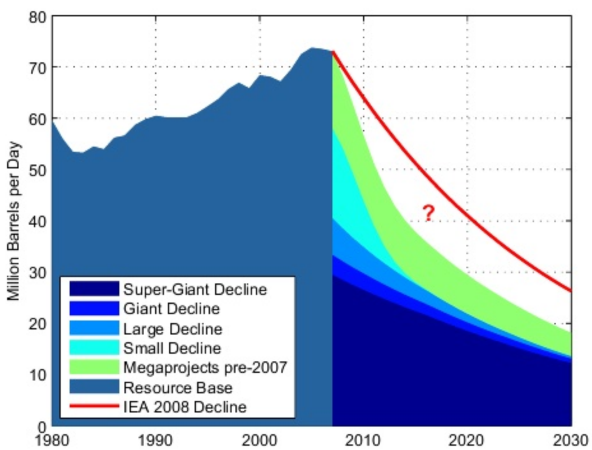


Figure 12. Potential Decline for the resource base using pre-2007 (inclusive) megaprojects from the Wikipedia database. The thick red line is the implicit decline (4.35%/year) used by the IEA.

Based on this decline profile and the logistic modeling for the SG/G category shown on Figure we can make an attempt to fill in the gap. I make the following 2 bold assumptions:

1. Because the Wikipedia megaproject database collect mainly projects that have been sanctioned (i.e. financially approved) and press release are available, we can reasonably assume that the difference with the IEA new supply additions is the unsanctioned project portion.
2. In addition, the green area is a coarse estimation of total new supply additions (including Yet-To-be-Found) that could come from the SG/G category, we can assume that the difference with the Wikipedia and IEA forecasts is due to contributions from Large fields and YTF.

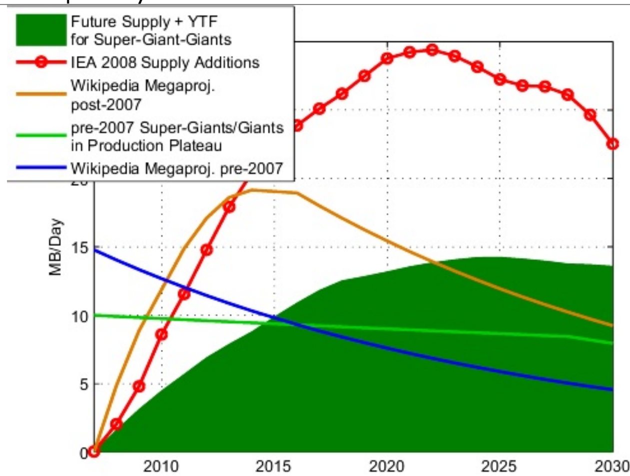


Figure 13. Potential contributions coming from new project additions.

Below is a possible scenario formed by stacking together the following components:

1. Declines for Super-Giants/Giants, Large and small fields of the resource based on the IEA analysis of decline rates as shown on Figure 10.
2. Pre-2007 contribution from Super-Giants/Giants not in decline is assuming that they are entering decline phase 1 in 2008 (green line on Figure 13).
3. SG/G New Supply+YTF: this portion includes potential future supply from megaprojects and new discoveries in this field category. It is based on a logistic modeling as shown on Figure 10 and shown as the green area on Figure 13.
4. Large Old Supply: contribution from Large field is based on the Wikipedia megaproject database based on fields online before 2007.
5. Large New Supply: contribution from Large fields based on the wikipedia megaproject database for sanctioned projects online after 2007 (in orange on Figure 13).
6. New supply unsanctioned: estimate of the unsanctioned portion of the IEA forecast for new supply by taking the difference betwen their new supply forecast and the Wikipedia megaproject forecast.
7. Canadian tar sands production reaching 3 mbpd in 2020.
8. Enhanced Oil Recovery (aka Reserve growth) as predicted by the IEA.

	'Super-Giant Decline'	'Giant Decline'	'Large Decline'	'Small Decline'	'SG/G pre-2007 growth'	'SG/G New Supply+YTF'	'Large Old Supply'	'Large New Supply'	'New Supply Unsanctioned'	'Tar Sands'	'EOR (IEA)'	Total	Overall Decline Rate (%)
2007	28.11	4.81	6.96	17.5	9.98	0	4.78	0	0	1.0	0.000	73.20	
2008	26.93	4.50	6.24	15.68	9.90	1.64	4.05	3.21	0	1.3	0.2	73.44	0.33
2009	25.81	4.21	5.59	12.59	9.82	3.15	3.34	5.71	0	1.4	0.3	71.61	-2.5
2010	24.77	3.93	5.00	9.06	9.74	4.4998	2.68	7.36	0	1.6	0.5	68.62	-4.2
2011	23.79	3.68	4.48	5.84	9.67	5.7134	2.04	9.16	0	1.7	0.5	66.08	-3.7
2012	22.74	3.44	4.02	3.37	9.59	6.9317	1.44	10.16	0	2.0	0.5	63.66	-3.7
2013	21.84	3.22	3.61	1.74	9.51	7.9128	0.87	10.69	0	2.2	0.5	61.55	-3.3
2014	20.96	3.02	3.24	0.81	9.44	8.8156	0.33	10.32	1.22	2.5	0.7	60.66	-1.5
2015	19.83	2.83	2.91	0.34	9.36	9.8992	0.0	9.13	3.24	2.7	1.0	60.24	-0.7
2020	15.37	2.05	1.61	0	8.99	13.202	0.0	2.21	13.35	3.2	2.8	59.99	0.3
2025	11.91	1.51	0.86	0	8.64	14.273	0.0	0.00	15.31	3.2	5.5	55.69	-2.0
2030	9.81	1.03	0.459	0	7.93	13.607	0.0	0.00	13.3	3.2	6.0	49.33	-4.9

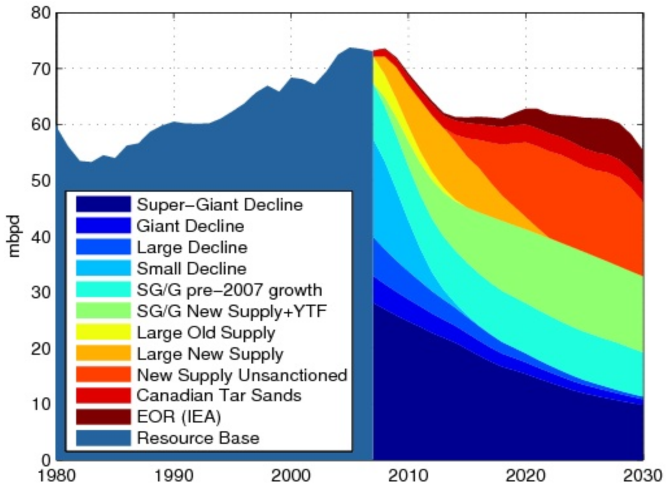


Figure 14. Production scenario based on the Wikipedia megaproject database for sanctioned project, the difference with the IEA new supply is supposed to come from unsanctioned projects (in orange).

Some important caveats:

1. There is a portion of YTF in the large/small fields category that is not included and could add a few mbpd by 2030 (see here for a discussion).
2. Reserve growth is also not included but it`s a long term and diffuse supply addition.
3. Some growth in production from small fields is not included (no data available).
4. It is hard to predict growth in the not-in-decline portion of SG/G fields, my assumption (point 2 above) is probably too pessimistic.