The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

GHAWAR: an estimate of remaining oil reserves and production decline (Part 2 - results)

Posted by Euan Mearns on April 27, 2007 - 11:59am in The Oil Drum: Europe
Topic: Supply/Production
Tags: aramco, ghawar, matthew simmons, production decline, reserves, saudi arabia [list all tags]

Two volumetric simulations (2D) of the initial and remaining reserves in Ghawar, the world's largest producing oil field, have been determined. The High Case scenario uses somewhat more optimistic assumptions than the Base Case scenario. Background and methodology are described in detail **here**.

Estimate of initial oil in place = 162 billion barrels (same for High and Base cases)

High Case
Produced oil = 63 billion barrels
2004 reserves = 43 billion barrels
60% depleted

Base Case
Produced oil = 55 billion barrels
2004 reserves = 34 billion barrels
62% depleted

The Base Case production model shows Ghawar on the edge of irreversible production decline that may start around 2010 or it may already have started. The High Case production model is more robust and shows plateau production maintained until around 2013.

Reserves estimates

The areas of unswept oil observed on the Linux simulation **(Figure 5, Part 1)** transferred onto **Croft's map** are shown in Figure 16. The measured map areas shown in Figure 16 are the same for Base Case and High Case. Base Case reserves estimates are also shown.

The reserves estimates for Base and High Cases are summarised in Tables 1 and 2. All details of input variables to these estimates are on the XL spread sheet that can be downloaded **here**.

All these estimates are to be viewed as provisional and subject to change as new information may come to light or as assumptions are refined.

All readers are also reminded that these estimates are a back of the envelope style calculation and are subject to large uncertainties. **Jeremy Gilbert** rightly pointed out that the only organisation with the data to perform this task properly is Saudi Aramco.

Note that the producing region boundary between Hawiyah and Uthmaniyah used here has been changed form those used by Croft and others. The traditional boundary chops off the north end of the Haradh – Hawiyah ridge that makes little geological sense so I have adjusted this boundary as

shown in Figure 16 to follow more closely the geological structure.

Should anyone wish to propose modifications to the input to this model then I will be pleased to make adjustments so long as a good argument for doing so is presented.

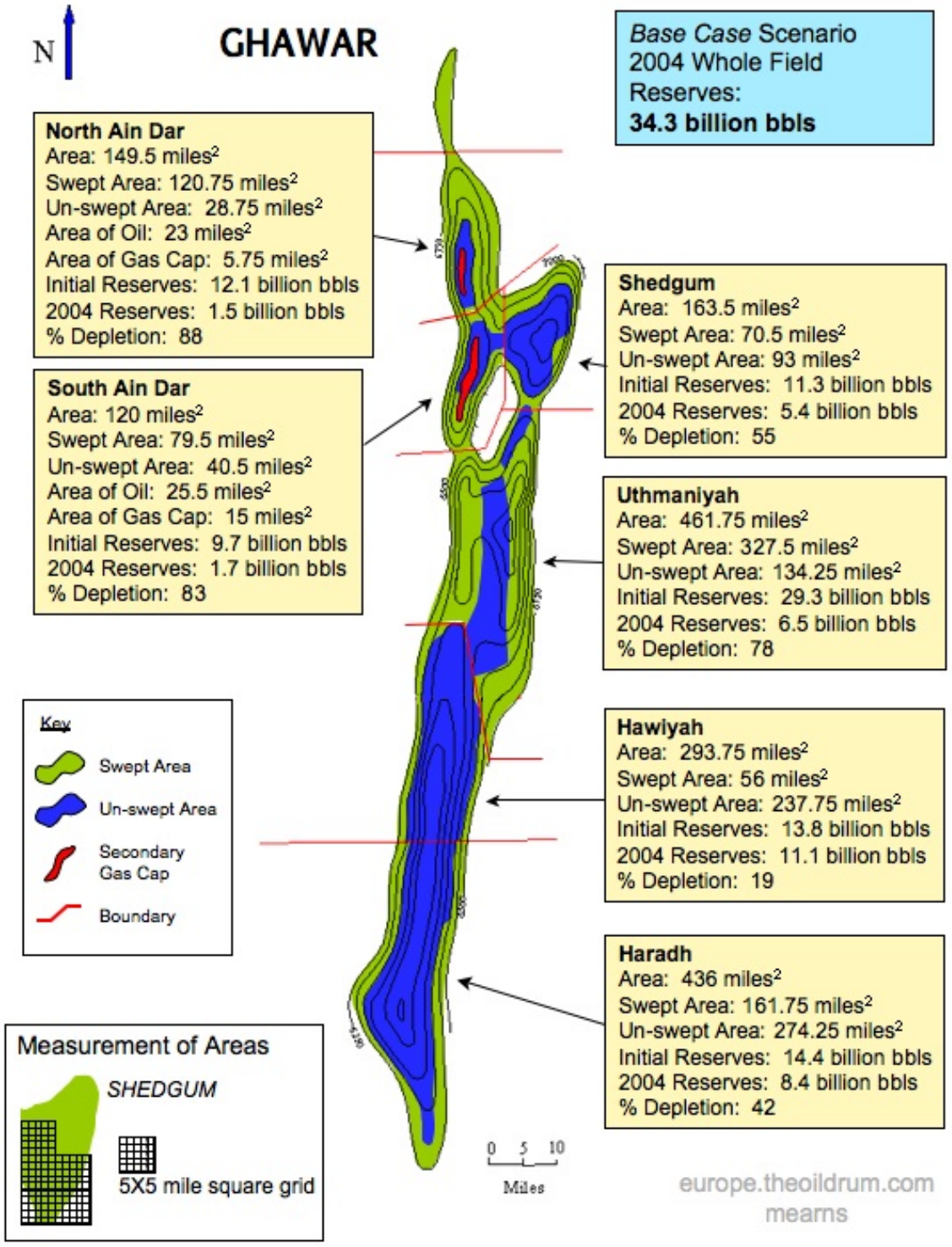

Figure 16. *Contoured base map of Ghawar from Greg Croft with areas of presumed dry oil and swept zones inferred from Figure 5 (Part 1) superimposed. The areas were measured by careful counting of 1 mile squares laid out in a grid as shown. Base Case reserves estimates are*

indicated. See Table 2 for High Case estimates.

The boundary between Hawiyah and Uthmaniyah has been modified from Croft to follow the geological structure.

Base Case	Initial STOIP	Initial Reserves	2004 STOIP	2004 Reserves	% depleted	Produced
N Ain Dar	20.4	12.1	2.51	1.49	88	10.6
S Ain Dar	16.4	9.69	2.78	1.65	83	8.04
Shedgum	21.1	11.3	9.58	5.14	55	6.15
Uthmaniyah	43.6	29.3	9.67	6.50	78	22.8
Haradh	29.7	13.4	18.7	8.42	37	4.96
Hawiyah	30.6	13.8	24.7	11.1	19	2.62
Totals	**162**	**89.5**	**68.0**	**34.3**	**62**	**55.1**

Table 1 *Base Case reserves estimates for Ghawar oil field, Saudi Arabia. All figures in billions of barrels.*

High Case	Initial STOIP	Initial Reserves	2004 STOIP	2004 Reserves	% depleted	Produced
N Ain Dar	20.4	14.3	3.14	2.21	85	12.1
S Ain Dar	16.4	11.5	3.48	2.45	79	9.06
Shedgum	21.1	13.4	12.0	7.62	43	5.78
Uthmaniyah	43.6	34.8	9.67	7.48	79	27.3
Haradh	29.7	15.8	18.7	9.90	37	5.86
Hawiyah	30.6	16.2	24.7	13.1	19	3.09
Totals	**162**	**106**	**71.7**	**42.8**	**60**	**63.2**

Table 2 *High Case reserves estimates for Ghawar oil field, Saudi Arabia. All figures in billions of barrels.*

There is no difference between the high case and base case initial STOIP (stock tank oil in place) – 162 billion barrels. The High Case initial reserves estimate – 106 billion barrels, is significantly higher than the Base Case – 90 billion barrels, owing to higher oil column thickness and recovery factors used in the former.

The base case suggests 34 billion barrels reserves remaining in 2004 with 55 billion barrels already produced.

The high case suggests 43 billion barrels reserves remaining in 2004 with 63 billion barrels produced.

The reserves depletion levels are 62% for the Base Case and 60% for the High Case – both significantly higher than the 48% depleted value given by Saleri.

Areas of over – and under – estimation

The following summarises my views on where the reserves estimates reported here either under or over estimate.

Overestimation

- Ignoring edge wedge effects will have lead to overestimation of initial STOIP. And overestimation of remaining reserves in Haradh and Hawiyah.

Underestimation

- In transferring swept area data onto Croft's map, the swept area in Haradh may have been overestimated leading to underestimation of remaining reserves (the estimated 37% depletion seems too high).
- All reserves estimates reported here are based on the unswept dry areas in Figure 5 and the wet area production immediately adjacent to the dry areas. No allowance is made for wet area only production. This may proceed for decades with high water cut.
- It is possible that the net reservoir thickness data provided by Croft does not take into account recovery from lower permeability rock made possible by horizontal drilling. Using thicker net pay (albeit with lower porosity and permeability) may add further to reserves.
- It is possible that the area on Croft's map leads to underestimation across Ain Dar - Shedgum

On balance, over- and underestimation will tend to cancel each other out, however, the balance sheet seems biased towards underestimation. It needs to be noted, however, that the reserves that are potentially underestimated are not easily produced being contained in either poor quality rock or in wet areas. These reserves will not significantly impact the decline of Northern Ghawar but may add significantly to tail end production.

Comparison with official Saudi statements

Ain Dar – Shedgum area

Dr Saleri provided us with a snapshot of Ain Dar Shedgum in his **2004 CSIS presentation** (large pdf) (all data believed to be 2004 status). The key figures:

	Saleri	High Case	Base Case
Produced	26.9	27	25
Remaining proved reserves	13.9	12	8
Initial reserves	40.8	39	33
Initial oil in place	68	58	58
Recovery (produced+proved)/initial	60%	67%	58%

The correspondence between Saleri's produced, remaining and initial reserves with my High Case scenario is striking. Sufficiently so to give me a fair degree of confidence that the methodology I have employed is generally valid. However, the agreement with initial oil in place is not so good, Saleri quoting a significantly higher figure of 68 billion compared to my high case estimate of 58 billion. And this then highlights a conflict in the way all the numbers are derived. My high case already assumes a high recovery factor of 67% while Saleri's numbers assume 60% recovery leading to the expectation of more probable and possible barrels to be produced as indicted in Figure 17.

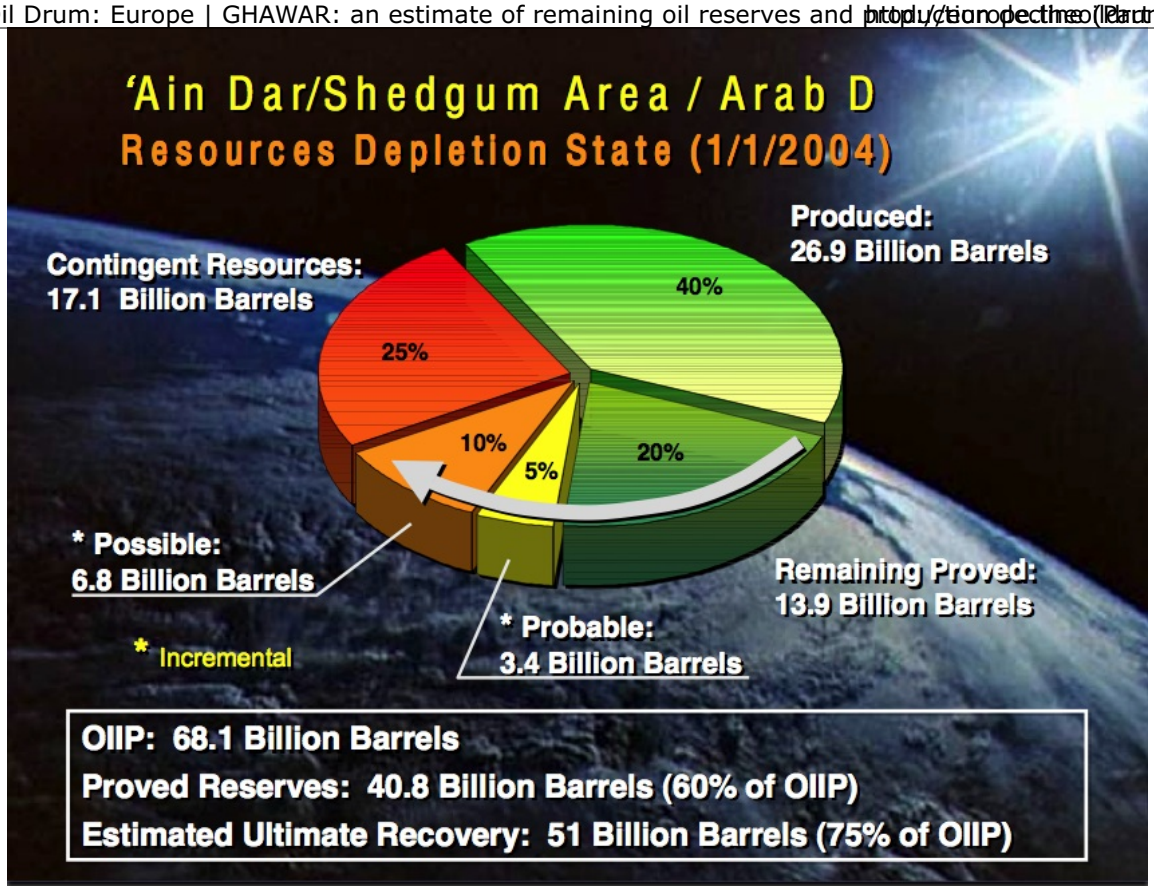

Figure 17. *The Aramco view of Ain Dar and Shedgum in 2004 from Dr Saleri's presentation (pdf).*

Whole Field

Heading Out brought the paper by **Jaffe and Elass** (pdf) to our attention in his post **Simple mathematics - The Saudi reserves, GOSPs and water injection**. Jaffe and Elass (2007) provide an indication of the current Saudi view of Ghawar's production history where they say that Ghawar still contains 70 billion barrels of reserves and is 48% depleted. In this case my figures have been adjusted for 3 years production (5 million barrels per day for 3 years is 5.5 billion barrels) to bring them into line with Jaffe and Elass' 2007 data.

The Jaffe and Elass data have been reduced as follows:

70 billion = 52% of reserves, therefore initial reserves = (70/52)*100 = 135 billion.
With 70 billion remaining we get the 65 billion produced figure (135-70).

	Jaffe and Elass	High Case	Base Case
Produced	65	68	61
Remaining proved reserves	70	37	29
Initial reserves	135	106	89
Depletion %	48	65	68

As was the case with Ain Dar – Shedgum, there is actually remarkable correspondence between the production figures – the High Case being a bit higher and the Low Case being a bit lower than Jaffe and Elass.

However, the similarity ends there. The much higher Saudi initial reserves estimate gives rise to a remaining reserves estimate that is double mine, and this in my opinion masks the precarious state of depletion of Ghawar. The Saudis say 48% depleted while my High Case suggests 65% depletion.

The initial STOIP figure I have for the field is 162 billion barrels and this assumes generally high oil saturations throughout. The Jaffe and Elass initial reserves figure of 135 billion implies 83% recovery against my initial STOIP value. My initial STOIP calculation does of course hinge on the map scale and Croft's average reservoir parameters being correct. If there are major errors there then perhaps someone could let us know?

Comments by Simmons

In his 2004 presentation, **Matthew Simmons** (large pdf) points to a 170 billion initial STOIP figure for Ghawar and he says that this matches Aramco's 1975 estimate (pre full nationalisation).

My figure of 162 billion is a bit lower and I wonder if map scaling issues across S Ain Dar – Shedgum may account for this difference?

Nevertheless, the agreement is pretty good (5% difference) – considering my figures are produced on the back of an envelope, these areas of agreement underpin my confidence in my general approach. This emphasises the significance of **differences** between my estimates of remaining reserves and those reported by Saudi Arabia.

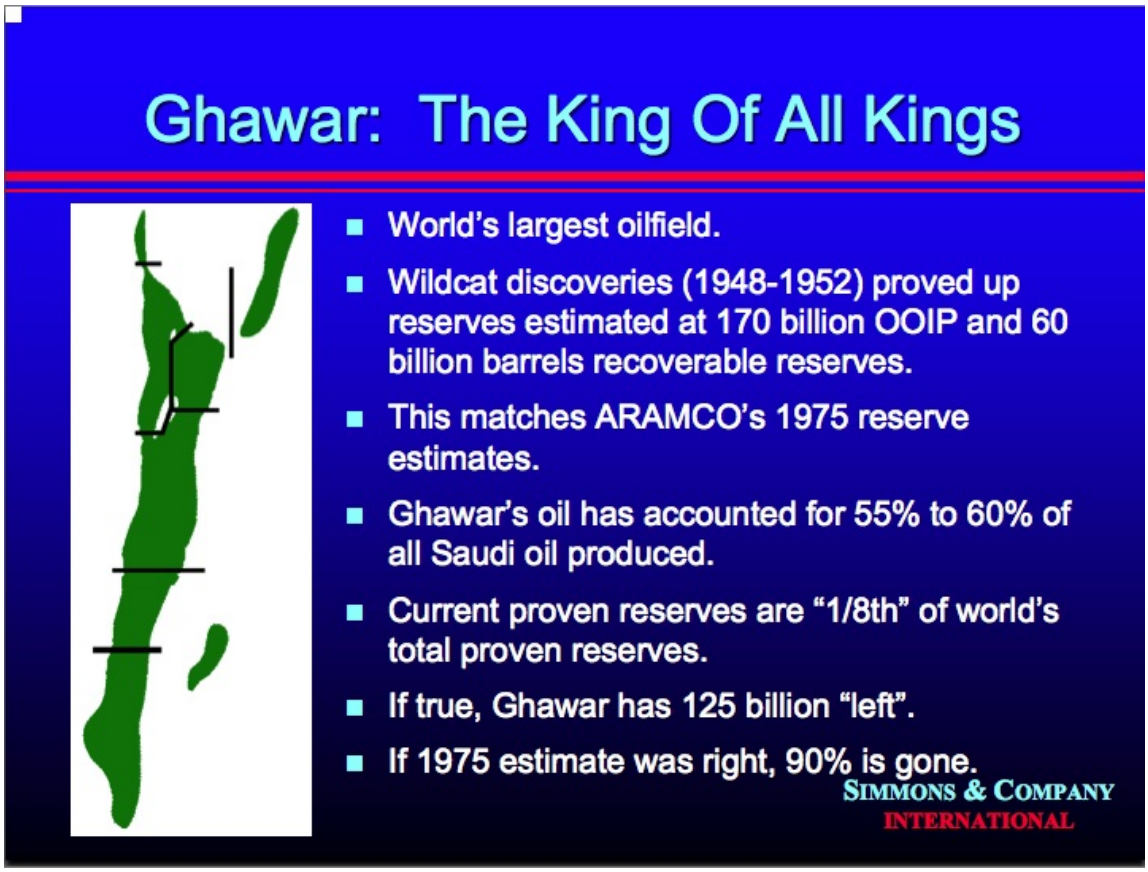

Figure 18. *A view on Ghawar's reserves provided by Matt Simmons in his 2004 presentation (pdf).*

Production models

The production models for base case and high case scenarios rely on certain assumptions being made. Some details exist about production in the different areas of Ghawar. Overall production is assumed to be 5 million barrels per day. Published data point to 500,000 bpd in N 'Ain Dar and 2,000,000 bpd for Ain Dar and Shedgum combined. Haradh is reported to be producing 900,000 bpd leaving 2,100,000 million barrels per day in Uthmaniyah and Hawiyah. The following distribution of production between the various areas has been assumed:

N Ain Dar	500,000
S Ain Dar	500,000
Shedgum	1,000,000
Uthmaniyah	1,500,000
Haradh	900,000
Hawiyah	600,000
Total	**5,000,000**

The production models have been run until all the estimated recoverable reserves have been consumed in the respective areas. Rapid decline over 5 year periods has been built into the models to take account of the growing use of horizontal wells in the development programs.

The reserves models suggest that Hawiyah contains the largest remaining reserves volumes and in each model a program of horizontal well drilling associated with new GOSPs are assumed to compensate for declining production in N Ghawar. It is envisaged that these projects would be similar to Haradh III, comprising smart MRC wells and each GOSP handling 300,000 bpd. In the base case, the reserves will only support a 2 GOSP development in addition to the assumed existing production. In the high case model, reserves would support a 3 GOSP extension to the field, each producing 300,000 bpd.

The base case production model presents a sobering picture of the state of N Ghawar (Figure 19). N Ain Dar is forecast to come off plateau production in 2010, followed by S Ain Dar, Uthmaniyah and Shedgum. The anticipated rapid decline of these areas points to most of the primary production in N Ghawar coming to an end around 2018 (Figure 19).

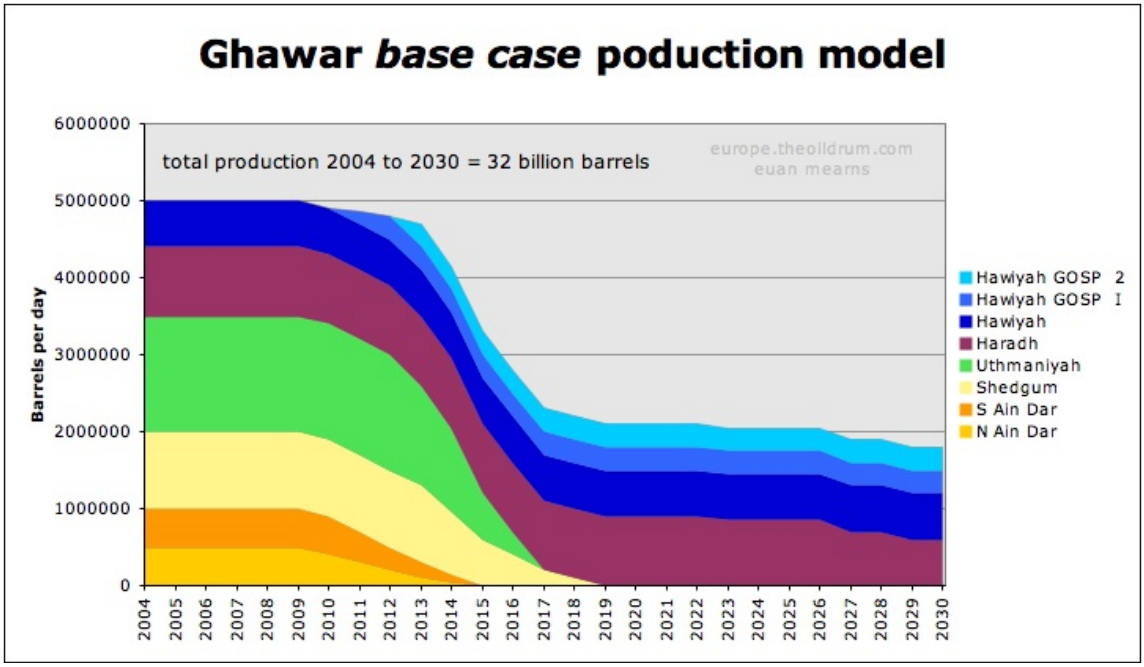

Figure 19. *Base Case production model for Ghawar. The model is run until all remaining reserves in sub-structures are consumed. Not shown is potential wet area only production that may prolong the tail if sufficient investment is made in water handling facilities.*

To compensate for falling production in the North, it is assumed that there will be further development of the South with Hawiyah GOSPS I and II partly offsetting the decline of the North. Around 2018, Ghawar production would settle on around 2,000,000 bpd but by 2030 most primary dry oil reserves will be exhausted.

It has to be noted that the timing of these events are based on the assumption that the Linux map is dated 2004. Should it reflect the situation in 2003 or earlier then the events described above will all happen correspondingly earlier – and 2010 is only three years away.

The High Case model presents a much more robust picture with plateau production close to 5,000,000 bpd sustainable until around 2013 (Figure 20). Following that, Northern Ghawar declines as described for the Base Case with N Ain Dar first, followed by S Ain Dar, Uthmaniyah and Shedgum. The higher reserves in the High Case also allows for a 3 GOSP redevelopment of Hawiyah with ample reserves to sustain a new plateau of 2,500,000 bpd until 2030 (whether reservoir performance will permit this or not is another issue).

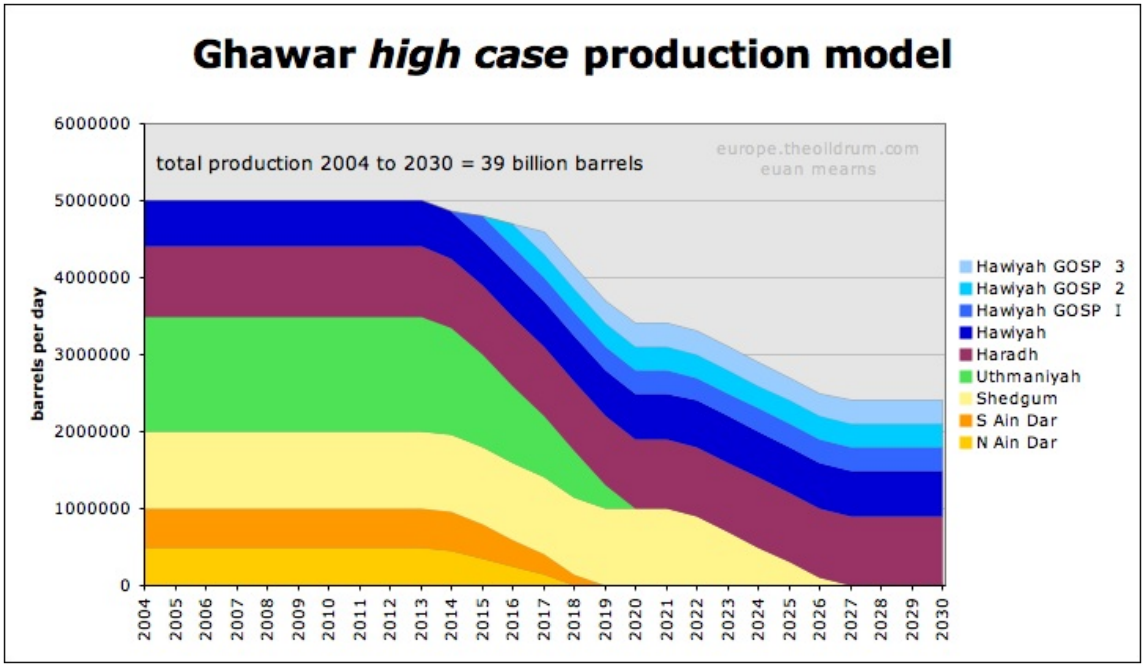

Figure 20. *High case production model for Ghawar. This model produces only 7 billon barrels more oil in the forecast period than the Base Case but this has a profound effect on delaying and reducing near term and longer term decline illustrating the sensitivity of these models to reserves uncertainties.*

The High Case provides a very different outcome to the Base Case. Throughout the forecast period, the High Case produces 7 billion barrels more oil than the Base Case (23% more). This does not seem a lot but it has a profound effect on the near term and longer term outcomes. All readers of this article need to bare in mind the large uncertainty of these forecasts.

The additional oil in the High Case model comes from assumed, thicker oil columns in 2004 and higher recovery factors, especially in Haradh and Hawiyah. In the absence of reliable data (in the

hands of Saudi Aramco) it would be unwise to discount the High Case model all together.

Consequences and conclusions

The ravages of 50+ years production on reserves in Northern Ghawar are there for all to see on the Linux oil saturation model (Figure 5, Part 1). Northern Ghawar is in a heavily depleted state and will shortly enter a period of irreversible decline. However, despite being around 88% depleted, regions like N ' Ain Dar, still contain a significant amount of recoverable dry oil – about 1.5 billion barrels in the case of N 'Ain Dar. This is sufficient to support 500,000 bpd production for a few years yet (183 million barrels per year).

One thing I feel is important for OECD based observers to understand is that Ghawar has not been developed like commercial oil fields in the west. The field has never been produced at anything close to its production potential and this means that existing lower rates of careful production can be maintained, even though the field may be 65% depleted.

The real trouble for Ghawar and Saudi Arabia will start when N and S 'Ain Dar and Uthmaniyah all begin to decline at about the same time, somewhere in the time frame 2010 to 2013 in my opinion. It is possible that this process has already begun and I eagerly await Stuart's interpretation of these vital, highly depleted areas.

In preparing these reserves and production forecasts I became acutely aware of their sensitivity to varying certain assumptions and I have swayed between seeing an immediate production crisis and my established view that Saudi production will be maintained for a number of years to come. The data have led me to settle on the latter point of view. New field developments such as Khursaniyah (gas), Shaybah extension and Khurais will in my opinion enable Saudi Arabia to grow production slowly between now and 2013.

As I see things, the main consequence of the pending decline in Ghawar for world energy supplies is that Saudi Arabia, and other OPEC countries, will not be able to meet rising demand in full, giving rise to repeated cycles of rising prices and demand destruction. Saudi Arabian oil production will of course decline one day, but that day still seems to be a few years off. Falling oil and gas production throughout the OECD is the major energy security problem confronting the World Economy today.

The main conclusion to draw from the reserves data presented here is that the produced oil volumes tally in a general sense with figures released by Aramco. There are significant discrepancies however, with the remaining reserves figures. The data presented here show significantly lower remaining reserves than reported by Saudi Arabia and this reduces the outlook for future production growth.

Acknowledgements

Over the past two weeks, Stuart Staniford and I have been working closely with each other and have exchanged hundreds of emails. Stuart has been doing all the work – finding and reading thousands of pages and sending me summary information and key diagrams. Stuart is working independently on a Ghawar reserves model and we agreed to keep our key assumptions from each other in the interest of obtaining two independent results. Stuart is applying his computing and graphics skills to produce a more sophisticated model than mine, which I await with great expectation and some trepidation. Stuart kindly agreed to allow my more humble offering to go first.

Bob Shaw found the Linux oil saturation visualistaion and numerous other key data sources. And so I am indebted to him and several other TOD posters for their

committed data mining and analytical expertise – Heading Out, Fractional Flow, Plucky Underdog and GaryP to name but a few.

Two industry friends who wish to remain anonymous provided valuable advice on the assumptions made in the models presented and have checked my spread sheet for methodological and data input errors. One is a Senior Production Geology Supervisor, the other is a Senior Reservoir Engineer.

Last must not least I need to thank my 14-year-old son Duncan who counted all the squares on the swept and un-swept zones (1624 squares in all) and who drafted many of the maps and diagrams presented in this post.

Saudi Aramco

One thing to emerge from the vigorous debate about Saudi Arabian reserves on TOD in recent weeks is the fact that Saudi Aramco are a highly competent organization doing a superb job of handling these assets that are so important to the global economy. Clear distinction needs to be made between the technical expertise of Aramco and the political statements about reserves and future production.

This article has been prepared in good faith, aimed at providing an independent view of the production history and remaining reserves in Ghawar. If here are major errors in the input data to my model then I will be pleased to revise this model should more accurate and reliable input data become available.

Recent Oil Drum articles on Saudi Arabia:

by Stuart Staniford

The Status of North Ghawar

Further Saudi Arabia Discussions

Water in the Gas Tank

A Nosedive Toward the Desert

Saudi Arabian oil declines 8% in 2006

by Euan Mearns

GHAWAR: an estimate of remaining oil reserves and production decline (Part 1 - background and methodology)

Saudi production laid bare

Saudi Arabia and that $1000 bet

by Heading Out

Simple mathematics - The Saudi reserves, GOSPs and water injection

Of Oil Supply trains and a thought on Ain Dar

by Ace

Saudi Arabia's Reserve "Depletion Rates" provide Strong Evidence to Support Total Reserves of 175 Gb with only 65 Gb Remaining

Further Evidence of Saudi Arabia's Oil Production Decline