Patterns In World Oil Production

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Summary and Conclusions:

All the data sets show the end of early exponentiation. This is the unambiguous sign that each examined reservoir is under stress. It is interesting that some data sets do not follow the initial free growth model. This means that even at start up, extraction was very expensive and difficult. UK and the USSR are examples. There may be distinct fields with exponential growth, but the overall tendency for such regions is that new fields did not come up with the ease needed to assure exponential growth in production.

All the data sets show peaking of production. From the Stage2 transition on out, production patterns tend to be *fragile*, possibly with several peaks can be traced to local politics.

All cases have potentials for future production. Such production will depend on the price of oil, though. Peak oil a la Hubbert seems to have happened because, today, no current production would be viable at $10US or $20US per bbl (nor even if we expressed price in 2012 dollars). Need will not go away so prices must rise. For the next several decades, we should see plenty of oil available, but at ever-increasing prices.

This report evaluates the growth of crude oil production (measured in bpd averaged over the year) from oil fields around the world. Our goal is to investigate if the traditional fields demonstrate evidence of terminal depletion. This analysis gives hints about future production trends.

Oil fields examined here	
1	Continental U.S
2	Venezuela
3	Mexico
4	North Sea – Norway
5	North Sea – U.K.
6	Saudi Arabia
7	Russian Federation

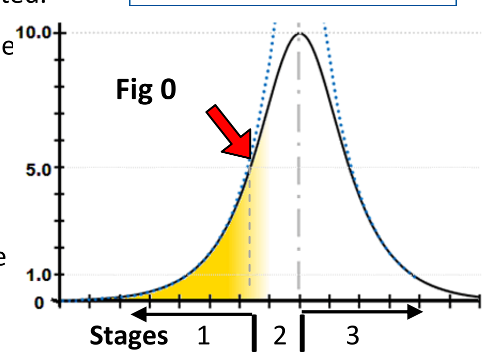
Our evaluation technique uses the three stages of any depletion curve (Refer to **Fig 0** and our *Exponential Growth and Depletion Of A Reserve.pdf*).

Stage1 Exponential Growth in production – 'free-growth' *rises without outside constraints*.

Stage2 Transition Interval between end exponential increases (arrow, **Fig 0**) and the point of maximum production after which it declines.

Stage3 Post Peak Production with negative 'growth' curve. Resource extraction is difficult, easily influenced by external drivers, cannot be predicted.

Our survey shows that production performance during Stage2 can also be dominated by external events – bumps and valleys may indicate corporate or national political stress more than reservoir health.



Our technique is to find the time when Stage1 ends (at arrow on plot).

This is not a perfect predictor of when "true" peaking may happen, but it *does show* that extraction is becoming increasingly difficult and this is the key information we desire.

After the end of its exponential production, a reservoir will begin to show signs of depletion; production will drop, extraction costs will rise, or both. When we can identify this point in the historical curve, the end of the reservoir's wealth is in sight.

The Earth still retains huge quantities of crude oil in its reservoirs. 2011 world 'proved' reserves per BP: **1,653 G bbl** (http://www.bp.com/)

Although oil ought not become scarce in the near future, prices will exclude those at the lowest earning levels from its use.

Note

1 G	1 US billion, 1 thousand million, elsewhere
1 bbl	1 barrel (US) oil, 1 m^3 = 6.2898 bbl
1 bpd	1 barrel/day

'Proved' reserves have generally agreed-upon sizes of economically extractable oil.

Charles J. Armentrout, Ann Arbor

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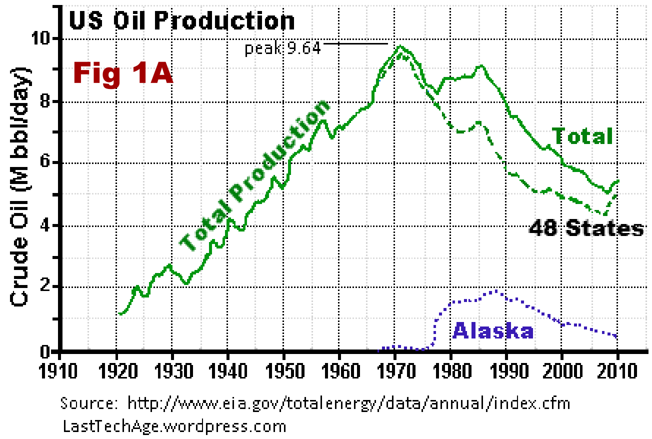
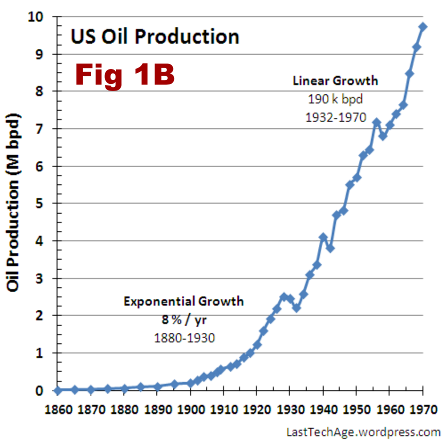
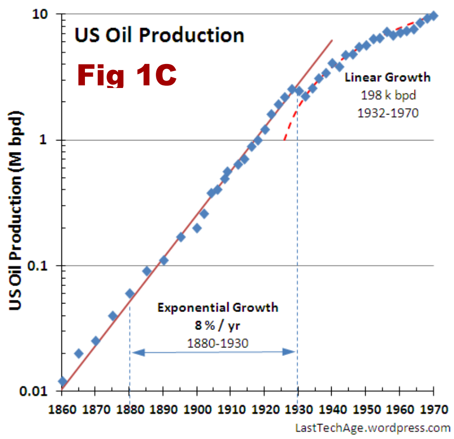
United States of America



USA was the first exporter of oil and oil products, and the first to find is production (barrels per day, bpd) of crude peaking – signifying the end of its easy crude oil pumping methods.

Fig 1A shows production from U.S. oil fields since 1920. Peak production occurred in November of 1970. Although we ought to expect exponential growth, the visual trend is a ragged straight line, growing a factor ≥ 3 in 40 years 1932-1970. Linear growth means the producers are struggling to maintain a high rate of increase by opening new fields and deploying new expensive extraction techniques. Without urgent intervention, production would have curved over and flattened into a broader peak value.





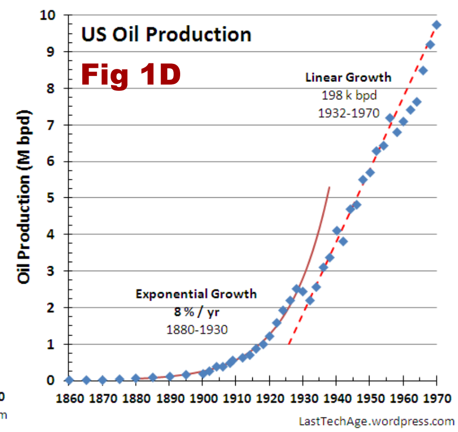


Fig 1B **Standard linear-linear plot.** Early production: 1860 –1970 (year of peak production)

Fig 1C **Log-linear plot of the same data.** This table shows the patterns:
The straight trendline indicates *exponential* growth for 1860-1930 but it was fit to 1880-1930. The *linear growth* during 1931-1970 displays as a curved trendline.

US Oil growth

Years	Time	Total Growth	Rate
1860-1930	70 yr	230 ×	8%/yr
1880-1920	40 yr	23.6 ×	8%/yr
1932-1970	38yr	3.5 ×	198 k bpd/yr

Fig 1D **Linear plot** showing the trendlines, both exponential and linear.

(1) *Exponential growth* – expanding without constraints … 8% per year for the first 70 years ending in 1930, never to happen again.

(2) *Linear growth* – production expanded at a nearly constant 200,000 bpd each year for the next 40year, ending in 1970. This was not the gentle roll-off into a peak plateau of models that are independent of outside constraints. This is evidence of a stressed industry.

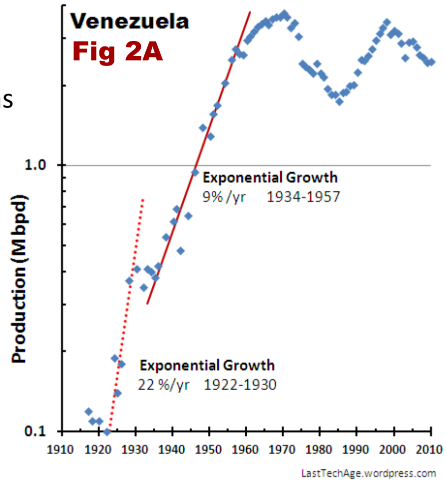
(3) *Very sharp production peak* – in 1970, when growth changed from positive to negative. Post peak turndown was much sharper (more painful) than it would have without the action of point **(2)**.

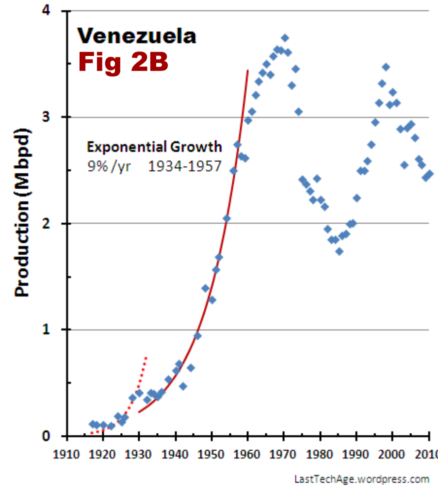
The huge efforts in the 1970s to restart upwards growth failed –even the Alaskan Prudhoe Bay fields did not have any long lasting effect.

- In 2011, production was 7.84 M bpd, with 'proved' reserves of 30.9 G bbl, less than 2% of world total. New estimates give much larger reserves, based on (much) higher prices allowing expensive new technologies.

Venezuela

Figs 2A and 2B shows an analysis choice that follows historical politics. The Mene Grande field was discovered in 1914, but WW-I delayed production. Each year, pumping increased by 22%, and Venezuela became the #2 oil producing country (after the US); growth was interrupted by the Great Depression.





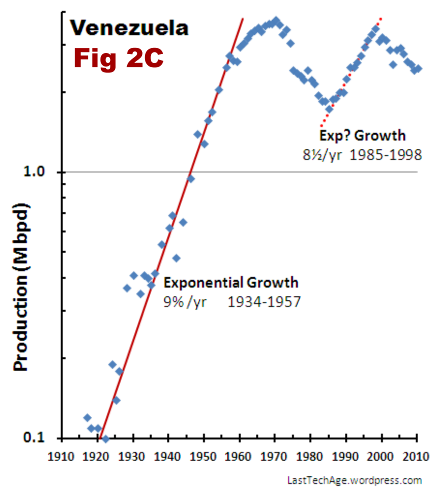
Exponential growth resumed for another 20 years after 1935 when Presidente Gomez died. Venezuela has seen huge political stress, including nationalization of all oil fields in 1975. The restart of probable exponential growth in 1986-98 indicates relative stability in this tumultuous region.

Fig 2 C and D use the observations:

(1) early 22% growth rate occurred for a growth of a factor of only 4

(2) the 1934-57 trendline can be extended back to 1920. for a 30× factor in exponential free growth.

For certainty that the trendline is exponential, the trendline should rise by a factor of about 10.



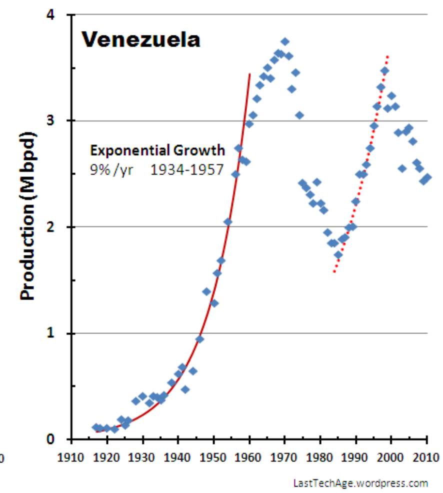


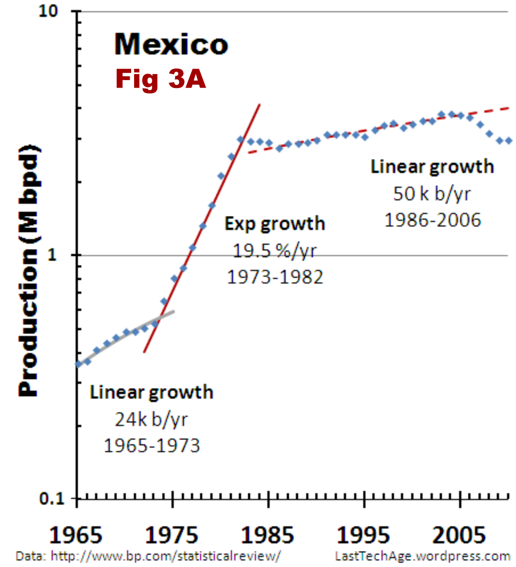
Fig 2 C+D are probably more useful, even though Fig 2A+B matches the historical story. If there had been no political constraints between 1957 and 1985, a broad single peak might have occurred in the 1983-85 timeframe, decline seen thereafter. Many commenters say Venezuela has move past its production peak.

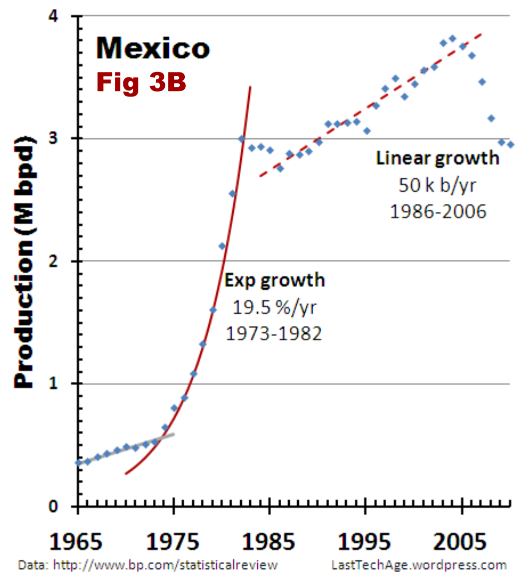
Venezuela oil production demonstrated exponential growth up to 1957. Using a Hubbert model, the end of free growth indicates that the reservoir they were drawing upon had reached its half full level. Extraction became ever-more difficult (expensive). Political instability easily disrupted production and the double peak appears to have masked the peak production point with inevitable decreases to come.

- The BP 2012 report lists 'proved' reserves for Venezuela in 2011 at 296.5 G bbl, with production at 2.72 M bpd. Venezuelan 'proved' reserves exceed 18% of all oil reserves in the world.

'Proved' resources are huge, so the peak in the data curve must indicate the health of only their current production fields. The untapped resources must lie in logistically difficult (expensive) regions. This does not mean there will no more oil produced, just that the price of crude must rise to justify its extraction. With higher prices justifying more expensive extraction methods.

Mexico





Oil was first discovered in 1901 and exports began in 1911. Production rose and peaked at just over 1/2 M bpd for 1920. Political and business issues blocked further growth since Venezuela had become the favorite for the industrialists to work with. In the mid to late 1930s the foreign oil companies were facing widespread labor complaints due to terrible treatment of their workers. The situation became so tense that Presidente Cárdenas nationalized the entire oil production industry in 1938.

The resulting boycott by foreign companies stopped the growth, and markets did not pick up until the U.S. crisis in the early 1970s. The 1920 production peak level was not matched until 1973, 53 years later. No earlier data tables have been discovered on-line, so we cannot include the stressful early years to the graphs.

The **Cantarell** complex of oil fields (in the Gulf of Mexico, near base of Yucatan peninsula) was discovered in 1976 and **Pemex**, the national oil company, started drilling shortly thereafter. Cantarell proved to be the 3rd largest field in the world and production exponentiated for 10 years. By 2003 it was the world's 2nd highest producing field, after the **Saudi Ghawar** field. Rapid production shortened Cantarell's useful life.

Fig 3A is the log-linear plot of the available data.
Fig 3B is a normal linear graph that shows the 3A trendlines.

(1) **Exponential growth** started ***before*** Cantarell started producing in 1977 but its height is due to it.

(2) **Linear growth** from 1986 to 2006 (34 years after the end of exponential growth in 1982) shows government efforts to force increases from an increasingly difficult field.

(3) **Production peaked** in 2004 and has declined every year since, including 2011 (which was 2.94 M bpd, down from 2.96 M bpd during 2010).

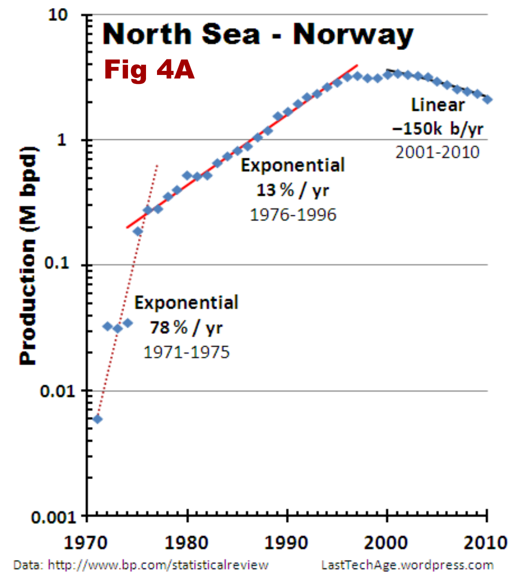
- The BP 2012 report lists 'proved' reserves in 2011 at 11.4 G bbl, 63% of the reserves for the U.S. This is about the the size of all the oil extracted from Cantarell.

Pemex has a number of new undeveloped fields that might expand reserves when in operation. These include the probably large **Ku-Maloob-Zaap** complex near Cantarell, and the **Sihil** below the current Cantarell reservoir. Logistics for these and other fields is difficult and extraction has been slow.

Has Mexican production has truly declined, as would be if they had crossed the overall Hubbert peak? Or, have social instability, relative poverty and political agendas been external constraints acting against the development of (possibly) large pools? The 2011 decline was very small; potential appears large; expect an upswing as Pemex pushes exploration and brings new fields on line (in step with increasing crude oil prices).

North Sea – Norway

Since the mid 1800s, oil and natural gas have been discovered around the North Sea basin (eastern UK coast across to western Norwegian coast and south to the northern coast of Europe). By international agreement in the late 1960s, five countries own concession rights: Norway, UK, Denmark, Germany, and Netherlands. The majority of the North Sea oil was found in UK and Norwegian regions.



In 1969 Phillips Petroleum announced oil off Norwegian waters at almost the same time that Amoco announced a find off-shore from Aberdeen (Scotland). Norway encouraged extraction and production began almost immediately.

Fig 4A shows production following along an exponential trendline, jumping by about 30 for about 5 years. Production grew at an annual 13% per year through 1996, when leveled off. Clearly, the mid 1990s was a time for regrouping and increasing effort. The curved 2001-2010 trendline represents a linear decay (the line itself is hard to see behind the close-spaced data).

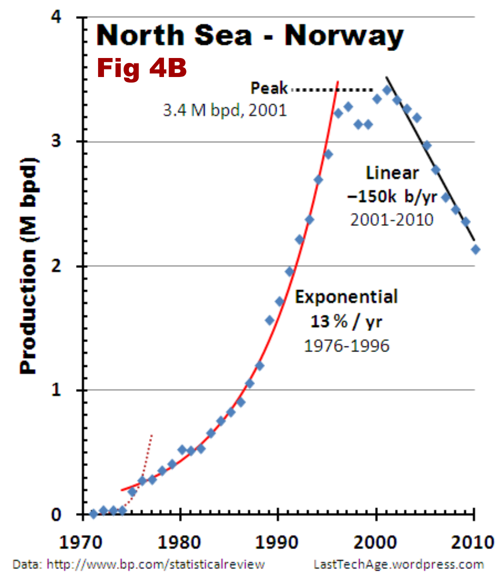


Fig 4B is a standard linear plot, with 4A's trendlines. Peak production from all the Norway fields occurred in 2001. Production has decreased since along a linear trendline. The linearly decreasing trendline (2001-2010) is clear here.

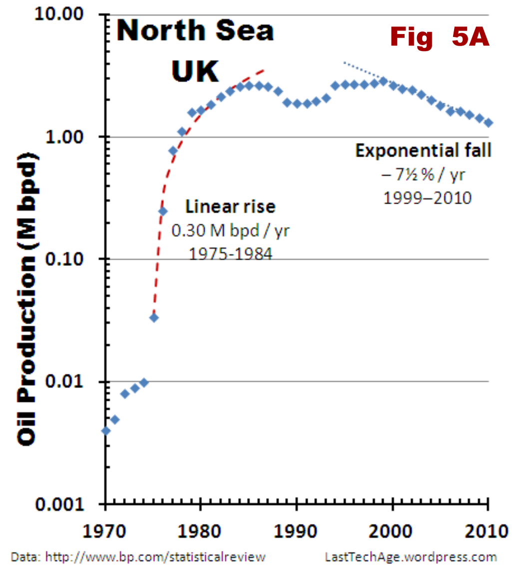
The North Sea oil is generally acknowledged as having crossed its Hubbert peak, in 2001 for Norway. Production is on its ever downwards curve, until it ceases (when profitability goes negative).

Norway has other sources of oil, especially in the Barents Sea in the arctic, a region also claimed [1] by the Russian Federation.

- The BP 2012 report lists 'proved' reserves in 2011 for Norway at 6.9 G bbl, and production at 2.0 M bpd.

[1] http://spectrum.ieee.org/energywise/energy/fossil-fuels/arctic-oil-geopolitics

North Sea – UK



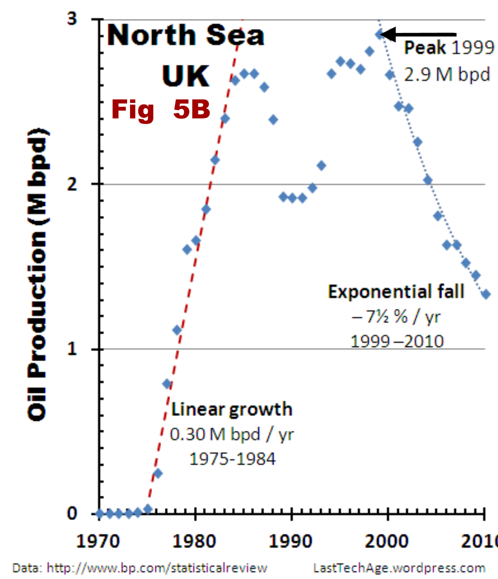
Since the mid 1800s, oil and natural gas have been discovered around the North Sea basin (eastern UK coast across to western Norwegian coast and south to the northern coast of Europe). By international agreement in the late 1960s, five countries own concession rights: Norway, UK, Denmark, Germany, and Netherlands. The majority of the North Sea oil was found in UK and Norwegian regions.

In 1969 Phillips Petroleum announced oil off Norwegian waters at almost the same time that Amoco announced a find off-shore from Aberdeen (Scotland). Shell UK Ltd. announced the huge Brent oil field in 1971.

UK business was not especially interested until crude prices rose by a factor of 4 during the first oil embargo of 1973 which focused the business mind. Serious pumping started in 1975. The huge Brent field first started production in 1976.

Fig 5A Log-liner graph of UK production, linear growth is a curved line, exponential free growth is straight.

Fig 5B Linear-linear chart with the trendlines from 5A. These graphs show astonishing behavior by the UK petroleum business community.



Growth did not follow the expected exponential rise seen when a large and valuable resource base starts to be used; compare to the parallel experience of Norway with its North Sea fields. The linear rise (curved red dashed line in 5A and straight red dashed line in 5B) indicates that they placed a number of oil wells, but cannot have used profits to fund new growth.

The peak in 1985 is actually a Hubbert peak (indicator that the tapped oil pools were becoming exhausted). The developed oil pools had to have been drained without replacement from neighboring fields found by exploration.

The massive explosion of the Piper Alpha rig with its huge loss of life has been blamed for the 1986-1994 dip, but the event was in **1988**. Piper Alpha certainly slowed things down until 1990 when new safety regulations were implemented. (The bottom of the production curve was in 1990). Oil prices tripled in 1979 during the second oil crisis. Certain UK commentaries blame the dip on the drop in world prices which started in 1983. If this were the whole story, why was Norwegian production not affected, too? There must be some other internal UK reason for the spectacular production dip. The linear initial rise indicates the companies were lackadaisical with initial investment. Might they have decided to let the fields drift and do a bit of profit-taking? (Such a decision could explain the underlying *why* of the Piper Alpha event.)

- The BP 2012 report lists 'proved' reserves for the UK in 2011 at 2.8 G bbl, with production at 1.1 M bpd. The UK ought to be strongly exploring the Shetlands to re-open its oil future. Is it?

Saudi Arabia

Oil was first discovered in Saudi Arabia in 1938, after 5 years of search. First export was in 1939. This was done by foreign companies operating under the name Aramco (Arab American Oil Company). Full ownership finally went to the Kingdom of Saudi Arabia in 1980 and the name ultimately became Saudi Aramco. (We skip 4 decades of intense political tension.)

The onshore Ghawar field is/was the largest known reservoir in the world, and the offshore Safaniya field ranks very high.

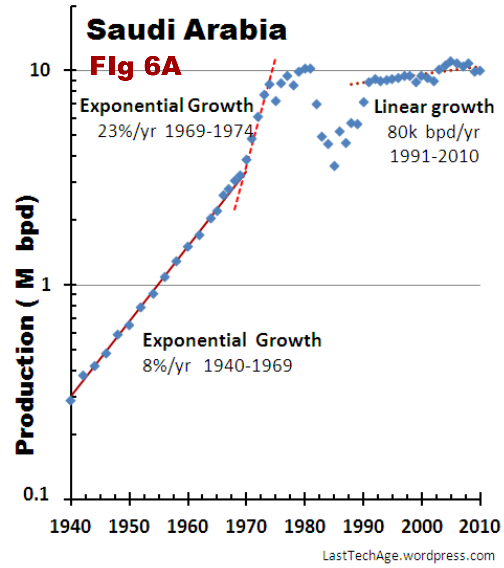


Fig 6A Log-linear graph. Production grew exponentially through 1969 with a regular 8% growth each year. Growth rate jumped to 23% (step is > factor of 2) and production fits an exponential trendline. We label this jump as exponential because the trendline fits the data points well, but expansion ended without the 10× growth needed for clear identification.

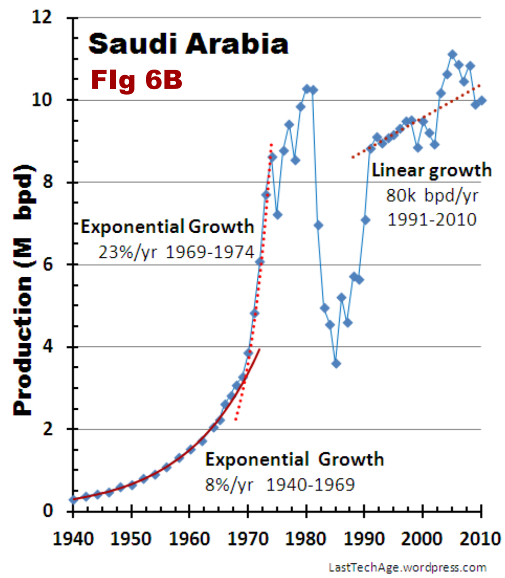


Fig 6B Linear-linear graph. Standard plot showing trendlines from 6A.

Referring to 6A, we can see that after 1974, Saudi oil lost any pretense for exponential growth. During the turbulent times of 1973-1980 (Yom Kippur war and the Iranian Revolution), production was scattered about a linear trendline. The Saudi's did not regain stable production until 1991. The 6A log plot suggests that these last years follow a straight line thereafter, but the 6B linear plot shows that production has been highly volatile; it is possible that The current fields are in actual decline. *The Saudi's have been quoted that they will need prices above $100/bbl to keep production at its high level.*

- The BP 2012 report lists 'proved' reserves in 2011 for Saudi Arabia at 265.4 G bbl, with production at 11.2 M bpd. The trendline would just about go through this value for 2011.

Can the Saudis keep production above the world price-stabilizing 11 M bpd rate, or even go beyond? The days of free expansion from a huge reservoir ended before the mid 1970s. The erratic production data shows that high production is causing real strain. By maintaining high production, the Saudi leadership is hurrying the depletion of its own underground treasure. This is a strategic decision only they should make. As with all countries examined, with higher prices will come more oil from increasingly difficult fields.

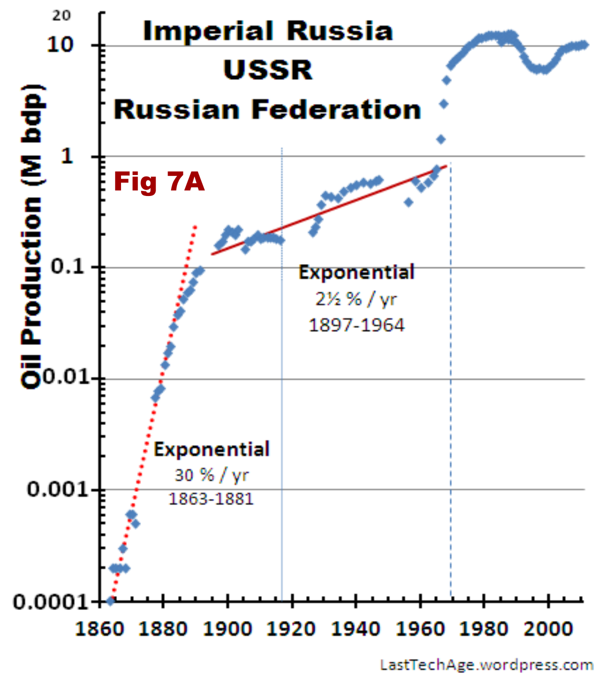
The right question is not "is Saudi oil production about to end?" But should be: "How long can the Saudis maintain extremely high production rates independent of price?" They went past the easy peak in 1969, right now they are doing what they can to maintain a robust shipment rate in the face of declining supply from their (current) reservoirs. Crude prices must rise, and probable steeply, if they are to extract meaningful quantities from more challenging reservoirs.

Russian Federation

This nation has been torn by strife and stress. The last 100 years are divided into Imperial Russia (…– 1917), Soviet Union or USSR (1917-1991) and the Russian Federation (1992–…). This is a difficult analysis: Not all Russian oil data sets on the internet mutually agree (example, BP tables are not like IEA tables), and Russia has been a difficult oil reservoir to analyze. **In the end, we used 2 sources for data.**

Data for 1965-2011 are from the BP Statistical Review of World Energy, 2012, because it covers 1965 through 2011.

Early data source is "*Oil Of Russia: past, present, and future*," by Vagit Alekperov; translated from the Russian by Paul B. Gallagher and Thomas D. Hedden. – 1st ed., Publ 2011 East View Press, an imprint of East View Information Services, Inc. Minneapolis. (See box, below) Full PDF here[(2)]. The data are in tonnes of oil and was converted to bbl for consistency. A single conversion factor was needed for agreement during the overlapping dates (1965-1980) of the Alekperov and BP data. This conversion was then applied to all the early data.



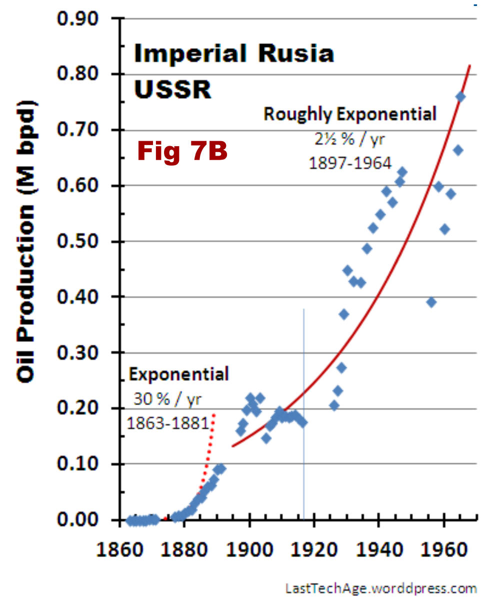


Fig 7A shows the data base, from 1863 to 2011, in log-linear form. The light vertical line at 1917 separates Imperial Russia from Communist USSR. The vertical dotted line at 1970 is the extent of Figure B. Before 1882, growth was exponential and expanded by a factor of about 300. By 1900, Imperial Russia was actually producing more oil than the US. This flattened out through the 1917 Revolution.

Fig 7B is shows the same trendlines on the more natural linear plot. The true initializing exponential occurred when production was so small, that it is hardly apparent on the graph.

Production during Stalin times was chaotic. The pattern appears as a series of very short trends. It also may be consistent with a slow exponential trendline covering growt between 1900 and 1965. But …

(A) The growth range is only about 5× (from 0.15 to 0.75), too small for a conclusion about any exponential pattern.

(B) The data show huge scatter about any proposed trendline.

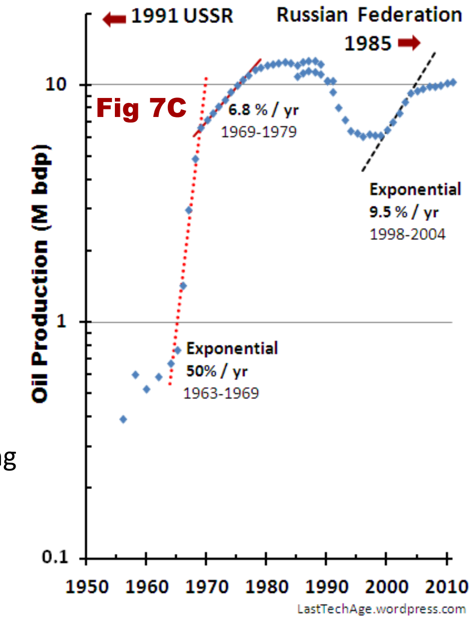
It is pretty certain that someone who lived through this time would not have recognized "exponential growth."

Dr Alekperov was born to an oil industry working family, and was himself a worker in the oil industry. He became a high manager of several oil companies, and earned Doctor of Economics. He is President of LUKOIL, and member of the Russian Academy of Natural Sciences. His book is based on original research to capture data in the archives before they are lost forever.

(2) http://www.litasco.com/_library/pdf/media/oil_of_russia_by_Vagit_ALEKPEROV_full%20edition.pdf

Russia, Current Times

The Volga-Urals field (7E) opened in the early 1950s and was joined by the start of pumping from the Western Siberian fields in the 1970s. These two, in combination with the others provided the boost needed for the rise in the 1970s.



The 1980s were unpleasant in the USSR. Highlights:

- 1982 Death of General Secretary Leonid Brezhnev
- 1984 Death of General Secretary Yuri Andropov
- 1985 Death of General Secretary Konstantin Chernenko
- 1986 Chernobyl reactor disaster with core melt

The USSR was officially dissolved 1991 Dec 25. If the US lost 3 presidents in 3 years and had a nuclear disaster with radiation poisoning over broad areas, we would have had trouble coping, too.

Fig 7C present oil production as a log-linear graph. These BP data follow the USSR through 1991 but start Russian Fed. data (lower of the two curves) at 1985. 1990s were also rough years – from this side of the Atlantic, it appeared that criminal gangs were in struggling for dominance. Oil production did not start back up until the end of the decade. It may be that the exponential rise shown is nothing more than a partial recovery.

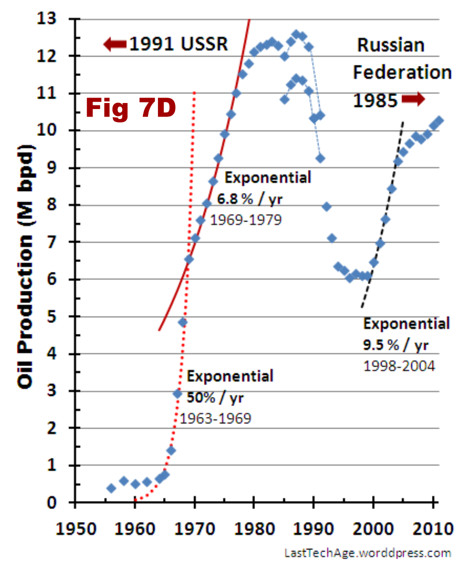
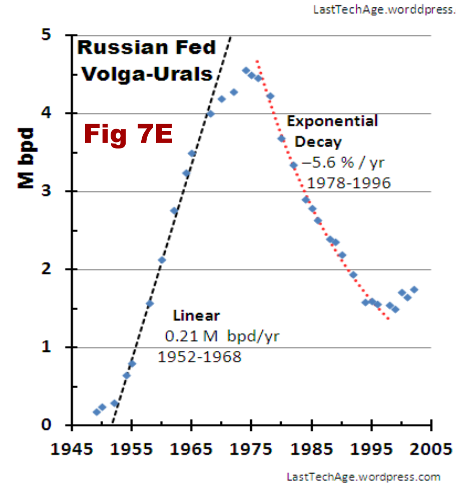


Fig 7D is the linear graph of the same data. Normal presentation but the curves are extraordinary. The 1985 bounce shows up in Venezuela and Saudi Arabia data sets and the UK was well into its major downward dip. The dip does not not show in data for Norway, Mexico or the US.

Fig 7E the Volga-Urals field is shown as a linear plot only. The initial development was linear, not exponential for this single field. *7D and 7E are not consistent in production rates, and I have no explanation*. V-U is now well into decline, but more expensive techniques now appear to be generating new oil. Eastern and Northern Siberian oil fields are surely in the same situation because the fields are difficult (expensive) to work.



Most of Russian resources lie in the depths of cold tundra, or under Arctic waters. One dilemma is that there are huge fields on the Barents sea shelf that extends much further than 200 miles from coast lines used for clear ownership. In some regions, Russia and Norway conflict on oil-rights claims; Russia also claims for other non-territorial arctic regions.

Opinion – the peaks of Figures 7 C-D are political, not Hubbert peaks. Most of the huge Russian resources should be classed as *expensive reservoirs* to go on-line when the price allows profitable extraction.