US drilling and production 1900-2021

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Number of rigs and wells & footage
US oil & gas drilling activity is the most important in the world. The percentage of US rigs versus the world was 60% from 1975 to 1985, then 45% from 1985 to 2000, peaked o, 2008 and back to 45 % in 2018:

![world & US number of rigs graph](image)

From 1960 to 2015, the number of US oilwells was between 500 000 and 600 000, when the number of US gaswells jumped from 100 000 to 500 000, most being marginal.
From past data up to 2010, it was obvious that 75% of the US oilwells were strippers, making 15% of the production:

EIA monthly review displays this graph 1949-2022 on oil and gas rigs as vertical, directional, and horizontal rigs in operation with a collapse in 2022 on vertical and directional rigs. The peak of vertical rigs was 2007 with none in 2022. NG rigs peaked in 2008, with few in 2022. Oil rigs peaked in 2014.
Figure 5.1 Crude Oil and Natural Gas Drilling Activity Measurements

Rotary Rigs in Operation by Type, 1949–2022

Rotary Rigs in Operation by Trajectory, 1991–2022

Good EIA display of wells and footage for 1949-2022

Figure 5.2 Crude Oil and Natural Gas Wells and Footage Drilled

Wells Drilled by Type, 1949–2022

Wells Drilled by Trajectory, 1969–2022

Footage Drilled by Trajectory, 1989–2022

Source: Table 5.2.
What is missing is the success ratio: because the high oil price in 1980 all the poor prospects on the shelf were drilled and many were dry!
The success ratio of oil & gas wells increases since a low of 60% in 1970 to 90% in 2010 as most of wells were shale plays in development and very little exploration!

The lowest success ratio was 60% in 1970 at the peak of production. The success ratio was about 80% (20% of dry holes) from 1890 to 1914.

**Chart 2**

*Dry Holes as Percentage of Total Wells Drilled, 1865–1914*


My display of EIA data:
The length of horizontal wells (purple) went from 9,000 ft to 18,000 ft from 2008 to 2020:

The display of footage and production (in quad = 1.06 EJ) shows well the poor return of the 1981-1984 footage burst. In contrary since 2010 increase in production with footage and since 2015 increase of production despite decrease in footage.
US oil & gas production is reported in EJ from 1949 to 2021 from EIA and 1900 to 2021 from ASPOFrance data.

US O&G production is modelled in future to decline as the rise since 2010: the main reason for a sharp decline is the shale play displays a strong decline after few years and needs as the Red Queen (keeping running to stay at the same place) to keep drilling: it is the EIA forecast AEO2022, which forecasts the O&G production peak beyond 2050 = completely unrealistic.
Most of shale plays are almost completely drilled and new child wells disturbed parent wells. EIA forecast is based in drilling many wells without bothering to check if there is enough room to drill them. There are also hopes that new refracturing will help.

EIA past production forecasts AEO 1979 to 2023 compared to real data show that in the past IEA was very poor in forecasting future production and it is likely that it is the same for their production beyond 2030:

In the past a successful well was completed by the same rig before to be put in production. With compact reservoirs, fracking needs a special equipment, but no rig: now fracking is now done later and well not yet completed is called DUC = drilled but uncompleted.

- **Frack spread = frack fleet**
- The annual number of frack fleets (frack spreads) was small in 19800 and starts to increase since 2003. The number of vertical wells decreases sharply after 2008.
The monthly of rigs (blue) peaked by end 2018, collapsed with covid19, and peaked again by end 2022. There are 3 times more oil rigs than gas rigs.

The weekly number of rigs and WTI price oilprice.com graph mid 2018-2023:
The annual number of horizontal wells peaked sharply in 2013 and the number of DUCs in 2020/

The number of US drilled wells is much less than the number of US completed wells, leaving the DUCs:
https://www.eia.gov/todayinenergy/detail.php?id=54179

Princeton energy advisors https://static1.squarespace.com/static/ displays the horizontal oil rigs count from Nov2014 to Nov 2022 by plays, as WTI price: Permian play is the largest.
The horizontal oil rig count (deep red) is followed by the shale plays production (lower grey). The frac spreads (light red) is similar.

Princeton energy advisors display a more detailed graph where frac spreads oil / horizontal oil rigs % (in blue) oscillates between 40 and 70 %.
The neutral Spread Ratio, the ratio of spreads to rigs which will hold the DUC inventory constant, is 52.8%.

The observed Spread Ratio remained at 45.7% for the week.

This implies that drill rigs are adding wells at a pace faster than they are being fracked, leading to a rise in DUC inventories.
Fracking in the United States

In the United States, fracking began in 1949. According to the Department of Energy (DOE), by 2013 at least two million oil and gas wells in the US had been hydraulically fractured, and that of new wells being drilled, up to 95% are hydraulically fractured. The output from these wells makes up 43% of the oil production and 67% of the natural gas production in the United States. Environmental safety and health concerns about hydraulic fracturing emerged in the 1980s and are still being debated at the state and federal levels.

New York State banned massive hydraulic fracturing by executive order in 2010, so all NG production in the state is from wells drilled prior to the ban.

View of fracking in 2020
View of fracking in 1950
Carl T. Montgomery and Michael B. Smith, NSI Technologies JPT Dec

Fig. 6—Vintage 1950s remotely controlled frac pumper powered by surplus WWII Allison aircraft engines.

-Production per foot and footage
US footage is compared for all wells, oil wells and gas wells production per foot:

The US O&G production per well is the same as per foot from 1950 to 1990, then increases a little until 2015 where it is much higher: 3 times in 2021.
US O&G footage is compared with EIA production per foot:

The production per foot oscillates from 1950 to 2021 between 100 and 450 GJ. The footage oscillates between 100 and 450 Mft.

Both curves are opposite, then footage is compared to prod/foot multiplied by -1:

The display looks with cycles of 30 years.
But the more you drill, the less you produce per foot! Despite all the improvements in exploration, drilling and production!

C.A. Hall, C.J. Cleveland “Petroleum drilling and production in the United States yield per effort and net energy analysis” Science 1981 started to find this kind of correlation, but they were far to forecast to continue with cycles in a similar range!
ASPO France data reports the energy content of US oil and gas production since 1900:

Since 1964 NG +NGPL represents more than 50% of the US O&G energy content!

And by using before 1949 a constant footage per well, the result is a longer and better graph:

Graphs of oil and gas wells from 1900 “Ecosystem services lost to oil and gas in North America” Brady et al 2015 Science:
The American Petroleum Industry 1966 Williamson et al reports US production and new wells since 1865:

**CHART 1**

*New Wells Drilled and Total Crude Oil Production, 1865–1914*

US average depth (in fact length) has increased from 4000 ‘ in 1950 to over 15 000 ‘ in 2021.

Using these data, the graph starts from 1900:

The graph could be displayed with production per foot compared with footage*-1
The peak of production per foot is 1971, 1999 and 2200 around 400 EJ, corresponding to the minimum of footage of 120 Mft.

The more US drills, the less US produces per foot.

When US drills more inside the reservoir in shale plays as since 2010, with long lateral lengths in the reservoir, it should be expected to increase the production per foot, but in fact the data shows that it is like before the shale plays:

-Law of diminishing returns
It is the “Law of diminishing return” known in agriculture as manufacturing. It was mentioned by Turgot in mid 1700s, then by Malthus, Ricardo & Anderson

The optimum is where the maximum amount of output per units of input is possible.

Here in the US around 1970, 1995 and 2020

“US upstream industry relying on longer lateral drilling to boost cash flows” S. Spencer 2021
"The 13,000 foot lateral is more economical than a 10,000 foot lateral, but you get less incremental production for each additional foot drilled,"

“Diminishing returns, or growing pains, from tight wells” S.Flowers 2017
There are also signs that inexorably ramping up the intensity of the extraction process is suffering from diminishing returns. Around 90% of horizontal Wolfcamp wells have been drilled with laterals less than 10,000 foot. Normalised productivity on longer laterals – those above 10,000 foot - has been 20% lower. Drilling costs rise exponentially with depth, and there’s a suspicion that longer wells are hitting a cost efficiency ceiling.

“The Horizon Accident, Peak Oil and the Law of Diminishing Returns” Bernstein 2010

Diminishing returns show up in oil just the way they do in agriculture. A concept called the Energy Return on Energy Invested (EROEI) illustrates the diminishing returns to oil
exploration effort through the history of the oil industry. EROEI measures the energy content of an oilfield divided by the energy needed to get the oil. In the 1930s, U.S. oil production is now estimated to have yielded an **EROEI of about 100**; The number dropped to 30-ish in 1970 and to the range of 11-18 by the year 2000. T

The graph production per foot versus footage shows that the maximum of production per foot over 400 EJ is reached when the annual footage is between 100 and 200 Mft.

- **production growth per foot and footage**
  But the above graphs could be misleading as the O&G production is from all producing wells for a certain year, when the footage is only the number of feet drilled for this certain year. It appears to be better to compare the production growth (production change) for this year with the corresponding footage. The result is different: the correlation is much less obvious and only up to 1985.
Since 2010 with the shale plays the production growth per foot increases, as the footage.

The graph of US O&G production change per foot versus the footage fills the space:

-oil & gas drilling cost
Data for all wells:
The comparison of costs for all wells with oil price is not good.

But there is a very good correlation between 1960 and 2006 between the cost per well and the cost per foot, in real ($2000) and in nominal. It means that up to 2006, there is little advantage to drill horizontal wells with more footage. It is a pity that EIA does not update these data.

Data for oilwells:

EIA nominal cost per oilwell and per foot are identical from 1960 to 2007:
Data for gaswells:
The NG cost for foot and per well vary together with NG price from 1960 to 2005, but beyond 2005, NG price is very low as NG is flared in order to produce oil!

Only in 2003 NG price was about equivalent with oil price: 2003 is the year with the minimum of flaring.
There is a very good correlation for gaswells between cost per well and cost per foot up to 2006:

EIA 2016 report on upstream cost
https://www.eia.gov/analysis/studies/drilling/pdf/upstream.pdf
The main cost is frac pumps, equipment in green with 24%.

Midland play is the most expensive:

Marcellus is the most expensive for proppant:
Figure 2-16: Historical trends of proppant (Lbs./Ft)

Figure 2-17: Drilling cost rate per foot

Figure 2-18: Completion cost rate per lb. of proppant
EIA reports only annual cost per foot and per well from 1960 to 2007 (data released in 2023!)
https://www.eia.gov/dnav/ng/hist/e_ertwo_xwpn_nus_dfa.htm

It is queer to see higher cost for dry holes after 1997: it means that the cost is only for drilling
and not for completing the well: dry holes have to be sealed, when producing wells needs to
be fracked before being completed!
EIA discontinues reporting US drilling cost per well and per foot after 2007!
And it is hard to find any US cost on Internet.
The Financial Times 2023 “What the end of the US shale revolution would mean for the
world” https://www.ft.com/content/60747b3b-e6ea-47c0-938d-af515816d0f1 displays this
from 2018 WTI, rig rate and production costs (nothing on fracking?)

It is well known that many oil & gas shale producers have been bankrupted: the best example
is Chesapeake. But if the company lost money, it is not the same for managers getting free
stock options on rising stock market.
Chesapeake net income (green) was negative for many years when long term (orange) peaked
for the period 2008-2011 with a stock price of around 22 $!
Oil and Gas Lease Equipment and Operating Costs 1994 Through 2009 (discontinued)
https://www.eia.gov/naturalgas/archive/cost_indices_equipment_production/current/coststudy.html

According to Reuters, estimates put the break-even point for fracking at around $50 per barrel, but other estimates put it as low as $30 per barrel.

-oil & NG price
It appears that the crude oil and NG prices have a strong impact on US drilling. US O&G drilling footage correlates very well with BP crude oil price 1861-2021 in real dollar 2021, except during the period 1945-1973 (first oil shock) called the “30 glorious“
US O&G footage correlates with NG price except during the 30 glorious and beyond 2010, where crude oil production is the main goal and where NG is flared in some LTO plays:

US NG price are low compared with the rest of the world and the US oil price. WB reports oil and NG price in $/MBtu
US NG price was only equivalent with oil price in 2003, when oil price was about 6 times higher than NG price in 2012 and 2.6 times in 2022:

The strong impact of crude oil price on US drilling leads to look for future drilling to future oil price but it appears that past annual forecasts on crude oil price WTI by EIA AEO 1982 to AEO2023 were very poor compared to real data!
EIA NG price forecasts from AEO 2009 to 2023 were very poor compared to real values.

-US oil price and dollar index

There was a good correlation between oil price WTI and negative dollar value since 2005 but the correlation stopped in 2021:
In fact, since 2015 WTI correlates with the dollar value:

-US O&G production forecasts
USDOE/EIA AEO2023 reference forecasts a flat liquids production until 2050 and an increase in NG production, based on heavy drilling without bothering to check where: it is unrealistic! Even the low oil and gas supply cannot hope to stay flat beyond 2030, as reserves are infinite: it is unreal! It is not just to keep drilling, it is to check if there is room left for drilling.
EIA forecasts to export on 2050 more petroleum products and liquefied NG than today: it looks unrealistic:

EIA past forecasts from 1979 to 2023 display a poor performance: the shale play was completely ignored in the forecast of AEO2011.

For US NG production
US NG production forecast for 2050 above 40 Tcf when the 2022 production is less than 36 Tcf is just wishful thinking.

For US crude oil production: AEO2023 (purple) forecasts for 2050 an increasing crude oil production:

In 2013 EIA forecasted for 2020 a value less than half the real data.
EIA was poor in the past to forecast present production, it is normal to doubt about their very high forecast for 2050.

**-EIA future wells**
AEO forecasts in T14 the future number of wells drilled in USL48 with about 30 000 wells in 2050 for AEO2023, against 20 000 wells in 2022 in sharp decline since 2008:

AEO2012 forecasted for 2022 57 000 wells against 20 000 on reality: more than twice wrong!

**-my production forecasts**
HL of US O&G production trends towards 5100 EJ: the peak is soon when AEO2023 reference forecasts the peak beyond 2050:
Modelling US O&G past production with 3 cycles gives a similar forecast:

HL of US NG production trends towards 2500 EJ: the peak is soon when AEO2023 reference forecasts the peak beyond 2050:

Modelling US NG past production with 3 cycles gives a similar forecast:
HL of US liquids production trends towards 2300 EJ: the peak is soon when AEO2023 reference forecasts the peak beyond 2050:

Modelling US liquids production with 2 cycles gives a fair estimate. Modelling USL48 should be easy, as Alaska (few fields) is different from the rest of the US. Also deepwater (few fields) production is hard to model
Conclusion

US oil and gas production and drilling data have varied a lot since 1900, as price and cost, but also technology.

Attempts to correlate oil and gas production per foot and footage give some wrong results on the law of diminishing returns.

It appears that it is hard to find any good correlation to get a better understanding of future production.

From the many graphs above it is hard to draw any definitive conclusion except that EIA/AEO forecasts in the past were poor compared to real data and it is likely that EIA forecasts in 2050 will be also bad, being unrealistic by assuming an increase by 50% of the drilled wells, when most shale plays are almost completely drilled.

EIA does not bother to check about where to drill.

USDOE/EIA/AEO2023 forecast is very unrealistic for the reference scenario, but also for the low oil & gas supply.

Europe expects to receive US LNG for a long time; it will be short or at best medium time.