IN11E-0669: **Permian Basin Tight Oil Model to Predict Future Output**

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Introduction

Tight Oil production in the US has grown at an annual rate of 1160 kb/d for the past two years, while World C+C output grew at an annual rate of 740 kb/d over the same period. Over the longer period of 2011 to 2018 US tight oil accounted for about 55% of the increase in World C+C output. Major tight oil plays such as the Bakken/Three Forks in North Dakota and the Eagle Ford in Texas have been studied by Hughes (2014) and others. The Permian basin has seen fewer recent publications, but United States Geological Survey (USGS) publications from 2017 put Permian Basin technically recoverable resources(TRR) at about 28 Gb (mean estimate) with a new evaluation of the Wolfcamp formation of the Delaware Basin expected soon (we have estimated an 8 Gb mean for this formation). At about 36 Gb, the TRR of Permian Basin tight oil is more than the 25 Gb TRR of the Bakken/Three Forks and Eagle Ford combined. Other smaller US tight oil plays might add a further 10 Gb of TRR so that the Permian basin alone may represent at least half of the US tight oil resource. The future output of the Permian basin will be a key to understanding the future level of World oil production.

A Simple Physical Model

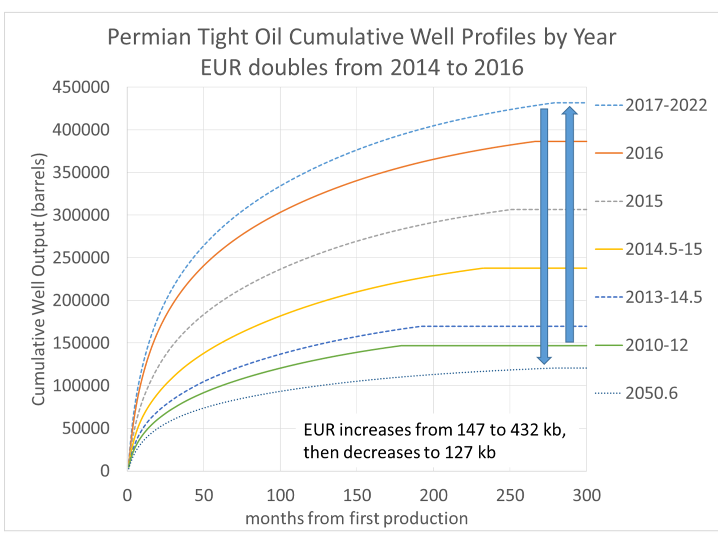

Figure 1 Arps hyperbolic well profile is fit to state level data gathered from www.shaleprofile.com

- well profile increases 2010-2017 and is assumed constant 2017-2022
- Increases in average lateral length, number of frack stages per foot of lateral, and pounds of proppant caused increase in new well EUR from 2010 to 2017.
- EUR decreases as sweet spots are fully drilled (medium case scenario=Jan 2023 start of EUR decrease)
- Schlumberger reports unit well productivity in Midland Wolfcamp decreased in 2018.
- Exponential terminal decline assumed when monthly decline rate=0.874% (10% annual decline rate)

Arps hyperbolic equation is $q(t)=q_0 / (1+D_i bt)^{1/b}$ where q(t)=monthly output, q_0=initial output, D_i=initial decline rate, b=constant, t=time in months from first well output.

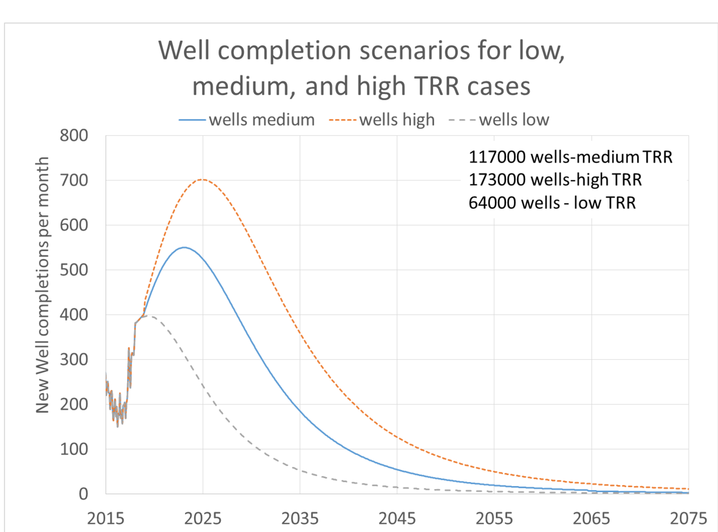

Figure 2 Three well completion scenarios corresponding to the low (F95), mean, and high(F5) USGS estimates for the Permian Basin with 64,000, 117,000, and 172,000 wells respectively. The Bakken was used as an analog with about 40,000 wells for the mean TRR case for the North Dakota Bakken scaled up by roughly a factor of 3.

- maximum entropy probability distribution (following Jaynes) mean=99,000 (18,000 wells drilled to date)
- 37% probability wells completed < 64,000
- 21% probability wells completed > 172,000
- 26% probability 64k < wells completed < 117k
- 16% probability 117k < wells completed < 172k
- Cumulative completed well function is $C(t)=a/(1+b/t^4)$, a=total wells completed, C(t) is cumulative wells completed in month t, and b is chosen so peak completed wells is about 400, 550, and 700 at t=120, 156, and 192 months respectively, t=0 at Dec 2009.

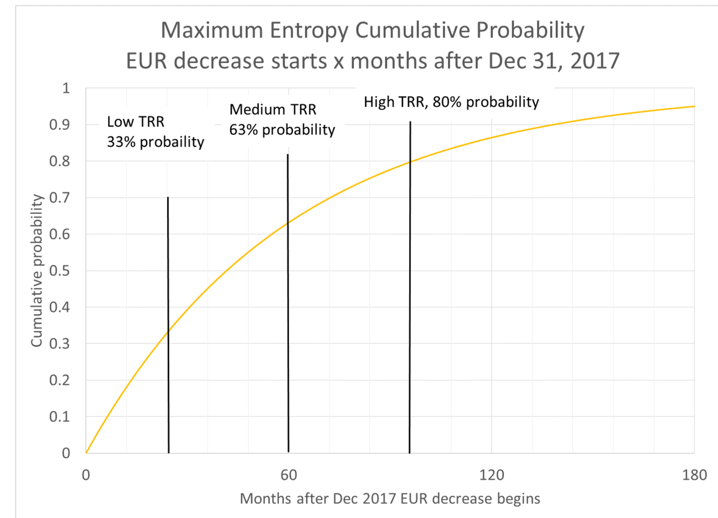

Figure 3 New well Estimated Ultimate Recovery (EUR) will decrease at some future date

- Bakken analog; we assume for mean Bakken case that EUR decrease starts in Jan 2020
- Permian mean case assumes EUR decrease starts Jan 2023; Permian ramp began about 3 years after Bakken
- Maximum Entropy (Maxent) Probability distribution used with mean=3 years=standard deviation
- Low TRR case, EUR decrease starts Jan 2020, 33% chance it may occur Dec 2019 or earlier
- Mean TRR case, EUR decrease starts in Jan 2023, 63% probability it begins Jan 2018 to Dec 2022
- High TRR case, EUR decrease begins in Jan 2026, 20% probability it occurs after Feb 2026 or later

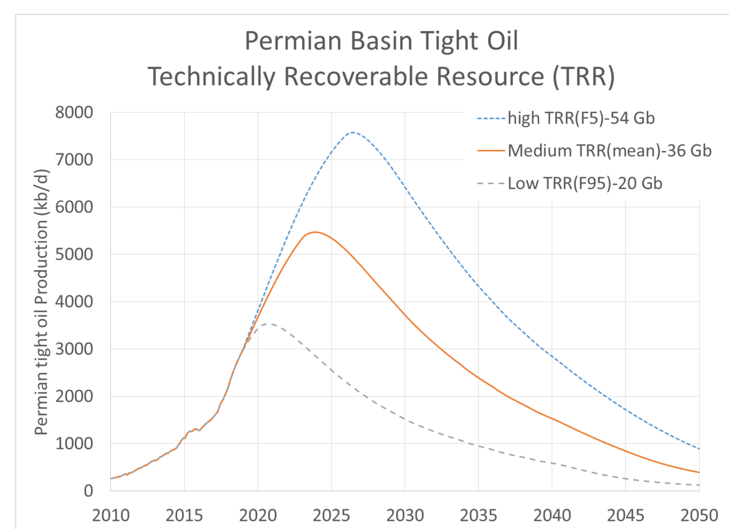

Figure 4 Output for 3 TRR cases is determined by the convolution of the well completion scenarios in figure 2 with the well profiles from figure 1 (using the average output per month for each well, monthly difference of cumulative well profile)

- Rate of EUR decrease after start date determined by cumulative wells completed and a target TRR set by the estimates of the USGS which determine the Low TRR (20 Gb-F95), Medium TRR (36 Gb-mean), and High TRR (54 Gb-F5) cases.
- For the hyperbolic equation from 2020 (low TRR case), 2023 (medium TRR case), or 2026 (high TRR case), D_i and b remain at the 2017-2019 level, the shape of the well profile is unchanged
- $q_0(t)=q' k^{(W-W_0)}$ and $k=r^{1/n}$, where $q'=q_0$ from 2017-2019, W_0=cumulative wells at start of EUR decrease and W=cumulative wells completed, n= total wells completed for TRR case after start of EUR decrease, r is a constant chosen so that TRR=20 Gb, 36 Gb, or 54 Gb for the respective cases. For medium TRR case n= 73,611, r=0.24, W_0 = 43,299.
- peak output is 3500, 5500, and 7500 kb/d in 2021, 2024, and 2027 for low, medium, and high TRR cases respectively

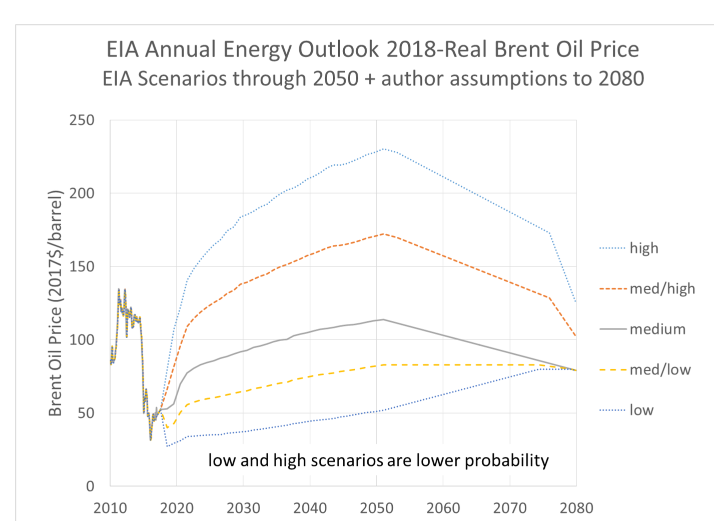

Figure 5 Real Brent Oil Prices in 2017$ from the US Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2018

- Low, Medium (Reference), and High Oil price cases taken directly from AEO 2018 (monthly interpolation between annual values)
- Med/low and Med/high cases are the average of low and Reference cases and Reference and high cases respectively
- Focus on Med/low, Medium, and Med/high cases due to higher likelihood
- Prices 2050-2080 assume transition to alternative transportation leading to faster demand decrease than oil supply decrease, causing a fall in real oil prices (except low oil price case where transition is slower)

Economic Assumptions

The following economic assumptions are combined with the oil price scenarios in Figure 5 and the previous geophysical analysis to find the Economically Recoverable Resource (ERR). All dollar costs are in constant 2017 US$.

- Well cost $9.5 million
- Operating expenses (OPEX) per well =$2.3/barrel+$15000/well each month
- Royalties plus taxes=32% of wellhead oil price
- Transport cost=$4/b
- Real annual discount rate=7% (nominal discount rate=9.5% at 2.5% annual inflation rate)
- Discounted net revenue over the life of the well for the assumed oil price scenario must be greater than real well cost for future wells to be completed
- Well is permanently abandoned (shut in) when monthly net revenue is less than $15,000

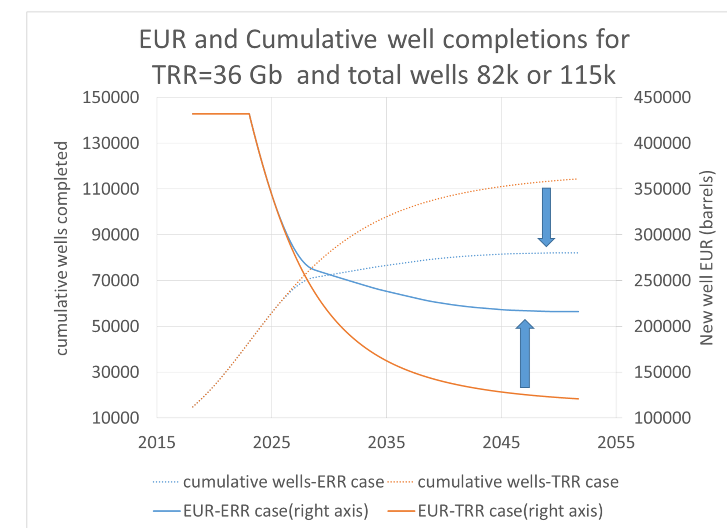

Figure 6 Application of economic assumptions and the AEO reference oil price scenario to the Mean TRR case of 36 Gb results in the medium ERR case.

- new well EUR versus time compared for TRR and ERR scenario
- cumulative well completions for TRR and ERR scenarios compared
- lower profits for low EUR wells leads to 33,000 fewer completions for ERR case
- lower cumulative completions for ERR case reduces overall decrease in EUR for ERR vs TRR scenario.

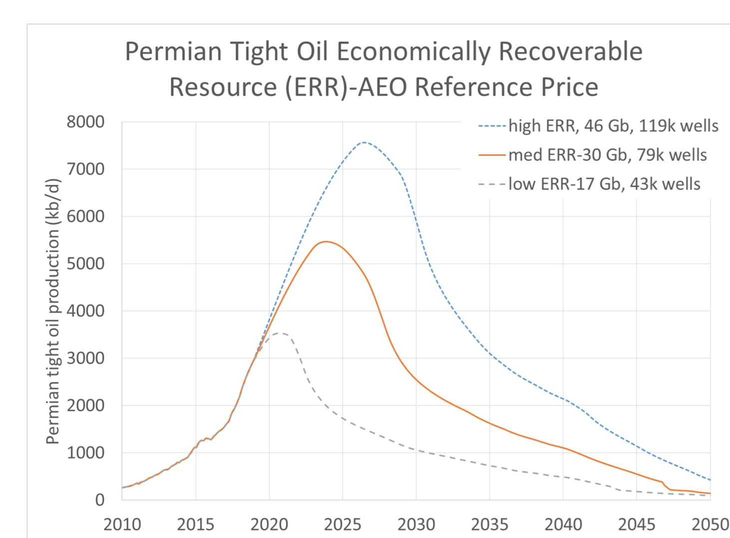

Figure 7 AEO Reference Oil Price Case (Medium Price) applied to 3 TRR scenarios from Figure 4 to give 3 medium oil price ERR scenarios (low, medium, and high).

- Output same as TRR case to peak output, lower output after peak as fewer wells completed
- ERR falls by 85% relative to TRR on average for 3 cases
- Wells completed 68% lower on average in ERR cases compared to TRR cases

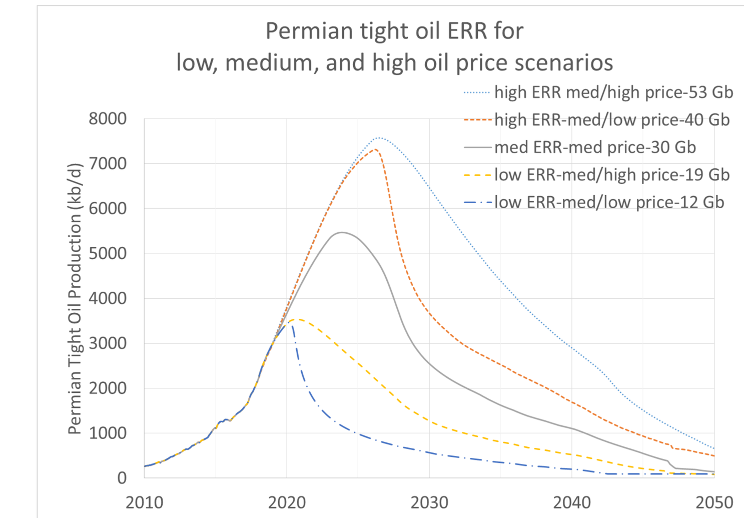

Figure 8 Several ERR scenarios, note that low ERR means the low TRR scenario is the geophysical basis to which an oil price scenario is applied (med/low, medium, or med/high), likewise medium and high ERR scenarios use the medium TRR or high TRR as their respective bases.

- Low oil price scenarios cause steep drop in output after peak, 3-7 years for 50% decrease
- Most likely range is low ERR-med/high oil price to high ERR-med/low price with 19-40 Gb range
- ERR range is 12-53 Gb based on low ERR-med/low price to high ERR-med/high price
- Maxent probability distribution (negative exponential function) with 30 Gb mean (4 Gb cumulative production and proved reserves) gives following probabilities for ERR ranges:

4-12 Gb	12-19 Gb	19-30 Gb	30-40 Gb	40-53 Gb	>53 Gb
26%	17%	19%	12%	10%	15%

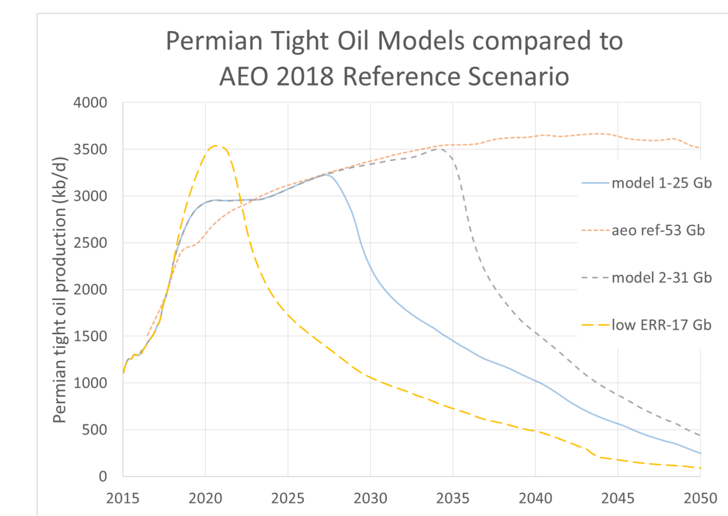

Figure 9 AEO Reference Scenario ERR for Permian Basin is 53 Gb including 2 Gb cumulative production 2010-2015 and 9 Gb output after 2050, nearly equal to High ERR-med/high price case.

- Model 1 tries to match AEO scenario with AEO reference oil price + medium ERR case
- Model 2 is similar to model 1, except that real well cost is reduced by half to $4.75 million 2017$
- Model 1 and Model 2 have new well EUR decrease begin in Jan 2019, total wells for TRR scenario assumed to be 172,000 wells, TRR=36 Gb as in medium TRR case
- Low ERR case with AEO reference oil price scenario shown for comparison
- Mean USGS TRR estimate for Permian Basin (36 Gb) is inconsistent with AEO scenario (53 Gb)

Conclusion

Based on USGS estimates and reasonable economic assumptions Permian Basin tight oil output is likely to peak between 2021 and 2027 with a mean estimate of 2024 at an output level between 3.5 and 7.5 Mb/d (mean estimate is 5.5 Mb/d), lower peak output levels and a high TRR could lead to a later peak, especially if well cost falls. Earlier peaks are also possible in a low TRR, high peak output scenario. Higher and/or later peaks will tend to be associated with steeper decline after peak and the reverse will be true for earlier and/or lower peak output. Economically recoverable resources are likely to be in the 12 to 53 Gb range (59% probability) with a mean estimate of 30 Gb and a median estimate of 22 Gb, probability that ERR>53 Gb is 15% and probability that ERR<12 Gb is 26% based on a maximum entropy probability analysis.

A major finding of this study is that the EIA's AEO scenario for the Permian basin is consistent with the USGS F5 TRR estimate using a high oil price scenario to estimate ERR, this is a serious shortcoming in the EIA analysis. Likewise, when considering the output of all US tight oil the EIA's AEO 2018 reference scenario has a URR of about 115 Gb, while the USGS F5 estimate for all US tight oil is about 105 Gb. The USGS mean TRR estimate is about 70 Gb and an analysis including reasonable economic assumptions (including the EIA's AEO 2018 reference oil price scenario) would result in an ERR for US tight oil of roughly 60 Gb, about half of the AEO 2018 reference tight oil output scenario. A peak and steep decline in US tight oil output before 2027 is quite likely (roughly a 75% probability), and odds are good (63% or about 2/3) the peak will occur before 2024. A peak in World C+C output is likely to follow within 3 years of the peak in US tight oil output. Plans for a transition to other forms of energy for transportation should begin today.