International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0026

HOW LONG CAN THE U.S. TIGHT OIL BOOM LAST?

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ABSTRACT

The long-term production of U.S. tight oil is forecast by using a composite model combining the Generalized Weng and Gompertz models. We show that U.S. tight oil production is likely to reach a peak within ten years, between 2019 and 2028, at a production rate between 7 and 13 million barrels per day (Mb/d), depending on the size of the ultimately recoverable resource (URR) estimate. Our most-likely 'medium-case' URR scenario suggests the peak year is probably around 2025, at a production rate of about 10 Mb/d. Comparing our results with those of the U.S. Energy Information Administration (EIA) suggests that the EIA is over-optimistic in its long-term production forecast of U.S. tight oil.

Keywords: Tight oil; Shale revolution; Production forecast; Ultimately recoverable resources

1. INTRODUCTION

The world oil market has been significantly affected by the U.S. shale revolution, where a combination of hydraulic fracturing and horizontal drilling enabled the U.S. to significantly increase production of oil and shale gas from its extensive formations of tight petroleum. However, there is no consistent answer for the question "*How long can the U.S. tight oil boom last?*" as forecasts differ. The U.S. Energy Information Administration (EIA) has taken a strongly positive position on future U.S. tight oil production, and has consistently raised its forecast of tight oil production over recent *Annual Energy Outlooks* [1]. According to its latest *Outlook*, the EIA under its high case predicts that U.S. tight oil production can keep increasing significantly until about 2035, before then plateauing and staring to decline. Other organizations that analyze future oil production, such as BP, OPEC and the IEA, generally hold similar opinions as the EIA. Some studies, however, show a quite different view compared to these of the 'mainstream' organizations. For example, in 2013, a report published by the Post Carbon Institute which analyzed decline curves of thousands of tight oil wells showed that the U.S. shale revolution will be hard to sustain in the longer term [2]. Such a difference in view suggests that additional modelling of future likely U.S. tight oil production is useful.

In terms of research on tight oil published in the academic literature, most of this focuses on analyzing formation conditions, geological characteristics, resource potential, different fracturing techniques and their impacts on single well productivity (e.g., [3]). Relatively few studies pay attention to the production decline curves of tight oil wells (e.g., [4]), the environmental impacts of tight oil extraction [5] or the economic impacts of large-scale development of tight oil [6]. For specifically analyzing the potential for future total U.S. tight oil production, there are few academic studies on this topic. Therefore, the aim of the paper presented here is to analyze the long-term production trend of the U.S. tight oil resources quantitatively.

2. METHODOLOGY AND DATA

2.1 Methodology

Oil is a non-renewable resource, which means that a likely pathway for its long-term production is to rise to a peak and then decrease (i.e., to follow an approximately 'bell-shaped' production curve), as opposed to increasing continually until the point where the resource is exhausted. Such a 'bell-shaped' profile is typical of production of both oil and gas from *regions* (i.e., areas having a significant number of discrete wells or fields), and reflects a combination of geological and economic (and, at bottom, probably also energetic) constraints. Therefore, considering the scarcity of data and the likely long-term production behavior of tight oil extraction from regions, a bell-shaped curve-fitting model is chosen in this paper.

Furthermore, bell-shaped curve-fitting models can be divided into two subtypes: symmetric models and asymmetric models. Brandt [7] analyzed 67 post-peak regions and showed that the production curves are generally asymmetric. Many other studies show similar findings (e.g., [8]). Furthermore, the study of Brandt [7] showed that the median production increase rate before peak is generally much higher than median production decline rate after peak, which suggests that the production behavior is significantly asymmetric with a positive skew. For this reason modelling with a positive skewed curve generally provides a better fit to historical production data than other curves.

By reviewing the literature, the generalized Weng model and the Gompertz model are two widely-used positive skewed curve models. It is difficult to choose one over the other. Therefore, both these two models are used in this paper, and the combined results (i.e., by averaging these two models' results) are used.

The basic equation of the generalized Weng model is given by [9]:

$$q(t)_{Weng} = URR\frac{1}{c^{b+1}\Gamma(b+1)}t^b\exp\left(-\frac{t}{c}\right) \quad (1)$$

where $q(t)_{Weng}$ is the forecast annual production at time t using the generalized Weng model, *URR* is ultimately recoverable resources, and b and c are parameters. $\Gamma(b+1)$ is the gamma function, when b is positive, $\Gamma(b+1) = b!$.

The basic equation of the Gompertz model is given by [10]:

$$Q(t)_{Gompertz} = URR * \exp(-\exp(-\mathrm{k}(\mathrm{t}-\mathrm{t_m}))) \quad (2)$$

where $Q(t)_{Gompertz}$ is the forecast cumulative production at time t using the Gompertz model, t_m is the peak year, and k and t_m are parameters. Then the annual production $q(t)_{Gompertz}$ can be obtained by using the following equation:

$$q(t)_{Gompertz} = Q(t)_{Gompertz} - Q(t-1)_{Gompertz} \quad (3)$$

The combination forecast production, $q(t)_{comb.}$, can be then obtained as follows:

$$q(t)_{comb.} = (q(t)_{Weng} + q(t)_{Gompertz})/2 \quad (4)$$

Both the generalized Weng model and Gompertz models can be solved by using a nonlinear least-squares numerical computation technique with initial guesses for the unknown parameters. The optimum values of the parameters are obtained by minimizing the root-mean-square errors (RMSE) of the production rate. where the basic equation for RMSE is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(q_{act}-q_{for}\right)^2}{n}} \quad (5)$$

where n is the number of data points, q_{act} is actual oil production, and q_{for} is estimated oil production.

2.2 Data and URR scenarios

In curve-fitting models, two types of data are needed: historical production and URR data. The historical production data for the U.S. tight oil resources by play are taken from EIA [11].

The ultimately recoverable resource (URR) of a class of petroleum is defined as the quantity already produced (i.e., *cumulative production, CP*) plus an estimate of that potentially recoverable under defined technical – and sometimes also commercial - conditions. There are two categories describing the potentially recoverable resources, i.e., *proved reserves* (PR, quantities of remaining resource that is judged recoverable at current prices using current techniques) and *unproved technically recoverable resources* (UTRR, quantities of the resource that can be potentially recoverable by considering future improvements in technical and economic conditions).

Some studies estimate the URR by simply adding CP and PR (e.g. [12]). However, such an estimate is likely to underestimate the URR, since it only considers the current recoverable quantities. Therefore, to measure the long-term potential production of petroleum resources, the EIA and IEA both suggest that the URR should be estimated by using "*CP+ PR+UTRR*". However, such estimates may, in turn, overestimate the realistic URR, since the scope for future improvements in technical and economic conditions are necessarily uncertain.

To reflect the uncertainty on future in economic and technical conditions, in this paper three URR scenarios are therefore used. These are: a *high scenario* where the URR is "*CP+ PR+UTRR*", a *low scenario* where the URR is "*CP+ PR*", and a *medium scenario* where the URR is the average of the high and low scenario URRs.

Cumulative production is obtained by summing historical production. The data for production and proved reserves are taken from EIA [13,14]. The unproved technically recoverable resources (UTRR) values used are the EIA's 'Reference case' values given in its *Annual Energy Outlook* 2019 [15].

3. RESULTS

The total U.S. tight oil production is forecast in this paper by aggregating each play's production. Figure 1A shows the forecast results using the generalized Weng model and the Gompertz model. It can be seen that these two models show similar forecast results. Furthermore, compared to the Gompertz model, the generalized Weng model tends to give a higher peak production and a delayed peak year. The combination results of these two models, which are the final results used by this paper, are shown in Figure 1B and Table 1.

According to the Figure 1B and Table 1, in our high URR scenario, i.e., that the assumed improvements in technical and economic conditions in the EIA's 'Reference' case can be fully achieved, U.S. tight oil production will keep increasing and reach its peak in 2028, at a peak production of about 13 million barrels per day (Mb/d). Our low URR scenario, which only considers tight oil already classed as proved and current economic conditions, shows that the U.S. tight oil production would peak this year (i.e., 2019), at a peak production rate of only a bit under 7.0 Mb/d. Our medium URR scenario, which we judge as the more likely scenario compared to the other two scenarios, suggests that the production will increase over the next several years to peak at nearly 10.0 Mb/d in the year 2025.

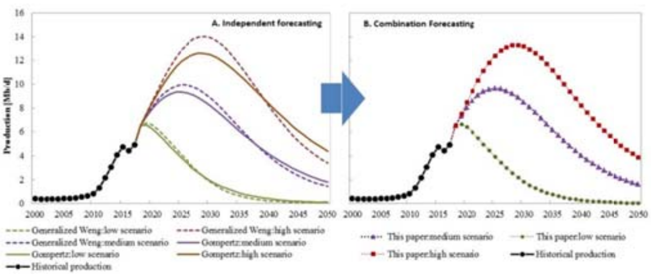

Fig 1 Combination of forecasts for U.S. tight oil production

Table 1 Forecast results for U.S. tight oil production under different scenarios

Low scenario			Medium scenario			High scenario		
URR	Peak Year	Peak Prod.	URR	Peak Year	Peak Prod.	URR	Peak Year	Peak Prod.
33Gb	2019	6.7Mb/d	89Gb	2025	9.7Mb/d	146Gb	2028	13.3Mb/d

A comparison of this paper's results with the latest version of AEO is shown in Figure 2. As can be seen in Figure 2A, all the scenarios we assume in this paper suggest a peak of U.S. tight oil production before 2030 and a relatively quick decline after peak; while in the EIA's study, only its low resource and technology case shows a peak before 2030 and a much lower decline after peak. From Figure 2B, we can see that all the EIA cases have a much higher cumulative production by the end of 2050 compared to this paper's scenarios.

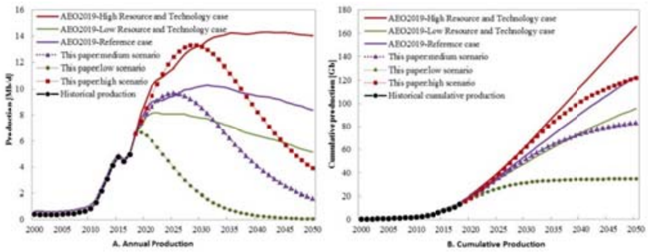

Fig 2 Comparison of this paper's forecast with those in the EIA's AEO report

As stated in the section of Introduction, compared with EIA's optimistic views on tight oil production, some studies show different opinions [2]. Moreover, in our full paper we examine the high UTRRs implicit in EIA modelling, and compare these to estimates from the USGS, BGR, IEA and Rystad Energy. This again indicates that the EIA's forecast may overestimate the long-term production of tight oil in the U.S. It should be noted also that there exist potential constraints on future tight oil production not considered in this paper. Taking the environmental constraint as an example, extracting tight oil relies on horizontal drilling and hydraulic fracturing, but studies have shown that these techniques may threaten the regional water resources, and cause induced earthquakes [16-18]. Such constraints may well lower the forecast results of this paper.

4. CONCLUSIONS

The long-term production of the U.S. tight oil resources is forecast and the results show that U.S. tight oil production will peak before 2030, and the peak production will be lower than 13 Mb/d. Considering the current relatively low oil price, uncertainty in improvements of tight oil production techniques, and other constraining factors, even the production shown in our model may hard to meet in reality. Overall, based on the above results, we conclude that a date of peak production of U.S. tight oil before 2030 looks almost certain, which means there are only 10 years or less to the end of the U.S. tight oil boom.

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