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Gas being burnt off at the Bakken shale oil field in North Dakota as a by-product of oil extraction.

A reality check on the shale revolution

The production of shale gas and oil in the United States is overhyped and the costs are underestimated, says **J. David Hughes**.

The 'shale revolution' — the extraction of gas and oil from previously inaccessible reservoirs — has been declared an energy game changer. It is offsetting declines in conventional oil and gas production, with shale gas being heralded as a transition fuel to a low-carbon future, and shale oil as being capable of reinstating the United States as the largest oil producer in the world, eliminating the need for foreign imports.

These heady claims have been largely accepted by government forecasters, including the International Energy Agency[1] and the US Energy Information Administration (EIA). The oil firm BP predicts that production of shale gas will treble and shale oil — also known as 'tight oil' — will grow sixfold from 2011 levels by 2030 (ref. 2).

The claims do not stand up to scrutiny. In a report published this week by the Post Carbon Institute[3] in Santa Rosa, California, I analyse 30 shale-gas and 21 tight-oil fields (or 'plays') in the United States, and reveal that the shale revolution will be hard to sustain. The study is based on data for 65,000 shale wells from a production database that is widely used in industry and government. It shows that well and field productivities exhibit steep declines. Production costs in many shale-gas plays exceed current gas prices, and maintaining production requires ever-increasing drilling and the capital input to support it.

Although the extraction of shale gas and tight oil will continue for a long time at some level, production is likely to be below the exuberant forecasts from industry and government. I see supplies of shale gas declining substantially in the next decade unless prices rise considerably. A more realistic debate around shale gas and tight oil is urgently needed — one that accounts for the fundamentals of production in terms of sustainability, cost and environmental impact.

SHALE GAS

Two technologies — horizontal drilling coupled with large-scale, multi-stage hydraulic fracturing (fracking) — have made it possible to extract hydrocarbons trapped in impermeable rocks (see *Nature* **477,** 271–275; 2011). In 2004, less than 10% of US wells were horizontal; today, the figure is 61%.

Most shale-gas production worldwide is in North America, although pilot projects are being conducted in many countries. Production has been on a plateau since early 2012 after a period of sharp growth. Shale gas has risen from about 2% of US gas production in 2000 to nearly 40% in 2012 (ref. 3); overall US gas production grew by 25% over the same period. The resulting supply glut drove US gas prices down severely. Prices have since recovered slightly but remain too low for many shale-gas plays without liquids production to be economically viable.

Large-scale shale-gas production was

initiated in the Barnett Shale formation a decade ago, and it spread quickly to other areas. Five plays produce 80% of US shale gas (listed from highest to lowest output): Haynesville in Louisiana, Barnett in east Texas, Marcellus (which spans West Virginia, Pennsylvania and New York), Fayetteville in Arkansas and Woodford in Oklahoma.

A pattern of events has emerged. When a play is discovered, a leasing frenzy ensues. This is followed by a drilling boom because the lease assignments, often 3–5 years long, can be terminated if the site is not producing gas. Sweet spots — small areas with high productivity — are identified and drilled off first, with marginal areas targeted next. Average well quality (as determined by initial productivity) rises at first and then declines.

In four of the top five shale-gas plays, average well productivity has been falling since 2010 (see 'Top five shale plays'). In the Haynesville play, an average well delivered almost one-third less gas in 2012 than in 2010. The exception is the Marcellus: supply is rising in this young, large play as sweet spots are still being found and exploited.

Wells decline rapidly within a few years. Those in the top five US plays typically produced 80–95% less gas after three years. In my view, the industry practice of fitting hyperbolic curves to data on declining productivity, and inferring lifetimes of 40 years or more, is too optimistic. Existing production histories are a few years at best, and thus are insufficient to substantiate such long lifetimes for wells. Because production declines more steeply than these models typically suggest, the method often overestimates ultimate recoveries and economic performance (see go.nature.com/kiamlk). The US Geological Survey's recovery estimates are less than half of those sometimes touted by industry[4].

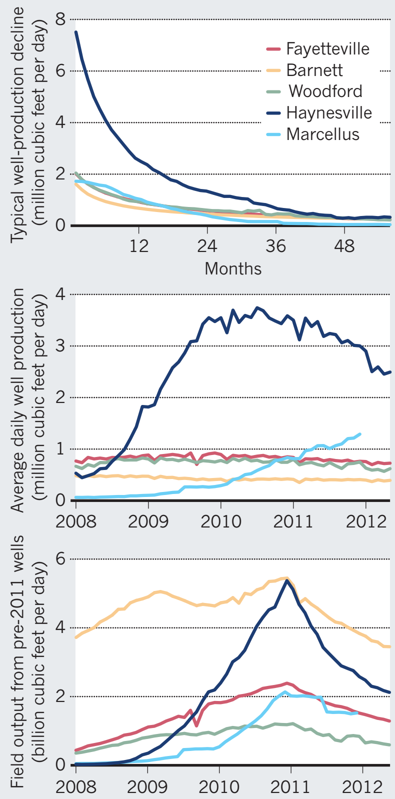
New wells must be drilled to maintain supply. In the Haynesville play, almost 800 wells — nearly one-third of those that were active in 2012 — must be added each year to keep shale-gas output at 2012 levels. With capital costs of around US$9 million per well, drilling to keep production flat costs some $7 billion a year. Full costs, including leasing, infrastructure and interest, are even higher[3].

Across the United States, this equates to 7,200 wells at a cost of more than $42 billion annually, simply to offset declines in production[3]. This investment by drilling companies — to sustain production to prop up share prices — is not covered by sales. In 2012, US shale gas generated just $33 billion (although some wells also produced substantial liquid hydrocarbons, which improved economics). To break even in shale-gas plays without liquids production, gas prices would have to rise[5].

Shale gas thus requires large amounts of capital from industry to maintain production[6]. Over time, the best shale plays and their sweet spots are drilled off, so the costs of keeping up supply will increase. Much of current shale-gas production is uneconomic, and will require higher gas prices just to maintain production, let alone increase it.

TOP FIVE SHALE PLAYS

Five US fields produce 80% of shale gas. The output of a typical well drops 80–95% in its first three years (top). Average well output across a field peaks and then falls as prime spots are used up (middle). Total field production falls 30–50% per year without new drilling (bottom).



TIGHT OIL

The story is similar for tight oil. Two plays produce 81% of US tight oil — Eagle Ford in south Texas and the Bakken in North Dakota and Montana. The productivity of new wells in both areas drops by about 60% after one year, levelling out to less than 40% in the second year, less than 30% in the third year and so on. Overall field decline, which combines the productivity of older and newer wells, is about 40% per year[3].

The ultimate output of these plays depends on the maximum number of available drilling locations. Wells cannot be drilled too close together because they drain the same reservoir volume, which increases costs and does not improve recovery. The EIA estimates that the Bakken and Eagle Ford plays can host almost three times the current number of wells, or nearly 12,000 each[3,7].

Assuming that the Bakken's current drilling rate of 1,500 wells a year is maintained, my analysis predicts that its production could rise to nearly 1 million barrels of oil a day. Given the EIA estimates of the maximum number of available drilling locations in the Bakken, however, I suggest that production will peak by 2017, when available well sites are exhausted, and then fall by 40% a year. I disagree with those who maintain that the Bakken's production can stay at that high level for many years — this would require thousands more wells than would fit[8].

LONG VIEW

Governments and industry must recognize that shale gas and oil are not cheap or inexhaustible: 70% of US shale gas comes from fields that are either flat or in decline. And the sustainability of tight-oil production over the longer term is questionable.

High-productivity shale plays are not ubiquitous, as some would have us believe. Six out of 30 plays account for 88% of shale-gas production, and two out of 21 plays account for 81% of tight-oil production. Much of the oil and gas produced comes from relatively small sweet spots within the fields. Overall well quality will decline as sweet spots become saturated with wells, requiring an ever-increasing number of wells to sustain production.

Production will ultimately be limited by available drilling locations, and when they run out, production will fall at rates of 30–50% per year. This is projected to occur within 5 years for the Bakken and Eagle Ford tight-oil plays.

The EIA's projections imply that, by 2040, the United States will recover all currently known shale-gas reserves, 58% of unproved shale-gas resources and 78% of unproved tight-oil resources[7,9]. These predictions are wildly optimistic given the fundamentals of producing these hydrocarbons. Similarly, the EIA forecast of gas prices strains credibility[9] because it is below many other estimates of the cost of production with steadily rising supply for the next two decades. Declaring US energy independence and laying plans to export the shale bounty is unwise. The long-term viability of the shale revolution must be accounted for in a sustainable energy strategy for the future. ■

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