# Can fracking, for gas and oil, power the Scottish economy?

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*"Scotland['s] set for [an] oil bonanza that heralds a new golden age for the North Sea lasting for another century"* Independent Scottish business pressure group (N56).

*"There can be little doubt that Scotland is moving into a second oil boom"* Alex Salmond, Scotland's First Minister (2007–2014).

These are bold, long-term pronouncements made during the run-up to the referendum on Scottish independence in 2014. Are they realistic? Before discussing their veracity and reliability this short article positions the quotes within a geological context by summarizing the history and utility of Scotland's earlier oil booms.

## Shale oil

The first commercial oil-works in the world were established in Scotland by James 'Paraffin' Young. His venture began on Thursday 17th October 1850 when he took out a patent for the low-temperature distillation of coal and shale. Young had discovered how to obtain paraffin oil and paraffin wax by heating rocks in a furnace. Works were established at Bathgate where local, exceptionally high-yielding, cannel coals formed the basis of the new industry.

Soon, when the coals ran out, Young switched to the more extensive, but lower-yielding, underlying oil shales. Production was initially on a small scale. Nevertheless the oil-shale industry prospered. There are more than 187 old shale mines and pits in Scotland, and at least 142 abandoned works where retorting, distillation and refining once took place. The vast majority of these enterprises remained small in scale and short-lived. Yet production prospered, improved retorts were introduced and by 1865 the industry employed 30–40 000

**Oil shale** is an organic-rich, fine-grained sedimentary rock. In Scotland the main oil-shale sequences occur in Lower Carboniferous rocks. Solid remains of freshwater algae accumulated in a shallow lake complex lying near the equator. The lake basin occupied most of what is now West Lothian, extending at times into Fife, Midlothian and Lanarkshire.

people. Production eventually peaked in 1912 when more than three million tonnes of shale were mined to yield 1.7 million barrels of crude oil and over 54 000 tons of sulphate of ammonia. Eventually Scotland's first golden age of oil came to an abrupt end in 1962, with the closure of the Westwood oil works.

Today, all that remains of the vast, old workings are faded warning notices, one old office building and a few miners' rows. No furnaces. No retorts. No industrial buildings. Much of the waste, however, endures to form the area's unique red slag-heaps, or bings. The burnt shale-debris rapidly weathers to leave a surprisingly free-draining, cohesive substrate and unexpectedly steep, yet stable, slopes. For many years saving the abandoned oil-shale workings has not been a top priority for local communities. Recently, however, an excellent museum has been established as part of the Almond Valley Heritage Centre. Also several bings have been landscaped and reclaimed as green space. Two, Broxburn (the Ayers Rock lookalike) and the Five Sisters, are today legally protected as Scheduled Ancient Monuments and their vegetation left to regenerate naturally. The unusual setting and nature of these exhausted industrial landscapes provide attractive areas for walking. So much so that the author, as a change from 'bagging' Munros, has bagged all 21 surviving bings.

**Oil and gas**

Scotland's next golden oil age opened in December 1969, with the surprise discovery of the Montrose oil field. An Amoco-led group had actually been prospecting for gas 130 miles east of Aberdeen, but struck oil instead. Soon afterwards the truly giant oil fields of Forties, Ekofisk and Brent were proven, confirming that the North Sea would become one of the world's great petroleum provinces. The tectonic history, which gave rise to the oil, was dominated by an episode of late Jurassic to earliest Cretaceous crustal extension. In broad terms the rifting related to the breakup of the supercontinent of Pangaea.

As is well known, conventional petroleum systems require an organic-rich source rock which, when geothermally heated by burial, can generate hydrocarbons; a reservoir, composed of a porous unit, in which oil or gas can accumulate; and lastly an effective seal, which prevents hydrocarbon escape. While the source rock responsible for virtually all of Scotland's offshore hydrocarbons is straightforward—the Kimmeridge Clay—the reservoirs are exceedingly varied. Some are structural, others sedimentological. Some reservoir rocks pre-date the

**Kimmeridge Clay.** This high-yielding source rock, of late Jurassic to earliest Cretaceous age, was deposited as mudstone and siltstone in land-locked marine basins. When sufficiently deeply buried the organic remains (principally dead plankton) become heated to temperatures of 50–150°C and start to be thermally broken down to produce oil. The Kimmeridgian is also notable in the USA as an important unit for shale-gas fracking. The Haynesville Shale in East Texas and Louisiana is a prime example with close similarities to the North Sea source rocks.

source rocks, the two having been juxtaposed by later faulting episodes. Others are contemporaneous; yet more as young as Eocene. Most reservoirs are sands but deposited in an astonishingly diverse array of marine settings and capped by various impermeable layers.

All these reservoirs and traps have had to be accurately pinpointed while buried beneath thousands of feet of overlying rock. Many North Sea reservoirs are very small, in area no bigger than a town. Drilling is the final arbiter of the likely productivity of oil and gas plays, but arguably the most important tool for exploring the North Sea and for gaining an impression of the subsurface has been detailed seismic imaging and interpretation. Following an initial exploration phase, Scotland's fields were quickly brought on-stream using innovative financial investment vehicles, specially tailored to cope with the very risky milieu of offshore drilling, and skilfully conjured up by coalitions of accountants, bankers and lawyers.

Oil first arrived onshore in 1975. Complete production profiles are plotted in Figure 1. The overall double peak, and intermediate slump, is often attributed to fluctuations in the price of oil. But this cannot be, as corresponding behaviour is not found for Danish or Norwegian fields. Instead the dip relates to repercussions following the Piper Alpha disaster in 1988, when UK oil production was deliberately cut back in order to allow extensive work programmes to implement new safety measures.

Once due allowance is made for the Piper Alpha effect the North Sea can be seen to be a mature basin. Today the most straightforward way to assess Scotland's likely remaining offshore oil wealth is a forward projection of the data of Figure 1. Using this approach I estimate an ultimate resource of $31 \times 10^9$ Bbl, with 11% still remaining to be recovered over the next decade. My total coincides closely with geologically grounded estimates, dating as far back as the mid-1990s, which were based on field-by-field appraisals of the porous volume of reservoir sands.

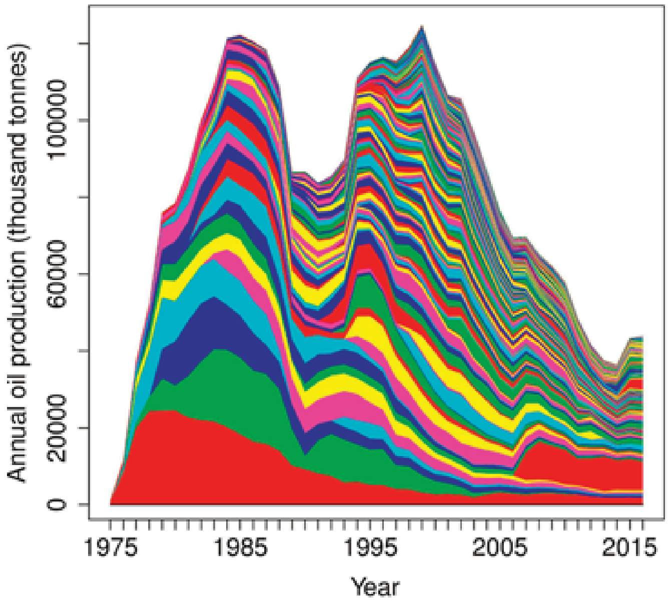


***Figure 1 Offshore oil production for 261 UK fields (1975–2016). Each coloured 'stripe' shows a different field. Note the steady fall in both field size and field longevity over time. Buzzard (first oil, 2007) is the only notable exception. Accordingly, recently discovered fields have typically generated <10 million Bbl of recoverable oil with lifespans of <16 years.***

## Shale gas

In the United States the recent advent of extended-reach drilling and hydrofracturing has opened vast new energy sources, such as black shales, and has significantly altered the domestic energy landscape (Figure 2). As an alternative to our dwindling North Sea oil supplies, equivalent sources are currently being sought in Scotland. Companies want to drill beneath the Central Belt for gas trapped within Carboniferous shale formations, and to liberate it by creating a dense network of connected spidery cracks by injecting fluid under high pressures (of up to 500 bar) and high flow rates (upwards of 50 gallons/sec).

On the environmental side, the evidence of the risks and benefits of fracking is fiercely disputed. Much of the furore, in the USA, has been driven by the lack of detailed chemical disclosure of hydraulic fracturing fluids. A typical US well costs around $8 million to drill, plus a similar sum during the production phase. Fracking involves injecting 5 million gallons of water (obtained from rivers, lakes, public water supplies or retreatment plants) plus proppants to keep incipient fractures open, plus 15 000 gallons of

***Figure 2 Aerial view (B. Gordon, EcoFlight) of hydraulic fracking pads. Looking north across part of the Jonah tight gas field (of Late Cretaceous age) in Wyoming.***

other chemicals. Hydrochloric acid is added to help clear out cement debris in the wellbore. In addition gelation agents, which improve proppant placement, friction reducers, corrosion inhibitors, an iron precipitation control, disinfectant biocides to control bacterial growth, oxygen scavengers and scale inhibitors are all basic additives.

A second major anxiety is earthquakes. Interestingly, induced quakes are not necessarily caused by the fracking process itself, but by the disposal of the huge volumes of flow-back and brine-laden waters produced along with the gas. In the US and Canada wastewaters are disposed of in deep wells. This practice serves to separate the waste from drinking supplies but it can have secondary consequences. Since the start of wide-spread fracking, felt earthquakes have become hundreds of times more common. The reason is that the wastewater disposal reactivates old, deep-seated fault lines. Further worries are greenhouse-gas emissions and leakage.

Local geology introduces additional snags. The structural geology of the Central Belt is not straightforward. The Carboniferous strata lie in a series of small sub-basins and can be subject to remarkably abrupt and extensive lateral change. In addition faults are encountered every ½ mile or so. Figure 3 provides an example. In this abandoned opencast section a syncline plunges into the photograph, decreases upwards in fold-amplitude, is shifted laterally by a fault, and is interrupted by a lava. Such profound discontinuities must inevitably create difficulties during extended-reach fracking and lead to well underperformance. Furthermore Scotland's low thermal gradient (22–30°C/km) and weak Tertiary exhumation history suggest the great majority of its shales, with the possible exception of those contained within deep synclines (e.g. Clackmannan, Midlothian-Leven, Solway), will barely have reached gas-generating temperatures.

**Glossary**

**Bbl***: Blue barrel (1Bbl = 0.14 tonnes)

**Gas-in-place**: Modelled estimate of the total volume of gas stored in a reservoir.

**Reserve**: Volume of hydrocarbons that can be profitably extracted from a reservoir using existing technology.

**Resource**: Hydrocarbons that may eventually become producible. Includes reserves as well as known oil and gas deposits that currently cannot be technologically or economically recovered, and even guesstimates of undiscovered potential reserves.

**tcf***: Trillion cubic feet.

*: Americanized Imperial units reign supreme in the petroleum industry.

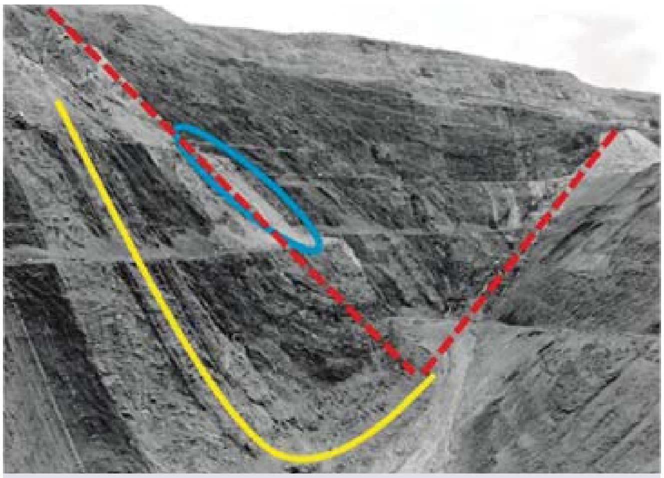

***Figure 3 Carboniferous shales and coals in a plunging syncline (yellow curve) at Westfield opencast site (nr. Glenrothes). A lava (blue oval) underlies the coals just beyond a strike-slip fault (red dashes). BGS image P000196.***

How could Scottish shale gas be accessed? KPMG, in their recent report for the Scottish Government on unconventional gas extraction, adopt a central estimate of 20 pads generating up to £6.5 billion of investment and creating 1400 jobs. Pads are areas of up to about 8 acres, which when cleared and levelled, would house the drilling equipment and the enormous assemblage of pumps, diesel engines, fleets of water trucks and sand mixers needed, along with wastewater impoundment dams. Pads have appeal as they concentrate industrial activity, so reducing the total noise, traffic movements, surface disturbance, and number of access roads and utility corridors. But are 20 pads really a viable means of generating a US-style shale gas industry in Scotland? The number of hydraulically fractured wells in the US is thought to have reached over 200 000. Gas-in-place estimates for Scotland broadly cover an area stretching from Glasgow & Motherwell, to Stirling & Falkirk, across half of Fife to Pittenweem, and then south through East Lothian to Penicuik. How can that heavily populated area, of around 800 sq. mile, possibly be fracked from just 20 pads? The effective footprint that can be hydraulically stimulated from a single pad in Scotland is likely to be small on account of the complex geology, inconsistent stress field and geo-mechanical incompatibility of extended-reach drilling with shallow targets. I envisage an efficiently designed, Scottish, multi-well pad would drain an area of around one sq. mile, as in recent pad placements in Tioga County, Pennsylvania or Septimus-Montney, Canada.

In Scotland matters are rapidly coming to a head. The Scottish Government is currently promising to take "*a final decision [on the future of fracking] by the end of 2017*". But what, despite the environmental risks, might the potential economic and fuel-security benefits be? The total in-place gas resource estimated for Carboniferous shales is 49.4–134.6 tcf, with an additional oil-in-place resource of 3.2–11.2 x $10^9$ Bbl. To me the key question is not the size of the technically recoverable resource, but what is a realistic assessment of future deliverability. In short, how can the reserve rather than the resource be physically estimated using current geological knowledge to the full? I suggest the best methodology is to employ an analogue approach. Production-decline curves, for other parts of the world, when combined with an appraisal of the key geological parameters which control recovery, allow the reserve to be quantified.

My results, for gas yield per unit area, are summarised in Figure 4. Note the crucial control of depth on total production. Depths should be neither too shallow (too cool for effective gas generation), nor too deep (methane and other hydrocarbon gases formed, but broken down leaving nonhydrocarbon gases ($CO_2$, $N_2$, $H_2S$) and depleted residues (pyrobitumen)). The diagram shows how Scottish shales with their modest organic carbon contents and shallow depths, not to mention their unremarkable thermal history and heavy faulting, barely correspond to even the poorest US-producing regions (e.g. Lewis, Conasauga, Ohio). Furthermore their frackability (ease of cracking or fracturing) remains unproven but could well be slight on account of their low quartz-plus-dolomite content. All in all Scottish shales may well have a success factor of zero.

In comparison to Scotland, the North of England has a gas resource estimated at 1300 tcf. Its simpler geology with deeper, thicker shales corresponds reasonably well with superior US provinces. Consequently if fracking is not commercially viable in the North of England it certainly won't be in Scotland. The Scottish Government would be well advised to wait and see what happens south of the border.

## A new golden age?

In conclusion I return to the concerns broached at the outset. If geological estimates of Scotland's remaining offshore oil reserves and of prospects for onshore gas are both so poor, how can the N56 view that Scotland

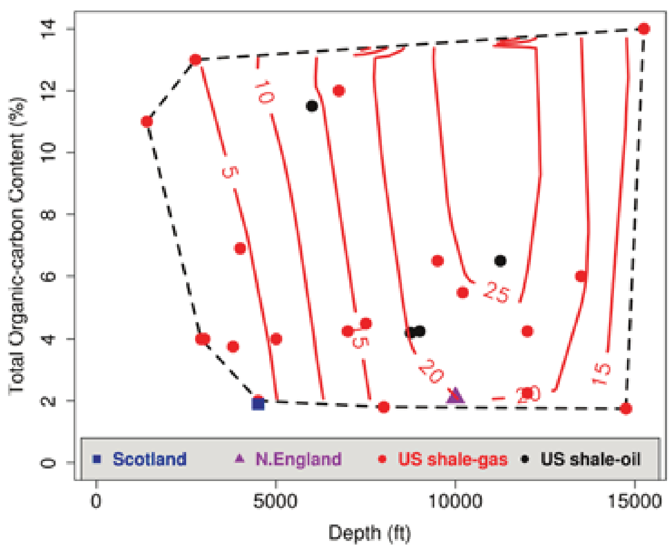


***Figure 4** Depth vs. total organic content. Contours (red lines) of estimated ultimate recovery (Bcf/ sq. mile) in 24 US shale-systems. Systems outwith the black dotted polygon.*

is set for a new black-gold bonanza of an additional 24 x $10^9$ barrels of conventional reserves, plus a further 21 x $10^9$ from unconventional (i.e. fracked) sources, be tenable? It can't.

The reason for the huge gap in expectations is twofold. First the N56 think-tank presented no geotechnical evidence, from either drilling or production tests, for major new conventional reserves anywhere offshore. Secondly they asserted that the offshore Kimmeridge Clay Formation can be fracked. Yes, the Kimmeridge is a rich, hybrid source rock. Yes, at 15 000 ft. below the central North Sea graben it can contain abundant oil and gas-in-place. But no, that does not make it an offshore reserve with any likelihood of becoming commercially recoverable within a reasonable time frame. The economics of offshore fracking are particularly bad. First, a top-rate US-style shale well typically yields only about 1/25th of a UK oil well. On top of that fracturing costs considerably more than conventional drilling, especially offshore. Lastly, when faced by such hefty economic disparities an appeal to an increase in oil prices does not provide a way out. Remember there are many developmental possibilities, if oil prices rise, for virgin giant fields around the globe, especially subsalt and deep-water. As a consequence expensive Scottish hydrocarbon is not going to suddenly become in demand.

**Coal-bed methane**

Finally it is worth noting that coal formations, if saturated with water, can contain copious amounts of methane gas adsorbed onto mineral surfaces. The methane desorbs if the water is pumped off the coals and the gas can then be accessed by production wells, often with minimal recourse to fracking. The potential for coal-bed methane, as opposed to underground coal gasification (which Scottish Ministers have determined will have no place in Scotland's energy mix at this time), appears to be locally very promising for the few relatively thick coal seams that escaped 19th and 20th century mining. It would be a fascinating happenstance if a 21st century source of hydrocarbon, in Scotland, returned us full circle to Young's original, masterly idea of generating hydrocarbons from coal.

**Additional information, data sources and references**

http://www.geos.ed.ac.uk/homes/thompson/

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