AAPG FOBEX 20 : "*Shale Gas*"

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Preface

Decades of oil and natural gas production around the world have resulted in a decline of these conventional resources. Basically, most of the oil and natural gas that can be produced using traditional methods is already being accessed. As new technologies are introduced, oil and natural gas producers are able to produce "unconventional" oil and natural gas resources that were previously impossible to obtain. Unlike the conventional pools of oil and natural gas, unconventional oil and natural gas do not flow naturally through the rock, making them much more difficult to produce. Think of the difference between a sponge and a piece of clay: it's easy to squeeze water out of a saturated sponge that's conventional oil and natural gas; squeezing water out of saturated clay is harder that represents unconventional oil and natural gas, and the challenge forces producers to find new ways to release the oil and gas. Unconventional often refers to low permeability rock where the pores are poorly connected, making it difficult for oil and natural gas to move through the rock to the well.

Unconventional oil and natural gas, shale gas in particular has been called the future of gas supply. While its development is in the very early stages, it has tremendous economic potential and we know that the interest in these considerable resources will increase

So are unconventional and conventional oil and natural gas the same? Regardless of how they are produced or the rock they come from, unconventional oil and natural gas are essentially the same as their conventional counterparts. The term “unconventional” simply refers to the methods that are used, as well as the types of rock from which the oil and natural gas are produced.

What is shale gas?

Shale gas is natural gas that is trapped within shale rock formations. Shales are fine-grained sedimentary rocks that can be rich in oil and natural gas. In the past decade, particularly in the United States, horizontal drilling combined with hydraulic fracturing has allowed access to large reservoirs of shale gas, completely transforming the natural gas industry and energy supply dynamics.

Hydraulic fracturing is the process most commonly used to release natural gas and oil from deep beneath the surface of the earth. Hydraulic fracturing is particularly important in the context of shale gas development. As shale gas reservoirs are trapped within rock

formations of very low permeability, the gas can only be released into the well by stimulating the shale formation through hydraulic fracturing. Fracturing fluid – on average 99.95% water and sand with a small proportion of additives – is injected at high pressure into the rock strata on average 3km below the surface. The force of the water creates a network of tiny fissures in the rock and the water flow acts as a delivery mechanism for the sand, which finds its way into these newly created cracks to ensure they remain open. This creates passageways through which natural gas can travel to get to the wellbore. The hydraulic fracturing process is usually performed at the start of the life of a well and normally lasts between three to five days after a well is drilled, cased and cemented, and the drilling rig is removed.

Is it different from natural gas? There is no difference. Shale gas is natural gas that comes from shale formations instead of other rock strata like limestone or sandstone. Natural gas from shale is a less carbon intensive fuel relative to other fossil fuels and just as reliable as a fuel source for Europeanhouseholds, businesses and industries.

Shale Gas Reservoir Characterization

How is gas stored in the shale reservoirs?

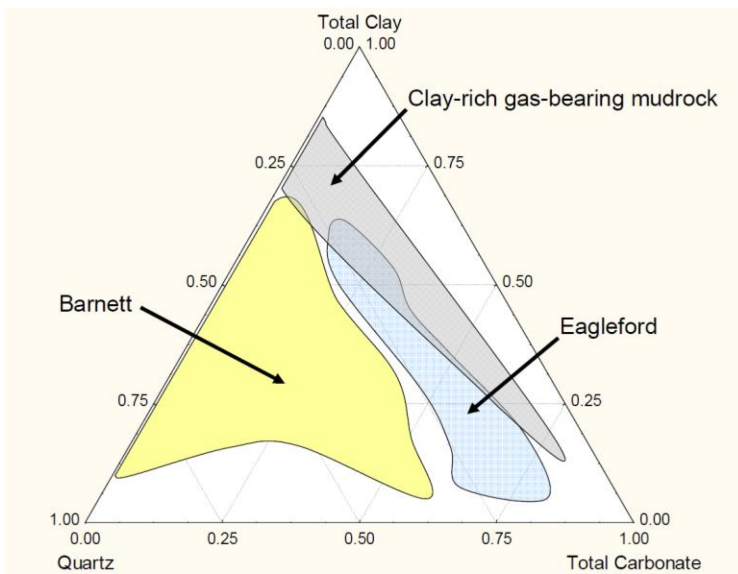
- As gas dissolved in kerogen.
- As gas adsorbed onto kerogen and clay particle surface.

- As free gas in natural fractures and intergranular porosity.

a. Depositional environment

- Marine shales have lower clay content and are high in brittle minerals, such as quartz, feldspar and carbonates.
- Brittle shales frac better during hydraulic stimulation.
- Nonmarine shales deposited in lacustrine, fluvial environments, tend to high in clay content, more ductile and less responsive to hydraulic stimulation.

So, mineralogy of the shale samples determines how efficiently the induced fractures will stimulate the shale.



Mineral composition is variable in shale gas reservoirs. (Passey et al., 2010)

b. Depth

Gas originates in source rocks as:

1. Biogenic gas due to the action of anaerobic micro-organisms during early diagenetic phase of burial

2. Thermogenic gas from breakdown of kerogen at greater depths and temperatures

Biogenic gas usually forms at depths < 1000 or 1100m (could be preserved at reservoir depths of 5km).

Depth criterion: > 1000m and < 5000m. Areas shallower than 1000m have lower pressure and gas concentration. Areas greater than 5000m have reduced permeability entailing higher drilling and development costs.

c. Thermal maturity

Measure of the degree to which a formation has been exposed to high heat needed to break down organic matter into hydrocarbons. The useful indicator of thermal maturity is vitrinite reflectance (Ro); whether the rock has generated hydrocarbons and could be an effective source rock. A prospective shale gas reservoir have typical values ranging from 1 to 3% Ro. Higher thermal maturity leads to the presence of nanopores, contributing to additional porosity in the shale matrix.

d. Total organic carbon (TOC) content

Organic matter such as micro-organism fossils and plant matter provide the carbon, oxygen and hydrogen atoms needed to create natural gas and oil. TOC of prospective areas equal to or greater than 2%. An attractive feature of the shale gas reservoirs is its organic richness.

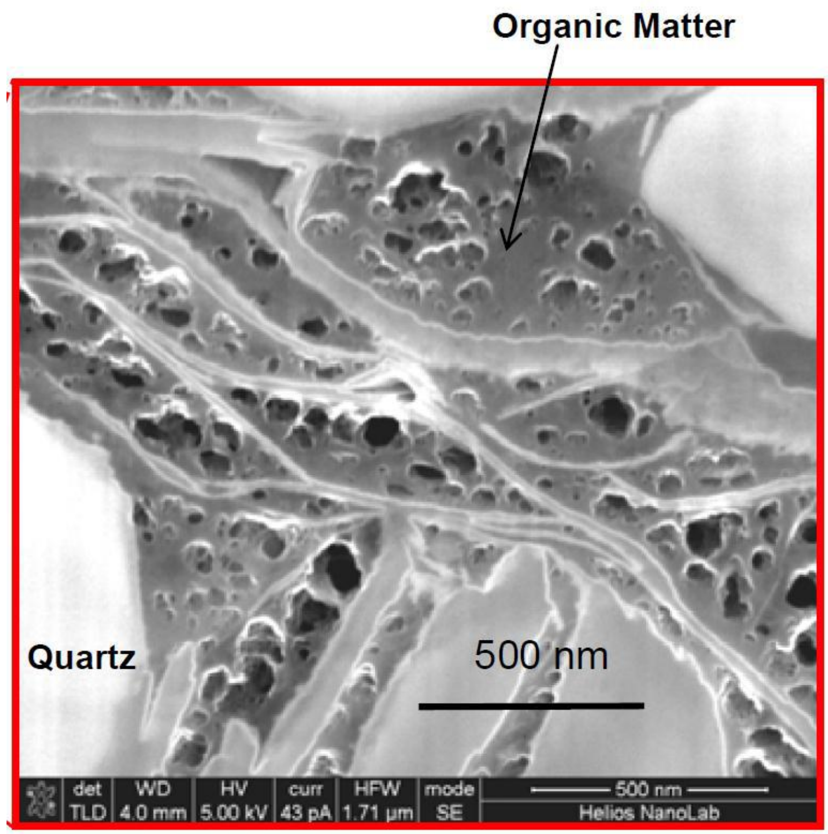
e. Permeability

Shale gas may be stored as free gas in natural fractures and intergranular porosity, as gas adsorbed onto kerogen and clay-particle surfaces, or as gas dissolved in kerogen. Permeability is achieved through natural fracture systems or hydraulic stimulation. Storage is mainly in the matrix and the permeability is assured by the fractures.

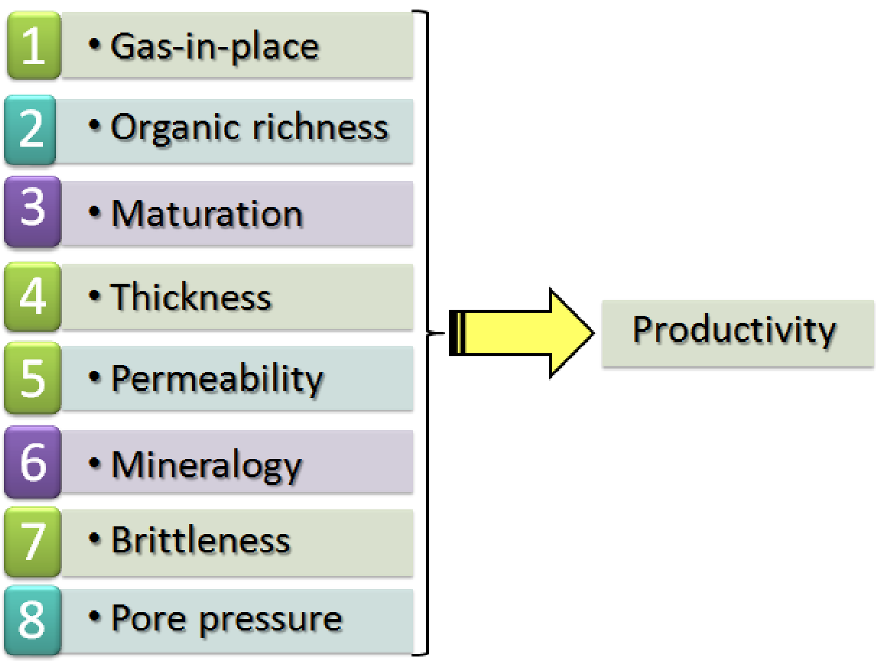
f. Gas-in-place

Governed by four characteristics: pressure, temperature, gas-filled porosity and net organically rich shale thickness.

- Pressure: areas of higher pressure are identified as they have higher gas concentration. (0.433 psi per foot: normal hydrostatic gradient).
- Temperature: A normal temperature gradient of 1oF per foot of depth is used.
- Gas-filled porosity: usually determined from cores and log curves.
- Net organically rich shale thickness: shale intervals determined from seismic interpretation are scrutinized for organic-rich intervals using logs. A net-to-gross thickness is then established.



Pores seen on SEM photomicrograph of a Barnett organic-rich rock containing gas. (Passey et al., 2010)

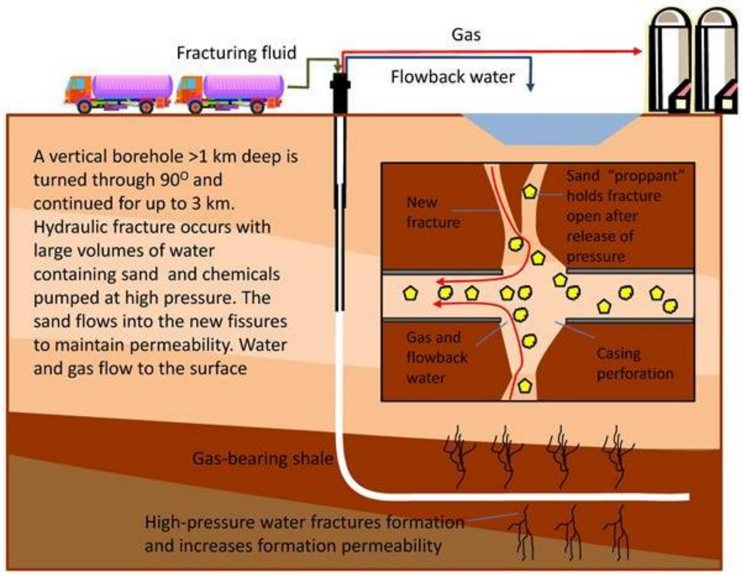


Elements of a successful shale gas play (Chopra et al, 2014)

Shale Gas Exploitation

Shale gas is predominantly (>90%) methane of thermogenic origin derived from and held in natural fractures and pore spaces or adsorbed onto organic material and minerals in shales at depths of generally more than 1 km.

"Fracking"



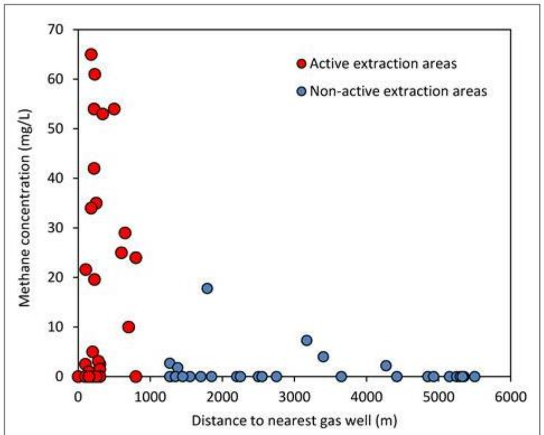
Overview of hydraulic fracturing (from Stuart 2012 adapted from Gregory et al. 2011)

Shale gas extraction involves drilling of deep horizontal boreholes and enhancing the natural permeability of the shale by hydraulic fracturing ("fracking"). Fluid is introduced to raise the downhole pressure above the fracture pressure of the formation rock creating fissures and interconnected cracks that increase the permeability of the formation. Fracking is used to overcome barriers to gas and fluid flow, one of the primary reasons why historical development of gas from shales has been limited. These barriers include the low natural permeability of shale formations and reduced permeability resulting from permeability impairment caused by drilling activities. Fracking and horizontal drilling have been in use for shale gas in the USA since the late 1940s.

The process typically involves the pumping of a sand-water mixture into the target shale zone at high pressure. The fluid pressure creates fractures or openings through which the sand flows, at the same time the sand acts to prop open the fractures that have been created allowing migration of both gas and water to the borehole. After the pumping pressure is relieved the fracture fluid returns to the surface through the borehole casing. This water is referred to as "flowback".

Lateral lengths in typical shale gas development wells are from 300 m to more than 1500 m and it is usually not possible to maintain a downhole pressure sufficient to stimulate the entire length of a lateral in a single stimulation. Instead fracking of the horizontal sections is performed in stages by isolating successive portions and performing multiple treatments to stimulate the entire length of the lateral portion of the well. The lifetime of an individual borehole may be only about 7 years.

Water resources issues



Methane concentrations as function of distance to nearest gas well (adapted from Osborn, 2011)

The drilling and completion of production boreholes require large quantities of water. Drilling of the vertical and horizontal components of a borehole may require 400–4000 m^3 of water to maintain downhole hydrostatic pressure, cool the drill head, and remove drill cuttings. Then, 7000–18,000 m^3 of water are needed for fracking of each section. These large volumes of water are typically obtained from nearby surface waters or groundwater and are not generally returned to the source. The volume of water consumed during fracking could make gas production costly and unsustainable in many areas of the world that are water-constrained.

Potential impacts, assuming no controls are in place, would be modifications to groundwater levels as well as surface water levels and stream flow. Operators need this water when drilling activity is occurring, potentially over a relatively short periods of time. Water withdrawals during periods of low stream flow could affect ecosystems, municipal water supplies, recreational activities, and industries.

Contamination sources and pathways

Groundwater may be potentially contaminated by extraction of shale gas both from the constituents of shale gas itself, from the formulation and deep injection of water containing a cocktail of additives used for fracking and from flowback water released during gas extraction which may have a high content of saline formation water.

Documented instances of groundwater contamination from the USA are predominantly related to the leakage of methane into groundwater. Osbourn et al. (2011) showed systematic evidence for methane contamination of drinking water allegedly associated with shale gas extraction, where the average vertical separation between drinking water boreholes and the shale was between 900 and 1800 m.

Methane concentrations as function of distance to nearest gas well (adapted from Osborn, 2011)

However, there is considerable uncertainty as to the source(s) of methane, its migration pathways and transport processes, and crucially there have been no background surveys in the USA prior to the start of drilling. In general thermogenic gas, such as shale gas, has a high methane content with low but significant concentrations of higher hydrocarbons such as ethane (C_2) and propane (C_3), with $C_1/(C_2+C_3) < 100$, and enriched ^{13}C with $\delta^{13}C$ methane in the range -110 to -55‰ (Révész et al, 2010). In contrast biogenic gas, commonly produced at shallow depths, has $C_1/(C_2+C_3)$ in the range 1000 to 10,000 and $\delta^{13}C$ methane in the range -55 to -20‰ and can be readily distinguished. Shale gas may also contain carbon dioxide, nitrogen, hydrogen sulphide, and rare gases.

The largest additive to fluid used for shale gas fracking is proppant, a granular material, usually sand, to hold or prop open the created fractures that allow gas to flow to the bore. Other commonly used proppants include resin- coated sand, ceramics, and sintered bauxite and zirconium oxide. In addition to water and proppant, many other additives are essential to successful shale gas reservoir fracture stimulation. These include hydrochloric acid, polyacrylamide, mineral oil, isopropanol, potassium chloride and ethylene glycol and low concentrations of pH buffers, corrosion inhibitors, biocides and gelling agents. There are proposals to use more environmentally-friendly compounds in fracking fluid and possibly to use other carriers such as LPG rather than water.

Flowback water is very variable in quality and can range from almost fresh to salinity greater than that of seawater.

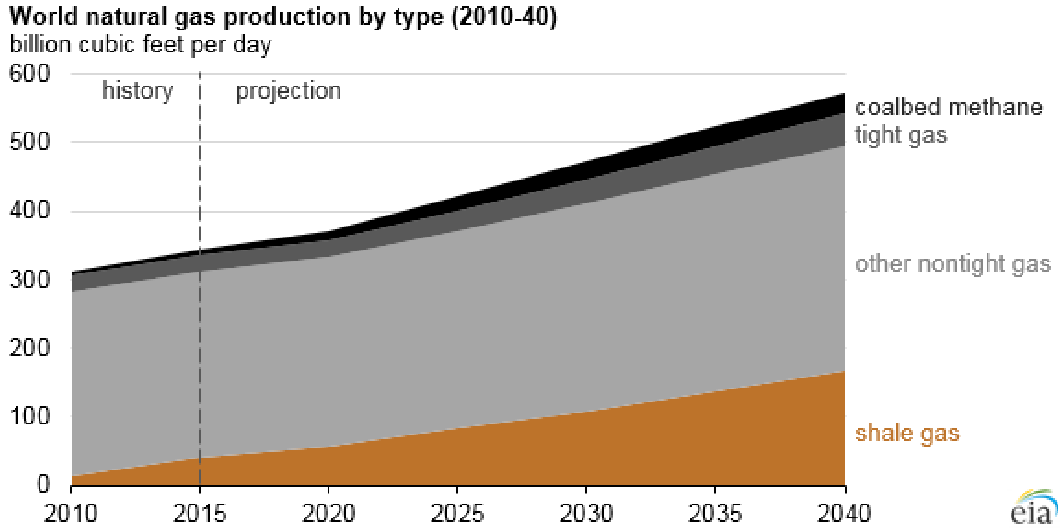
Pathways for contaminants to groundwater could potentially include:

- Subsurface permeability created by the fracking process allowing ingress of gas or fracking fluid
- Accidental releases during preparation of fracking fluids or from fluid leaks, blowouts and casing failures

- Storage, disposal, treatment or reuse of large volumes of flowback water

Anecdotal reports of health problems in the USA in shale gas exploitation areas for both humans and livestock are ascribed to both water and air pollution.

World Shale Gas Production



Source: U.S. Energy Information Administration, *International Energy Outlook 2016* and *Annual Energy Outlook 2016*

Although currently only four countries—the United States, Canada, China, and Argentina—have commercial shale gas production, technological improvements over the forecast period are expected to encourage development of shale resources in other countries, primarily in Mexico and Algeria. Together, these six countries are projected to account for 70% of global shale production by 2040.

In the United States, shale gas production accounted for more than half of U.S. natural gas production in 2015 and is projected to more than double from 37 Bcf/d in 2015 to 79 Bcf/d by 2040, which is 70% of total U.S. natural gas production in the AEO2016 Reference case by 2040.

Several AEO2016 side cases illustrate the effect of technological improvements on cost and productivity. Shale gas production in 2040 is projected to be 50% higher under the High Oil and Gas Resources and Technology case, reaching 112 Bcf/d, while in the Low Oil and Gas Resources and Technology case, production is projected to be 50% lower than the Reference case, reaching 41 Bcf/d.

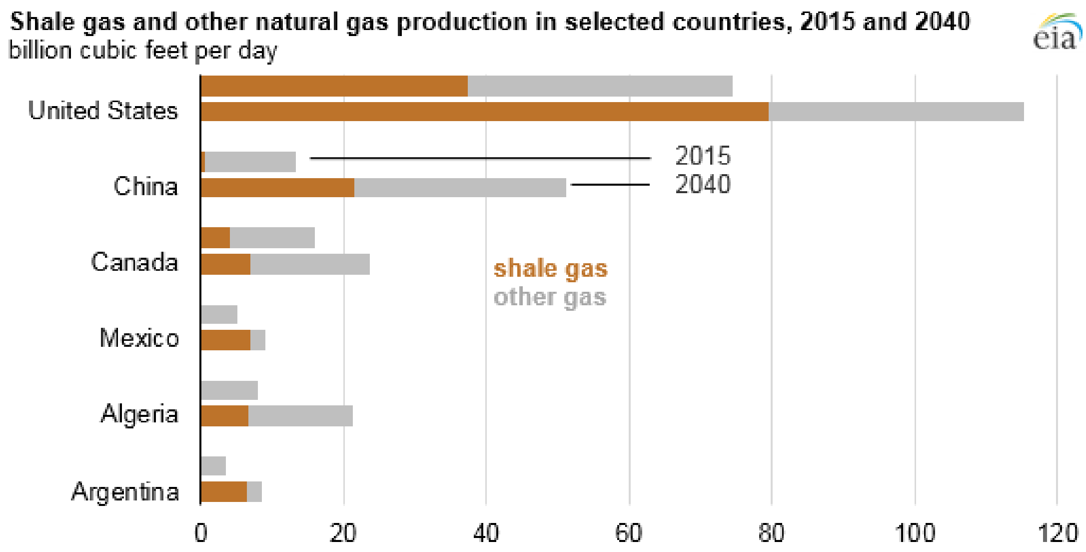
Canada has been producing shale gas since 2008, reaching 4.1 Bcf/d in 2015. Shale gas production in Canada is projected to continue increasing and to account for almost 30% of Canada's total natural gas production by 2040.

China has been among the first countries outside of North America to develop shale resources. In the past five years, China has drilled more than 600 shale gas wells and produced 0.5 Bcf/d of shale gas as of 2015. Shale gas is projected to account for more than 40% of the country's total natural gas production by 2040, which would make China the second-largest shale gas producer in the world after the United States.

Argentina's commercial shale gas production was just 0.07 Bcf/d at the end of 2015, but foreign investment in shale gas production is increasing. Pipeline infrastructure in Argentina is adequate to support current levels of shale gas production, but it will need to be expanded as production grows. Current shortages of specialized rigs and fracturing equipment are expected to be resolved, and shale production is projected to account for almost 75% of Argentina's total natural gas production by 2040.

Algeria's production of both oil and natural gas has declined over the past decade, which prompted the government to begin revising investment laws that stipulate preferential treatment for national oil companies in favor of collaboration with international companies to develop shale resources. Algeria has begun a pilot shale gas well project and developed a 20-year investment plan to produce shale gas commercially by 2020. Algerian shale production is projected to account for one-third of the country's total natural gas production by 2040.

Mexico is expected to gradually develop its shale resource basins after the recent opening of the upstream sector to foreign investors. At present, Mexico is expanding its pipeline capacity to import low-priced natural gas from the United States. Mexico is expected to begin producing shale gas commercially after 2030, with shale volumes contributing more than 75% of total natural gas production by 2040.



Source: U.S. Energy Information Administration, *International Energy Outlook 2016* and *Annual Energy Outlook 2016*

Note: Other gas includes coalbed methane, tight gas and other (nontight) gas.

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