CHAPTER 2

SHALE OIL & GAS

A process of '*change of conventional oil flows*' of oil supply is taking place. Its centre of gravity is the 'Americas'. The growing output of Canadian tar sands, the huge ultra-heavy oil resources of the Venezuelan Orinoco Belt, and the recent discoveries of Brazil's ultra-deep offshore pre-salt formations, are all pieces of the unconventional oil mosaic that, by 2020, could deliver more than 10 million barrels per day from America alone. Yet the most surprising and fastest-growing frontier of unconventional oils is that of the Shale and Tight Oil in the United States.

Shale Oil reservoirs are rich with clay and fissile, meaning they split in layers where the presence of clay stone is massive. These layers may stretch horizontally for hundreds and thousands of miles. Unlike Shale formations, tight oil formations are made of siltstone (a mixture of quartz and other minerals, predominately dolomite and calcite, but many others may be present) or mudstone without a lot of clay in the reservoir. Most tight oil formations look like Shale Oil ones on data logs, hence the continued reference to both as "Shale." For consistency, the terms "Shale formations," and "Shale plays," or "Shale/ Tight Oil" plays and formations in this dissertation are synonymous with each other.

Shale Oil, Tight Oil, & Oil Shale: Similar Names & a Few Significant Differences

Shale Oil is conventional light oil with low sulphur content, trapped underground, in unconventional soil formations with extremely low porosity and permeability which in turn makes it extremely difficult for extraction of these hydrocarbons, unlike conventional hydrocarbons that are extracted by simple, vertical drilling. Shale Oil reservoirs are largely found amongst clay deposits, which are found in layers where clay stone is present in large quantities. On the other hand, tight oil is extracted from siltstone formations. Siltstone is a mixture of quartz, dolomite and calcite. Tight Oil is also conventional, light oil with low sulphur content. Despite their minor differences, since most tight oil formations resemble Shale during seismic data logs. Apropos, the term Shale Oil is commonly applied to both i.e. Shale Oil as well as Tight Oil. Interestingly, most U.S. so-called Shale plays are in effect tight oil formations. The term 'Shale plays' is refers to the oil & gas fields that are producing oil & gas from Shale Oil & Gas basins, Tight Oil basins etc, by hydraulic fracturing, a process that is explained later. Shale Oil must not be confused with Oil Shale, which for several decades enjoyed much higher popularity in the United States.

Oil Shale (*not Shale Oil*) is a predecessor of conventional oil also termed as kerogen. In fact it is kerogen, which constitutes the building blocks of conventional oil. Like Shale Oil, Oil Shale is also trapped in rocks with low porosity and permeability. However, oil Shale rocks are closer to the surface than those containing Shale and tight oil. Thus, both the oil Shale formations that contain kerogen and kerogen itself are unconventional.

We have known about the existence of huge Shale Oil formations in the United States for decades, but high cost and various technological barriers made development impossible. Paradoxically, oil Shale plays received much more attention until a few years ago, especially after the oil shocks of the 1970s, because they appeared more accessible than Shale formations. Oil Shale plays lie near the surface, while Shale Oil formations may reach 15,000 feet or more.

The concept of 'peak oil' was often put forward by geologists, in oil availability in the world had peaked and soon the world would run out of oil. Rising growth and increasing global demand for oil pushed crude oil prices high. These developments led to large scale investments for development of new oil & gas sources, especially around the turn of the current century. One such development was horizontal drilling and hydraulic fracturing, nowadays termed 'fracking'. These technologies have enabled the production of immense quantities of Shale Oil & Gas in the U.S., or the 'Shale revolution'.

Horizontal drilling and hydraulic fracturing are often referred to as 'new' technologies, but this mistake contributes to the scepticism and open criticism surrounding their use. The first horizontal well in history was completed in Texon, Texas, in 1929. At that time, it proved to be an imperfect and costly technology, useless in a world of low oil prices. It took about five decades before horizontal drilling finally established itself as a commercially viable technology in the early 1980s, thanks to both dramatic increase of oil prices following the 1970s shocks, and significant improvements in geology, oil drilling and telemetry. Since then, horizontal drilling has been widely used by the oil industry.

A Description of the Hydraulic Fracturing Processes

Hydraulic fracturing, the most controversial technique used for both Shale Gas & Shale Oil extraction, was first used in 1947 in Grant County, Kansas, US. According to a report by the National Petroleum Council, "*By 2002, the practice had already been used a million times in the U.S.*" The same report stated that in

2011, up to 95 percent of wells drilled in the U.S. were hydraulically fractured, accounting for 43 percent of U.S. oil production and 67 percent of U.S. natural gas production. (National Petroleum Council, September 2011)

Thus, far from being new, hydraulic fracturing involves some practices that have been termed controversial, since these were introduced to the public only in the last few years following the U.S. Shale Oil & Gas boom. These criticisms largely relate to green house gases, large quantities of water for 'fracking', chemical and waste water disposal and resource intensive drilling. Environmental concern, therefore have been increasingly voiced. Europe therefore has not allowed fracking, while the US has, and thus witnessed the Shale revolution and the associated economic benefits.

The combination of horizontal drilling and hydraulic fracturing is a complex process. In horizontal drilling, a well is vertically drilled for thousands of feet into the earth, and then turned horizontally to reach the hydrocarbon reservoirs. While the well is being drilled, a protective steel pipe (casing) is inserted in the wellbore. This pipe is perforated within the target zones that contain oil or gas. At this point, hydraulic fracturing may start. Fracking involves pumping a mix of fracturing fluid (water), sand (proppant), and chemicals down the perforated still pipe and into the reservoir at ultra-high pressure to create small fractures in Shale/tight formations which free up the oil and gas to flow up the well.

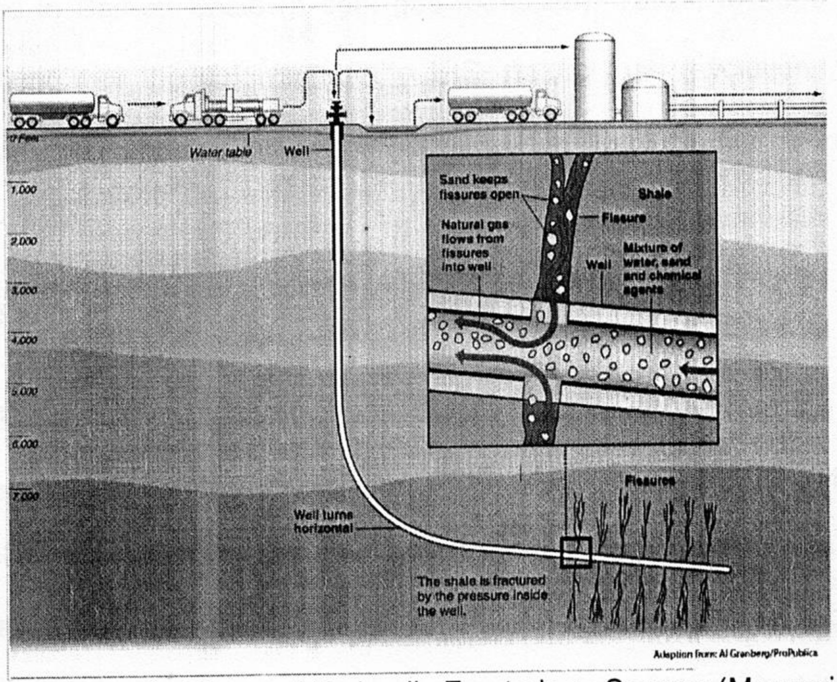


Figure 1: Schematic Figure of Hydraulic Fracturing. Source: (Magueri, 2012)

Sand prevents the fractures from closing when the injection is stopped (other kinds of proppants may be used, such as ceramic, that many experts consider more effective), while chemicals serve to tailor the injected material to the specific geological situation, protect the well, and improve its operation. Once the fractures have been created, injection ceases and the fracturing fluids begin to flow back to the surface as shown in Figure 1.

Horizontal fracking operations occur in multiple stages, sometime every 300 feet along the horizontal (lateral) arm of the wellbore, and each stage involves the repetition of pumping sand, water, and chemicals in a specific section of the well. Multiple fracking stages allow for a dramatic increase in oil & gas production.

The first large scale, combined application of horizontal drilling and fracking of Shale formations, pioneered by a small U.S. company, Mitchell Energy occurred in Barnett Shale (a tight gas formation), Texas, in 2000. That initial experiment was the catalyst for the U.S. natural gas revolution, which went unnoticed and underestimated for many years even though its results were already clear.

Shale Plays In the US/ Americas

From the mid-1990s to 2009, most experts believed that the U.S. would become a great natural gas importer, due to the steep decline of its domestic production of methane, the main component of natural gas. No one either anticipated or recognized the Shale-gas revolution as it was taking place. Even most industry leaders considered it a temporary bubble bound to evaporate quickly for several reasons, such as high extraction costs, poor estimates of recoverable Shale gas, steep decline of well productivity after a rapid output increase, and many more. It took at least nine years after the early stages of development of Barnett Shale before the big oil companies jumped on the Shale Gas wagon by paying exorbitant amounts of money to buy either small Shale Gas players, or pieces of acreages and working interests of other companies. Similarly, between 2008 and 2009, the United States Geological Survey, EIA, and the Potential Gas Committee significantly increased their estimates of the recoverable natural gas resources of the United States. Yet, Shale Gas production exceeded even those amendments, jumping from virtually zero in 2000 to more than 130 billion cubic meters in 2011, contributing to a dramatic decrease of natural gas prices in the U.S. and structurally changing the perception of the country's natural gas future. Shale Oil seems to be repeating this trajectory (Magueri, 2012) .

In general terms, a few wells have to be drilled to gauge the recoverable oil from a conventional field, although that initial estimate could change over time due to additional drilling activity, the extension of drilling to other areas of the field, the improvement of the field's geochemistry and physics knowledge, and the advent of new technologies. What's more, a conventional producing well may produce oil for years once completed. On the other hand, the huge differences in permeability, porosity, and thickness of a Shale/tight oil formation require many more exploration wells be drilled in different areas of the field before making it possible to have an idea of the effective recoverability rate from the whole formation. The rapid output increase and decline of Shale/tight oil producing wells further complicates matters, which makes Shale/tight oil operations a "drilling-intensive" activity. In other words, it requires continuous drilling of new wells for maintaining and increasing production.

Before examining the extent of the Shale/tight oil revolution in the U.S., it is worth noting that it is not only the result of a huge resource endowment, but it also stems from some distinctive features of the U.S. oil industry and market, which make it difficult to be replicated in other areas of the world, at least in a short period of time.

First of all, in the U.S., individuals and companies may own property rights on mineral resources, while in most parts of the world these rights belong to states only. This fact gives a huge incentive to land owners to lease their property rights and to the oil industry to lease or buy them.

Another major feature of the uniqueness of the U.S. and Canada is the presence of thousands of independent oil companies, ranging from very small to multibillion companies that historically played the role of pioneering new frontiers. The strategies and business models of these independent companies are usually much different from those of the large, integrated multinational oil companies, and require a short digression. Oil independents typically search for high risk-high reward opportunities whose potential is uncertain and whose initial development cannot comply with the rigid financial criteria used by big oils for taking investment decisions. Moreover, most of these companies, oftentimes owned by a single person or a small group of partners, are mostly focused on cash flows and growth, rather than profits and high profitability, at least in the first stages of their development. As long as they are successful in their undertakings while being cash-positive, they will succeed in getting the money they need to grow their business. Eventually, they can decide to sell their entire business to larger independents or bigger oil companies, as well as to go public. Their time-frame for success, thus, is much shorter than that of big multinational oil companies: they couldn't afford the be cash-negative for long periods of time, otherwise their investors could stop supplying money; they cannot be unsuccessful in their growth-strategies, otherwise they cannot make money by selling part of their equity.

Although highly innovative, then, oil independents usually do not engage in proprietary technology development (an exception is represented by larger independents), but they apply or adapt existing technologies in innovative ways to new targets, improving their processes and applications, thanks to the help of oil service companies (such as Halliburton or Schlumberger) that are the real owners of technological know-how in the oil and gas sector. Another feature of the U.S. (and Canada) oil and gas sector is the presence of several financial institutions, funds, capital ventures, equity firms that are eager to fund independent companies, oftentimes by becoming their equity partners.

A final, unique feature of the U.S. (and Canadian) hydrocarbon arena is the broad availability and flexible market of drilling rigs and other essential tools of oil exploration and production. For instance, the U.S. and Canada have about 65 percent of all drilling rigs existing in the world. All these features are foreign to other parts of the world, and they make the U.S. and Canada a sort of unique play for experimentation and innovation, such in the case of U.S. Shale Oil and Gas or Canadian tar sands.

Problems Typically Afflicting Shale 'Plays'

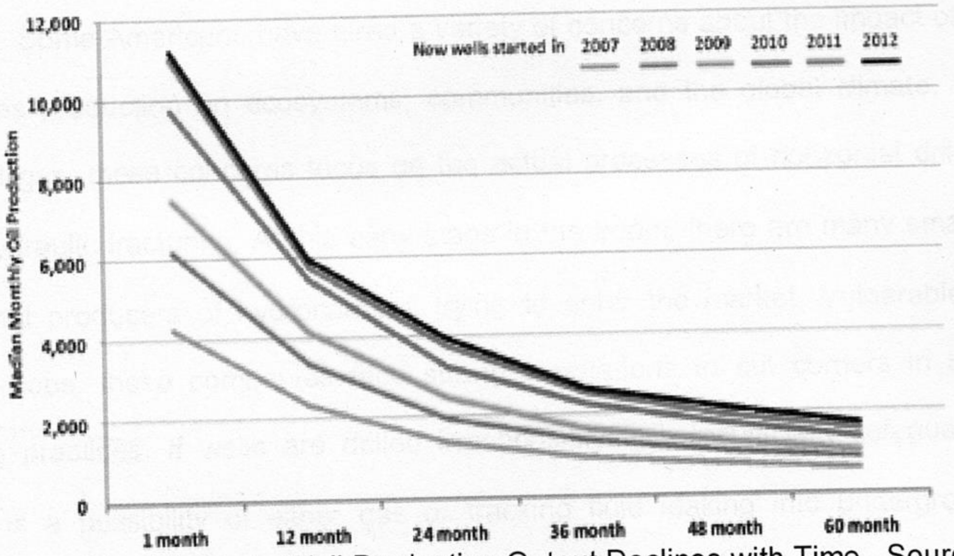


Chart 1: Shale Well Production Output Declines with Time. Source: (Maugeri, 2013)

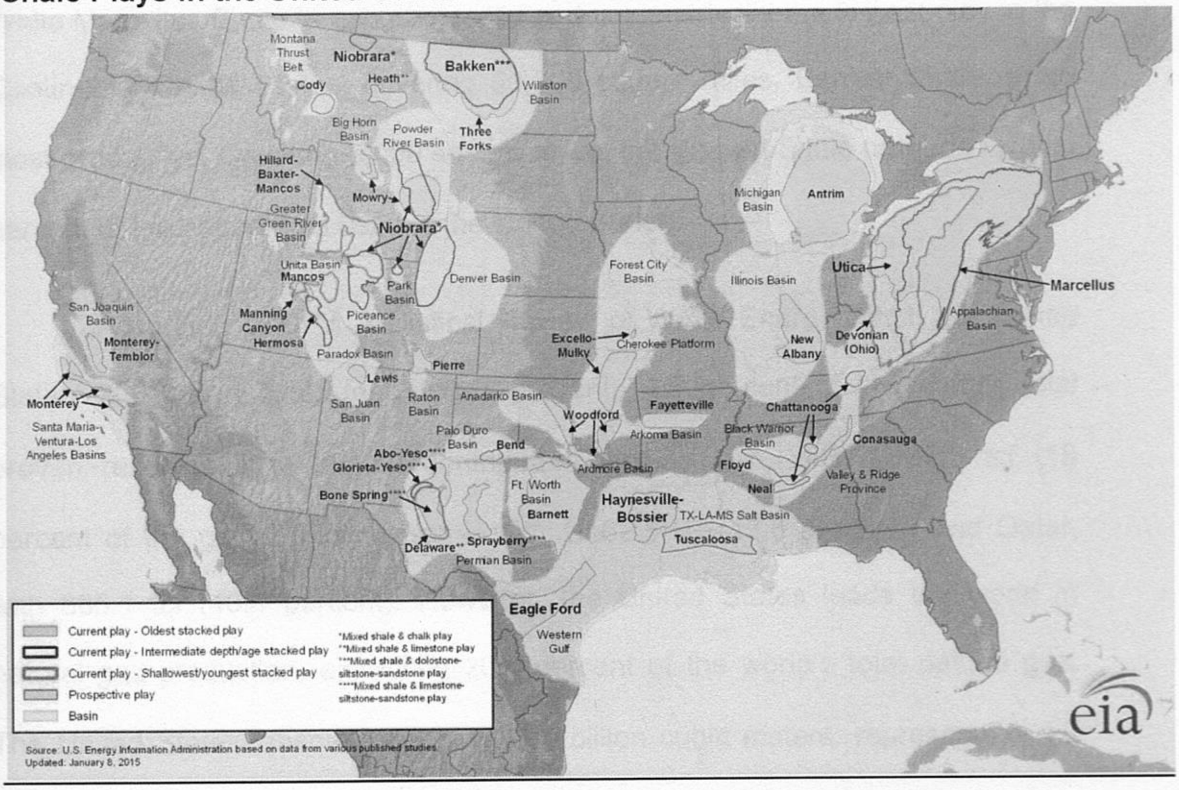
The first problem, or rather a typical production characteristic of Shale Oil & Gas production is rapid decrease in production output, after an initial increase. Shale Gas& Shale Oil wells exhibit their peak production rates during the first weeks of operation, generally referred to as initial production during the first 30 days, or IP30. Eventually, they register 40 to 50 percent lower rates by the end of the first year of production and a further 30 to 40 percent decline rate by the end of the second year.

Regulatory Considerations & Concerns in development of Shale plays is now centre-stage in many a nation. UK is the latest centre of this cause célèbre (The Guardian, 2015). Although as of now, the oil and gas boom in the US looks to proceed unhindered, potential regulations could still stall growth. Common to both oil and gas is the need for the government to continue opening up federally owned lands for exploration and production. While individually owned mineral rights fuelled the initial boom, more exploration is needed to continue growth. Large oil and gas companies also fear any kind of environmental disaster that would bring government focus onto exploration, drilling, or production.

Some Americans have aired a variety of concerns about the impact of oil and gas production on ecosystems, communities, and the global climate. For natural gas, these concerns focus on the actual processes of horizontal drilling and hydraulic fracturing. At this early stage in the boom, there are many smaller marginal producers of hydrocarbons trying to enter the market. Vulnerable to price drops, these companies face strong temptations to cut corners in their drilling practices. If wells are drilled irresponsibly with insufficient safeguards, there is a possibility of either gas or fracking fluid leaking into underground aquifers and contaminating the water supply. This is particularly pertinent in more populated areas such as Pennsylvania where drilling in the Marcellus Shale passes through aquifers used by larger populations. To date, there are no confirmed cases of groundwater contamination from hydraulic fracturing, despite widespread use of the practice since the 1940s. If, however, there were to be a clear link between natural gas extraction and groundwater contamination, the government would be hard-pressed to avoid imposing restrictive regulations. In this case, the entire industry would suffer. Fracking is also associated with release of higher amounts of greenhouse gases and this has been flagged by many environmental activists, worldwide.

Shale Oil development faces even greater opposition. In addition to resistance to the extraction process, oil producers also have to assure oil regulators that oil transportation is safe. Fears surrounding the development of the Keystone XL pipeline mirror greater opposition to the expansion of the US pipeline network. Opponents warn that a spill could severely damage local ecosystems and cost millions to clean up. While recent reports indicate that the oil flowing from Canadian oil sands is no more likely to cause corrosion in a pipeline than crude from any other source, reservations against the pipeline remains steadfast. If the Keystone XL pipeline fails to gain governmental approval, other pipeline projects in the United States aimed at improving aging infrastructure and enabling more efficient transport of American crude may also be derailed. Pipelines are not necessary to the growth of the American oil industry. However, the alternative transport method, by freight train, is far less efficient and much more expensive, not to mention accompanied by its own safety risks. The unconventional oil industry faces even stronger opposition to non-Shale extraction. For instance, the BP Deepwater Horizon crisis soured many on offshore drilling. Further governmental regulations have the potential to handicap continued development of unconventional oil resources.

Shale Plays in the United States



Map 1: Map Showing Shale Gas in the United States. Source: (EIA, 2015a)

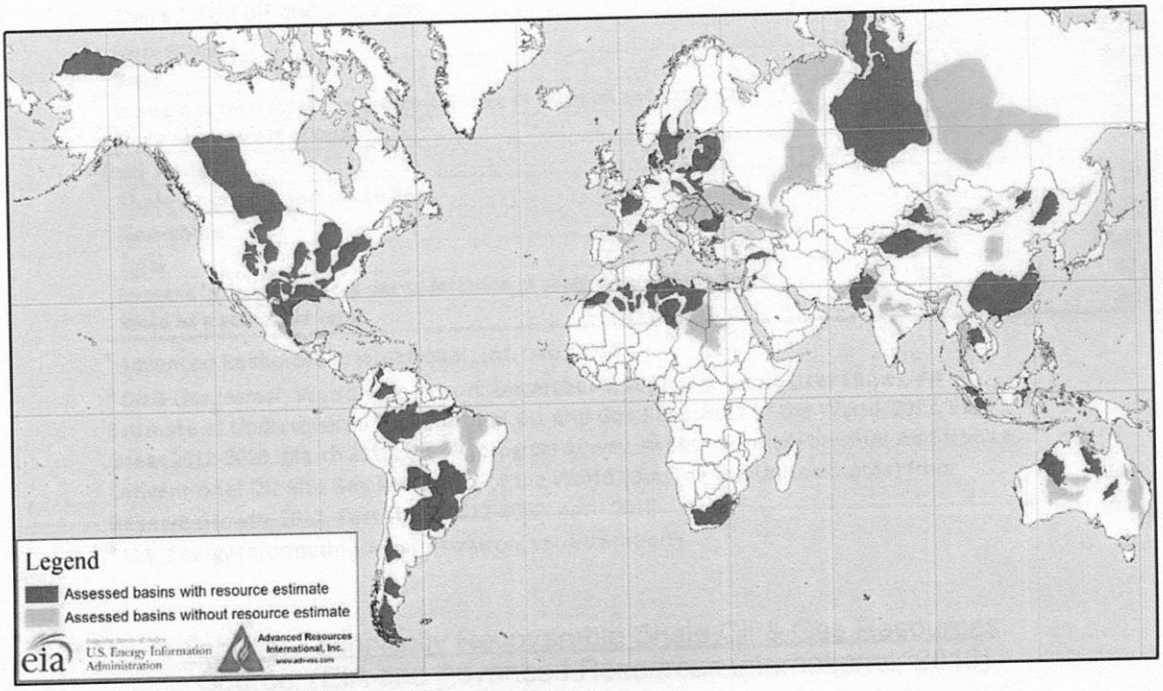
Estimated Shale Oil and Shale Gas resources in the United States and in 137 Shale formations in 41 other countries represent 10% of the world's crude oil and 32% of the world's natural gas technically recoverable resources, or those that can be produced using current technology without reference to economic profitability, according to an EIA-sponsored study on 10 June 2013. (EIA and Advanced Resources International, 2013)

There are 22 known Shale plays across the contiguous United States. Of these 22, six produce considerably more natural gas than the rest. These are the Barnett Shale in Texas, Woodford Shale in Oklahoma State, Haynesville Shale in East Texas and Northwest Louisiana, Antrim Shale in Michigan, Fayetteville Shale in Arkansas and Marcellus Shale in the Appalachian Basin. While Marcellus Shale is geographically and volumetrically the largest play in the Continental United States, covering 50,000 square miles, Barnett Shale is the most productive. Covering 5,000 square miles, the Barnett Shale produces seven percent of the natural gas used in the United States.

According to BP's Statistical Review of World Energy 2013, the United States' 300 trillion cubic feet (tcf), represents 4.5 percent of the world's total proven reserves. The largest contributors include Iran, with 1,187.3 tcf (18 percent of the global total), Russia, with 1,162.5 tcf (17.6 percent), and Qatar, with 885.1 tcf (13.4 percent). However, the United States leads the world in natural gas production, extracting 20.4 percent of the world's total natural gas. The United States' absolute figure, 681.4 billion cubic meters, represents a 4.7 percent increase over last year's numbers.

American oil reserves follow a similar pattern with the most productive oil plays being Bakken Shale in North Dakota and Eagle Ford in Texas. The United States' 35 billion barrels represent only 2.1 percent of the world's total proven reserves, compared to Canada's 173.9 billion barrels (10.4 percent), Venezuela's 297.6 billion barrels (17.8 percent), and Saudi Arabia's 265.9 billion barrels (15.9 percent). The more impressive numbers, however, come from increased US oil production attributable to unconventional Shale development. In 2011, the US produced 7.868 million barrels per day. In 2012, production jumped to 8.905 million barrels per day, a 13.9 percent increase. This marked, percentage-wise, the second largest increase in the world, trailing only Libya (+215.1 percent). In absolute terms, US production led world increases, rising by around 1.037 million barrels per day between 2011 and 2012.8 continues to increase steadily.

Global Assessments of Shale Oil & Gas Basins



Map 2: Source: Global Assessments of Shale Oil & Gas Basins. Source: (EIA and Advanced Resources International, 2013)

Technically Recoverable *Shale Oil and Shale Gas* Resources by the EIA estimates Shale resources, considered in conjunction with EIA's own assessment of resources within the United States, indicate technically recoverable resources of 345 billion barrels of world Shale Oil resources and 7,299 trillion cubic feet of world Shale Gas resources. See Table 1, which follows.

Total world resources	Crude oil (billion barrels)	Wet natural gas (trillion cubic feet)
Outside the United States		
Shale oil and shale gas[1]	287	6,634
Non-shale[2]	2,847	13,817
Total	**3,134**	**20,451**
Increase in total resources due to inclusion of shale oil and shale gas	**10%**	**48%**
Shale as a percent of total	**9%**	**32%**
United States[3]		
Shale / tight oil and shale gas	58	665
Non-shale	164	1,766
Total	**223**	**2,431**
Increase in total resources due to inclusion of shale oil and shale gas	**35%**	**38%**
Shale as a percent of total	**26%**	**27%**
Total World		
Shale / tight oil and shale gas	345	7,299
Non-shale	3,012	15,583
Total	**3,357**	**22,882**
Increase in total resources due to inclusion of shale oil and shale gas	**11%**	**47%**
Shale as a percent of total	**10%**	**32%**

[1] Advanced Resources International, Inc. (ARI) 2013.
[2] *Oil & Gas Journal*, Worldwide Report, December 3, 2012; U.S. Geological Survey, An Estimate of Undiscovered Conventional Oil and Gas Resources of the World, 2012, Fact Sheet 2012-3028, March 2012; U.S. Geological Survey, Assessment of Potential Additions to Conventional Oil and Gas Resources of the World (Outside the United States) from Reserve Growth, 2012, Fact Sheet 2012-3052, April 2012.
[3] U.S. Energy Information Administration, various reports.

Table 1: Technically Recoverable Shale Oil & Gas Resources.
Source: (EIA and Advanced Resources International, 2013)

While the assessment by ARI and EIA considers more Shale formations than were assessed in the prior version of this assessment, it still does not assess many prospective Shale formations, such as those underlying the large oil fields located in the Middle East and the Caspian region. Currently, only the United States and Canada are producing Shale Oil and Shale Gas in commercial quantities. The same cannot be said, however, for other countries with recently discovered Shale deposits. Countries like China, the United Kingdom, Poland, and Russia are struggling to exploit their Shale reserves for a variety of reasons. While Chinese Shale deposits are geographically difficult to access, European countries face significant political opposition to fracking and horizontal drilling.

Experts from both business and policy communities assert that the conditions enabling the US Shale Oil and Gas boom are unique in the world today. They point to the distinctively American combination of private property rights, individual mineral rights, a pre-existing network of pipelines, a robust venture capital market (not to mention other widely available financial tools), and an abundance of risk-taking entrepreneurial spirit. The results of this exceptional endowment are plain – although the United States possesses only approximately one quarter of the world's technically recoverable Shale resources, it accounts for nearly one hundred percent of global Shale hydrocarbon production.

The 'Bakken Shale': A Case Study

The most important frontier of Shale Oil development so far is the Bakken Shale, a tight oil formation mostly composed of silt and sandy silt, and thus a case study is considered relevant. The Bakken Shale is part of the Williston Basin, a huge sedimentary basin that stretches about 300,000 square miles across North Dakota, South Dakota, and Montana in the U.S., and Saskatchewan and parts of Manitoba in Canada. The Williston Basin includes other Shale formations, such as Three Forks, Tyler and Spearfish.

First discovered in 1951 in North Dakota, the Bakken formation (about 200,000 square miles, or 520,000 sq km) was too costly to develop for many decades. Only at the beginning of the 2000s, the small Lyco Energy Company and giant Halliburton attempted a combination of horizontal drilling and hydraulic fracturing in a small section of Montana's part of the formation (the *Elm Coulee field*). The outcome was so promising that it led the independent company EOG Resources to repeat the experiment in 2006, in the North Dakota section of the

Bakken formation (the *Parshall field*). That was the real beginning of the Shale Oil revolution. Thanks to the Bakken Shale, oil production in North Dakota skyrocketed from around 110,000 barrels per day (bbl/d) in 2006, to more than 530,000 barrels in December 2011.

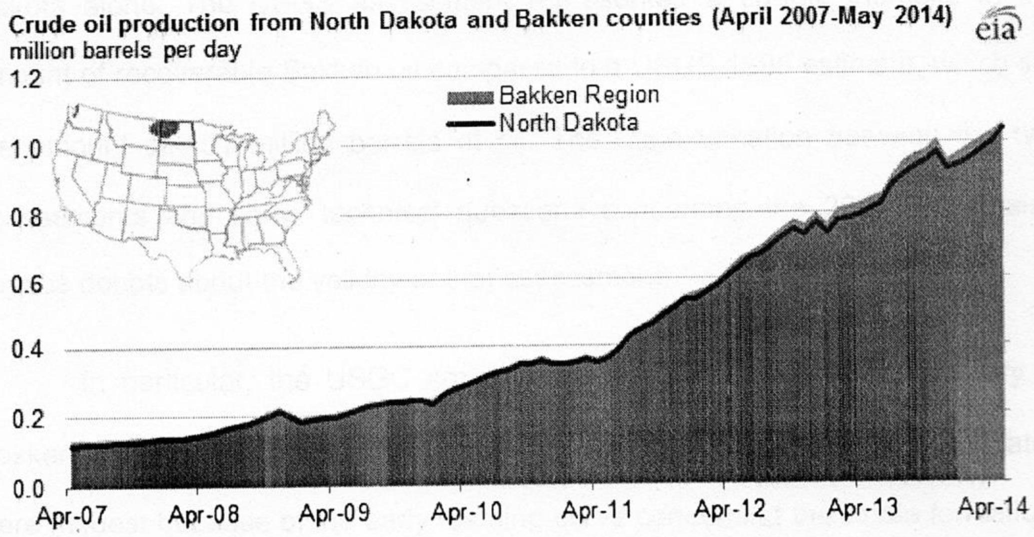


Chart 2: Source: U.S. EIA, Petroleum Supply Monthly and Drilling Productivity Report, August 2014. Source: (EIA, 2014c)

North Dakota crude oil production surpassed 1.0 million barrels per day (bbl/d) in April and May 2014. (EIA, 2014c). This record is the result of increasing crude oil production from the Williston Basin's Bakken and Three Forks formations in North Dakota and eastern Montana. Energy Information Administration, in its state overview of North Dakota, in 2013, wrote "*In 2013, North Dakota was the second largest crude oil-producing state in the nation and accounted for over 11.5% of total U.S. crude oil production; a 177% increase in production from 2010 to 2013 was primarily driven by horizontal drilling and hydraulic fracturing in the Bakken formation*"

All these figures are in sharp contrast to a 2008 U.S. Geological Survey assessment of the Bakken Shale, that estimated 3.0 to 4.3 billion barrels of undiscovered, technically recoverable (not economically recoverable, necessarily) oil in the portion of the Bakken formation stretching from Montana to North Dakota alone. The USGS assessment represented a 25-fold increase in the amount of recoverable Bakken oil compared to a USGS 1995 estimate, which set the amount at 151 million barrels of oil. The huge variation between the two assessments and some technical questions concerning the 2008 study raise serious doubts about the validity of that assessment.

In particular, the USGC concluded its analysis of per-well recovery in Bakken in July 2007, when drilling rigs in the region were few and recovery rates were modest because of the early learning curve concerning the whole formation: horizontal drilling-hydraulic fracturing was tested only a year before. Since then, however, the activity in Bakken has exploded, as demonstrated by the drilling-rig count in the play.

On a weekly basis, there were around 50 active drilling rigs in the Bakken Shale between 2006 and early 2008, almost equally divided between Montana and North Dakota. They jumped to about 90 in early 2008, and then diminished to less than 40 in mid-2009. But at the beginning of February 2012, there were 200 active drilling rigs, 183 of which in North Dakota alone,36 and a total of about 6,000 producing wells, compared to less than 100 in July 2007, when the USGS ended its analysis. In the same timeframe, observed ultimate recovery rates have dramatically increased, jumping from 50,000-100,000 estimated ultimate recovery (EUR) barrels per well in 2007 to 600,000-800,000 EUR barrels per well in 2011.

The North Dakota Industrial Commission Department of Mineral Resources (NDDMR) has recognized the improved well EUR as well as the Three Forks potential, and in January 2011 announced that recoverable reserves from the Bakken. Three Forks reservoirs could reach 11 billion barrels in North Dakota alone. That is five times the NDDMR 2008 estimate of 2.1 billion barrels of oil production in just the North Dakota section of Bakken.

The EIA monthly report of February 2015 reported Bakken producing 1.31 Million Barrels of oil per day and 1,541Million cubic feet of gas per day (EIA, 2015b).

Conclusion

While concluding the chapter, it can clearly be summed up that technological breakthroughs and hydraulic fracturing has enabled extraction of a new.'unconventional' source of oil & gas, Shale Oil & Shale Gas. Production over the last decade has continued to grow, especially in the US. Unique conditions have made 'fracking' and thus Shale Oil & Gas production possible in the US. Estimates indicate significant shale basins globally. However, like any form of oil & gas extraction, it has its own set of peculiarities & dimensions. There are the optimists & there are the 'nay sayers'.