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MASTER'S THESIS

SHALE GAS IN INDIA – CHALLENGES AND OPPORTUNITIES

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AUTHORSHIP STATEMENT

The undersigned Bibhulal Sinha, a student at the University of Ljubljana, Faculty of Economics, (hereafter: FELU), declare that I am the author of the master's thesis entitled Shale gas in India – challenges and opportunities, written under supervision of Assistant Professor, Matej Svigelj, Ph.D.

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INTRODUCTION

Energy is an essential element for survival and maintenance of the quality of human life. We are entirely dependent on the continuous supply of energy for our existence and sustenance. Energy is essential for development and progress.

Energy is available in many primary forms such as coal, petroleum oil, natural gas, biomass and nuclear. These energy forms are the non-renewable type. We use the maximum amount of coal and oil among the non-renewables in India. Coal is available in maximum quantity. Oil and natural gas are convenient forms of energy and widely used. Gas creates the least environment pollution among fossil fuels. However, the reserves of coal, oil and gas are limited.

The major renewable forms of energy are hydropower, the wind and solar. They are the cleanest forms of energy. There is no adverse environmental effect due to renewable forms of energy. Research and development is going on renewable forms of energy in many countries. However, the research and development is taking considerable time to develop to take the leading position as a primary source of energy.

The demand for all form of energy is increasing. The demand for natural gas is expected to rise at the highest rate as gas is the most convenient and the least polluting fossil fuel.

Shale gas can be regarded as an alternative to the conventional natural gas. In recent years, the world has noticed a significant change in energy equation due to fast developments of shale gas. The United States (hereinafter: US) has been producing shale gas for many decades, but the actual growth of shale gas production was observed after 2000. The extraction of shale gas is feasible and economically viable in the US today because of horizontal drilling and hydraulic fracturing technology. Shale gas is an enormous success in the US.

Shale gas is widely available and evenly distributed in basins in many countries. Many of those countries are now trying to emulate the US success path to shale gas. The frontrunner countries in shale gas other than the US are Canada, China and Argentina. These countries have started producing shale gas/oil. However, the economical viability of shale gas recovery from across the world will be different from the US because there are variations in shale rock formations in different regions.

There are challenges on the path of recovery of shale gas. The major ones are population density, the requirement of large quantities of water, the infrastructure of road and pipeline and potential groundwater pollution. Moreover, there are challenges like air pollution from equipment, fugitive emission, an increase of land use, the effect of fracturing in the seismic zone and so on. Utmost care is required to minimise groundwater contamination, disposal of produced water and recycled water, air pollution and avoid earth faults.

India has a significant quantity of shale gas reserve. India is in the initial stage of exploration and production of shale gas. It has a long journey to make for safe and sustainable shale gas development. Successful development depends on the regulatory framework that promotes investment in exploration and production of shale gas and at the same time considers environmental impacts on society.

In India, there is a huge supply deficit and heavy reliance on import of natural gas. There is a considerable quantity of technically recoverable resources of shale gas available in India. Domestic shale gas can satisfy increasing natural gas demand and reduce huge import bills of

India. Development of this sector will further enhance economic activity, such as investments, employment, and additional downstream sectors/industries, all leading to increase in gross domestic product (hereinafter: GDP).

The purpose of this thesis is to study and analyse the impact of exploration and exploitation of shale gas and formulation of strategies for shale gas development for energy security, economic viability and environment of India.

The analysis of shale gas activities is carried out for different parts of the world such as the US, the European Union (hereinafter: EU), and highly populated country like China. The major areas, such as exploration and production activities, economics, environmental impacts and shale gas policies of those countries are studied. The analysis, examination and study are also carried out for the present energy scenario, energy sources, consumption pattern of natural gas in India. Also, a discussion is carried out on shale gas reserve, shale gas developments, and factors affecting the shale gas activities in India. The factors discussed are gas pricing policy, shale gas policy and shale gas economics.

Based on the inputs of shale gas activities in the US, the EU, China and India, the strength, weakness, opportunity and threats (hereinafter: SWOT) are identified for shale gas activities in India. The threats, challenges and opportunities are part of the SWOT analysis. Finally, this thesis brings out the strategy recommendations based on the impact of strength and weakness on opportunity and threats using the TOWS (threat, opportunity, weakness and strength) matrix. These recommendations can be used as the guidelines to take India towards the path of successful exploration and production of shale gas.

Shale gas activities of different regions of the world such as the US, the EU, and Asian countries like China are studied and analysed. Statistical data are utilised at various stages of the analysis. The study is mainly based on an analysis of secondary data and information. The data and information are obtained from relevant literature such as research papers, scientific analysis reports, institutional reports, journals and international publications. Most of these sources are from websites of international agencies, state-owned companies, government agencies and institutions. These support the description of the problems and any potential new findings. The combination of numerous different existing views, data and facts are used as a tool for analysing, comparing and determining a solution to the problem. Based on the studies of multiple regions, the inputs are reviewed vis-a-vis Indian conditions, for final analysis and recommendation.

The **first chapter** of the thesis addresses the importance of energy and different type of energy sources that exists. This chapter studies the importance of natural gas among other primary forms of energy in the world. Then the analysis is carried out on the reserve and production, consumption behaviour and the global market of natural gas. Data are collated to understand demand and supply position and future trends in the world.

The **second chapter** of this thesis is divided into four parts. The **first part** analyses shale gas and the importance of shale gas as an alternate source of energy, reserve and production of shale gas, and developments so far in shale gas extraction technology. The US is the pioneer of shale gas. The **second part** analyses the status of shale gas, economics, environmental challenges and shale gas policy of the US. The t**hird part** deals with the analysis of shale gas in the EU. The EU is considered for study because member countries are divided to take a decision on shale gas. One group believes shale gas as a replacement of coal and while the other group favours renewable energy instead of fossil fuels. The **fourth part** covers analysis of shale gas in China. China is the most populous country in the world. The living condition, terrain and environment are to some extent similar to that of India. The third and fourth part addresses the status of shale gas, economics, environmental challenges and shale gas policy in the EU countries and China.

The **third chapter** of the thesis discusses energy scenario of India. While addressing shale gas in India, it delves into reserves of India with a break up of its shale gas basins and exploration, development status so far and shale gas policy. It also studies the natural gas pricing mechanism and shale gas economics, which are closely linked to the success of shale gas in India. In this chapter, identification of the strengths, weaknesses, opportunities and threats of SWOT matrix is carried out. Using the SWOT matrix, the strategies are evolved and suggested for successful exploration, development and production of shale gas in India.

1 OVERVIEW OF NATURAL GAS

1.1 Importance of Energy

Energy is a vital and essential requirement for every aspect of human life. All over the world we need a continuous supply of energy. It is the primary driver of industrial activity required for the economic development of a country. Energy is necessary for the transportation of goods and people. Residential and commercial sectors also demand considerable quantity of energy in the form of electricity. The energy required for these usages increase with the growth of a country and technological advancement.

Developed countries utilise more energy than developing countries. Developed countries with only 20 percent of world population consume more than 50 percent of world's energy, whereas developing and underdeveloped countries with 80 percent population consume less than 50 percent. Developing countries mainly China, India, Brazil, Indonesia and South Africa are economically growing at a fast rate, thus have growing energy demand. Energy demand depends upon the standard of living, population and economic growth of a country. Kharas and Gertz (2010) estimated that 5 billion populations would reach middle class by 2030 from the present figure of 1.8 billion. The requirement of better living for the middle class will demand much more consumption of energy (ExxonMobil, 2015; Kharas & Gertz, 2010).

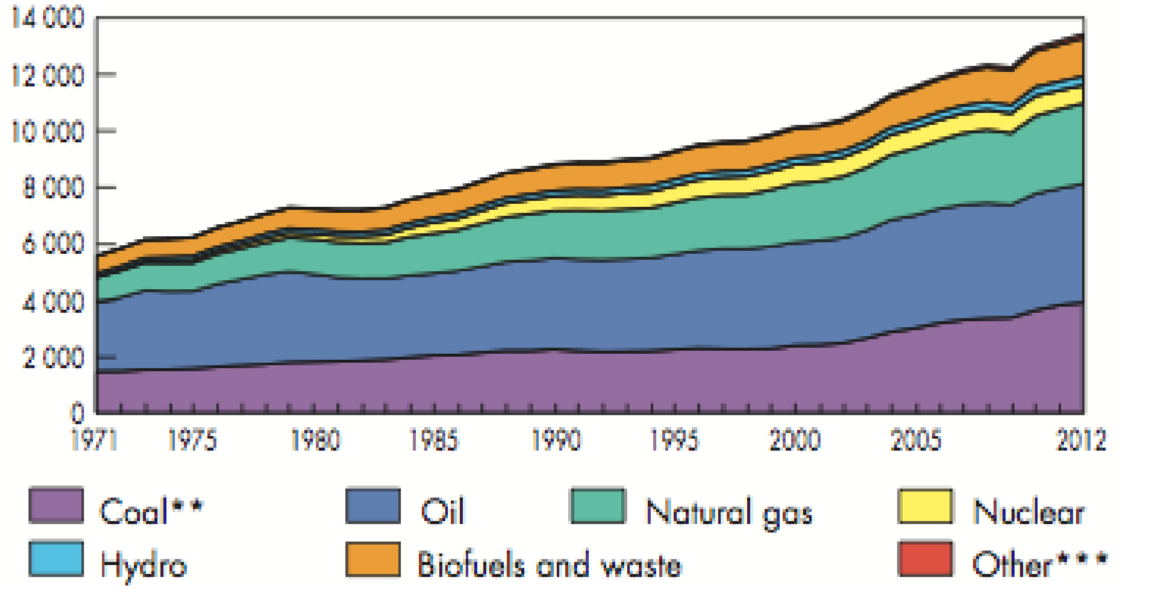
Economic growth is the priority of the developing countries. To match the growth, they require increasing quantity of fossil fuels such as coal, oil and gas. Among the developing countries, China and India will play leading role in terms of population size and rise in standards of living in future. The requirement of the energy of these two countries will account for 50 percent of the growth in global energy demand. Other developing countries with high growth rate will also represent significant rise in energy demand due to increase in population and economic development (ExxonMobil, 2015).

World's population is expected to rise by 30 percent from 2010 to 2040; whereas the world GDP is predicted to grow by 140 percent. The energy consumption is predicted to increase by 35 percent during this period after considering energy savings due to technology advancement (ExxonMobil, 2015).

1.2 Energy sources

The primary source of energy is available in many forms. They fall into two groups, renewable and non-renewable types of energy. Non-renewable sources are nuclear and fossil fuels such as coal, oil and natural gas. Oil is mainly used for transportation and feedstock of chemical industries as raw materials. Gas is used for electricity generation, heating, transportation and feedstock and is preferred for low emission. The primary use of coal is power generation and industrial application.

Figure 1. World total primary energy supply 1971-2012 by fuel (Mtoe)

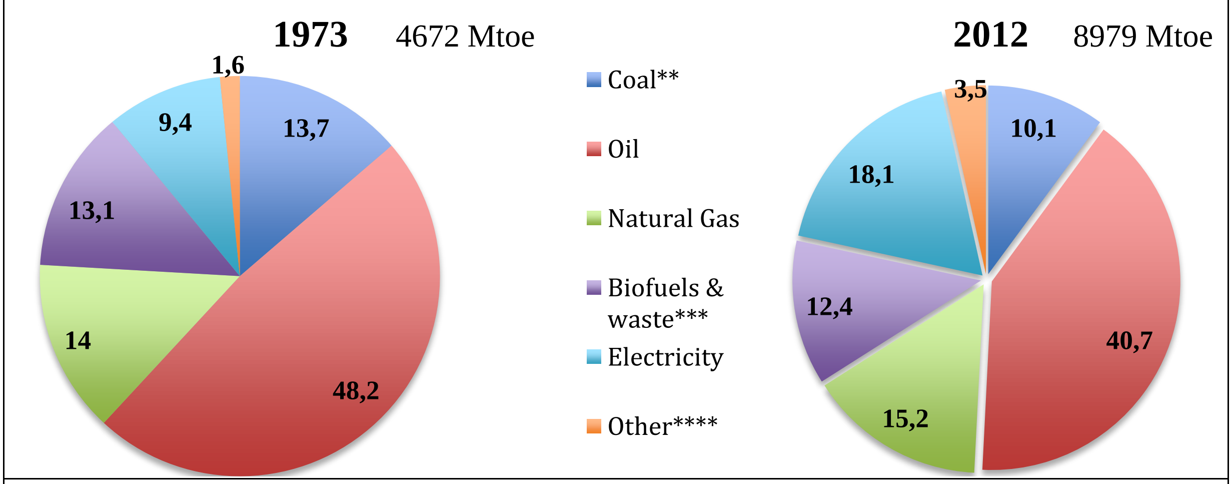


* In Millions of ton of oil equivalent (hereinafter: Mtoe)
** Peat and oil shale are combined with coal
*** Others include geothermal, solar, wind, heat, etc.

Source: International Energy Agency, *Key World Energy Statistics*, 2014, p. 6.

Figure 1 exhibits an increasing trend in supply of total primary energy over the years due to the advancement of technology and significant investment. There is a significant decrease in percentage consumption of oil and increase in consumption of gas in 2012, compared to that of the 1970s. It is because of percentage increase in availability of gas, convenience and impact on the environment. The consumption of a type of energy varies from country to country depending upon availability, convenience, performance, affordability and impact on the environment.

Figure 2. Fuel shares of total consumption in 1973 and 2012 in %



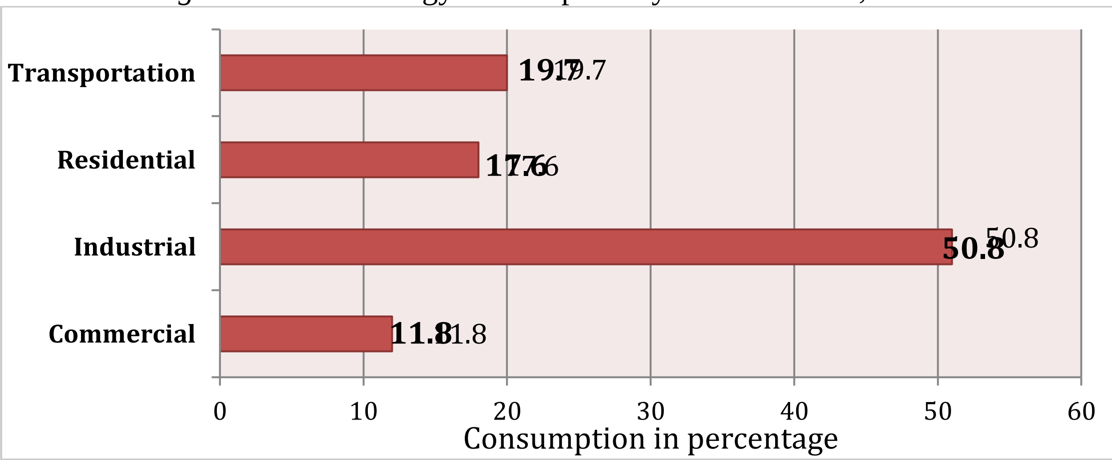
* In Mtoe
** Peat and oil shale are combined with coal
*** biofuels and waste fuel consumption considered for a number of countries
**** Others include geothermal, solar, wind, heat, etc.

Source: International Energy Agency, *Key World Energy Statistics*, 2014, p. 28.

Figure 2 displays fuel consumption of various types of fuels in 1973 and 2012, in percentage. In 2012, the consumption of oil was highest at 40.7%, natural gas consumption accounted for 15.2% of global energy consumption, and the share of non-renewable energy was more than 96%. Natural gas has the highest growth rate in consumption among the fossil fuels in 2012 compared to 1973. According to British Petroleum (2015), natural gas is expected to be the fastest-growing fossil fuels (1.9% p.a. from 2013 to 2035). The demand for coal is anticipated to be slowest growing fossil fuels as many nations are shifting towards low emission fuels like gas, nuclear, and renewable energies.

Figure 3 indicates four major end-use sectors for energy consumption in 2011. These sectors are transportation, residential, industrial and commercial sectors. As per the US Energy Information Administration (hereinafter: USEIA) (2015a), the industrial sector consumes the maximum energy. Electrical power sector consumes 39 percent.

Figure 3. World energy consumption by end-use sector, in 2011



Source: USEIA, *How Much Energy is Consumed in the World by Each Sector?*, 2015.

1.3 Reserve and production of natural gas

Natural gas is available in both conventional (easier to produce) and unconventional (harder to produce) geological formations. So far, the sole focus of the gas industry is conventional natural gas. However, the reserve of conventional natural gas is limited. According to the USEIA (2013a), the proven reserve of natural gas in the world is 6557.8 trillion cubic feet (hereinafter: Tcf). Table 1 indicates the reserve and production of natural gas of India, the US, China, Europe, Russia and the Middle East countries in 2013. Middle East countries possess more than 43 percent of total gas reserves. The proven reserve of natural gas of India is 47.8 Tcf. If we observe the past trend, the estimates of total recoverable resources have improved over time as knowledge of the geology has increased and recovery technology improved.

Reserves-to-production (R/P) ratio is an indicator of the length of time that the remaining reserves of gas or oil would last if gas or oil produced at the present rate. The reserves of oil and gas remaining at the end of any year divided by the production in that year give the R/P ratio. R/P ratio of the world for natural gas was 55.1 in 2013. The R/P ratio for natural gas in India for the year 2013 was 40.2, which implies that the available gas reserve of India will last for next 40 years if India continues to produce at the current rate (British Petroleum, 2014).

Table 1. Reserve and production status of conventional natural gas, 2013

	Proven Reserve at the end of 2013			Production in 2013			R/P Ratio
	Trillion cubic feet (Tcf)	Trillion cubic meters	Share of world (%)	Billion cubic meters	Million tons oil equiv.	Share of world (%)	
World	6557.8	185.7	100.00	3369.9	3041.3	100.00	55.1
India	47.8	1.4	0.73	33.7	30.3	1.00	40.2
USA	330.0	9.3	5.03	687.6	627.2	20.62	13.6
China	115.6	3.3	1.76	117.1	105.3	3.46	28.0
Europe (incl Russia)	1999.5	56.6	30.49	1032.9	929.6	30.57	54.8
Russia	1103.6	31.3	16.83	604.8	544.3	17.90	51.7
Middle East countries	2835.4	80.3	43.24	568.2	511.4	16.82	100+

Source: BP, *BP Statistical Review of World Energy June 2014*, 2014, p. 20, 22, 24.

It is important to explore and discover new gas fields to enhance reserve volume of natural gas. The other way is to find an alternate source of energy including renewables, minimize production and consumption of natural gas. To achieve longer reserve life, the national oil company of India, Oil and Natural Gas Corporation (hereinafter: ONGC) keep on exploring new reserves and add to the existing reserve volume (ONGC, n.d.).

1.4 Consumption of natural gas

Consumption of natural gas is increasing compared to other types of energy. This increase is because of low emission, versatility, good burning quality, reliability, flexibility and availability. Moreover, gas can be supplied uninterruptedly through pipelines to the end-users. Consumption of natural gas is expected to increase by 65 percent in 2040, compared to its use in 2010 (ExxonMobil, 2015).

Natural gas is vital to transportation, residential, industrial and commercial sectors. Natural gas is used as fuel for major industries like paper and pulp, metals, chemicals, petroleum refining, and food processing. It is feedstock of plastic, chemicals, and fertilizers. In transportation sector also, natural gas is increasingly used as it is cheaper and has good ignition efficiency.

Table 2. Consumption of natural gas in 2013

	Billion cubic meters (Bcm)	Million tons oil equivalent	Consumption (in %)
USA	737.2	671.0	22.02
Russia	413.5	372.1	12.35
China	161.6	145.5	4.83
India	51.4	46.3	1.54
European Union	438.1	394.3	13.09
Europe (incl Russia)	1064.7	958.3	31.80
OECD	1596.5	1444.4	47.69
Non-OECD	1751.1	1576.0	52.31
World	3347.6	3020.4	100.00

Source: BP, *BP Statistical Review of World Energy June 2014*, 2014, p. 23, 25.

Natural gas is preferred over other fuels like coal and nuclear power generation, because of economic, environmental, technological and regulatory changes. It is also preferred over other fuels for electricity generation because installation time of gas power plant is quite less (around two years). The consumption of natural gas is anticipated to surpass the consumption of petroleum oil in less than 20 years (Center for Climate and Energy Solutions, 2013, p. 11). The global gas demand is expected to ascend to 159 Tcf in 2035 - up from 109 Tcf in 2008 (Robertson, 2011).

The consumption of natural gas in developed countries of North America, Organisation for Economic Co-operation and Development (hereinafter: OECD), Europe, Australia and countries like Japan remained constant since 2003. Consumption of natural gas increased in developing countries/regions, such as Africa, Asia, mainly China, India and Brazil due to growth in economic development. Table 2 shows the consumption of natural gas in major countries/groups including India, the US, China, Russia, and the EU in 2013. The consumption of gas in the US is highest, whereas India consumes only 1.54 percent of world gas usage (British Petroleum, 2014, p. 23).

1.5 Overview of global natural gas market

The major reserves of natural gas are concentrated in few geographic locations. According to Center for Climate and Energy Solutions (2013), seventy percent of world's gas supply is from Russia, Middle East, and North America. Natural gas is traded globally between countries/regions. The natural gas market depends on the reserve, production associated with demand and ability to meet the demand for supplies from other regions.

Natural gas is traded globally through long distance pipelines and liquefied natural gas (hereinafter: LNG) through tankers. Pipelines are normally utilized for regional market and the land transportation of natural gas. The majority of trading of natural gas, both international and domestic is carried out through pipelines. However, there is an increasing trend for trading LNG through tankers to distant offshore locations. In 2013, 30.5 percent of total natural gas trading was in LNG. Trading of LNG is expected to increase by 30 percent in 2017. High transportation cost and difficulty in transportation of natural gas by these modes act as barriers to the global gas market (Center for Climate and Energy Solutions, 2013, p. 10).

The EU countries import natural gas mainly from Russia, Norway, and the Netherlands. The US is importing from Canada. Asian countries import mainly from former Soviet Union countries and Asia-Pacific countries, through pipelines. European and Eurasian countries import LNG mostly from Qatar, Algeria, and Nigeria. Asia-Pacific countries import LNG from Qatar, Australia, Malaysia, Indonesia, Trinidad & Tobago, Russia, Oman, Algeria and Nigeria. India imports LNG mainly from Qatar. In 2013, total exports by countries globally by pipelines were 710.6 billion cubic meters; whereas total exports of LNG was 325.3 billion cubic meters (British Petroleum, 2014, p. 28).

The natural gas market is determined by supply, demand and evolution of natural gas market itself. In addition to the availability of conventional natural gas, the factors that affect supply are (USEIA, 2014b):

- availability of natural gas in unconventional reserves
- new cross country pipelines
- floating LNG technologies capable of floating liquefaction and floating gasification of natural gas
- new LNG capacity

- national level policies such as environmental policies, safety and energy security objectives
- cost reduction due to technology improvements.

The economic growth of the developing countries and national level policies are the key to demand of natural gas. The growth of Asian countries is the primary driver of the demand for natural gas worldwide. China and India are leading countries that will influence demand globally in future (USEIA, 2014b).

The global market for natural gas is evolving with respect to market structure and organization. It depends mainly on the development of bilateral trade between buyers and sellers. Development of natural gas hubs, spot markets, and market globalization are the three areas for the evolution of the natural gas market. Pipelines transportation dominates this market. However, LNG market is expected to change the scenario. Expansion of LNG market has made gas a globally traded commodity. In recent years, international over-the-counter trading increased along with LNG spot market trades. Gas produced in Qatar, Trinidad can be purchased by customer countries at hubs located at places like London, Amsterdam, Singapore, and so on (USEIA, 2014b).

2 INTERNATIONAL SHALE GAS DEVELOPMENTS

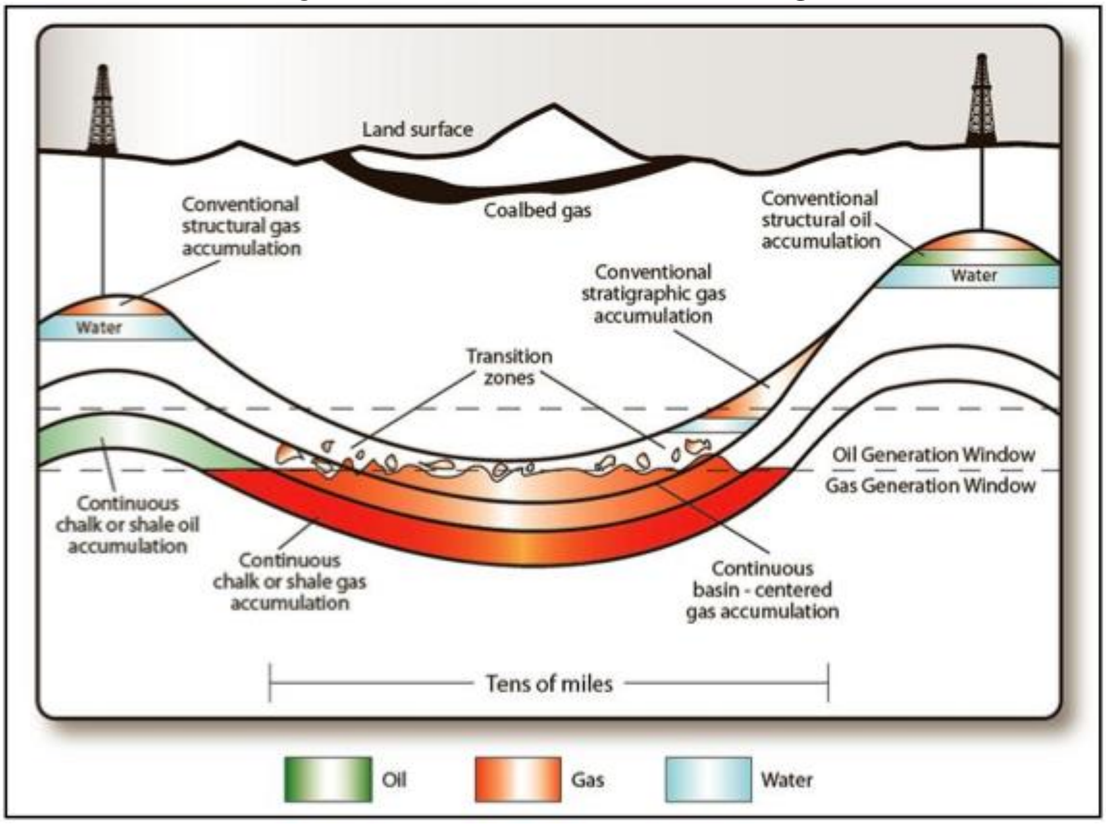
2.1 Shale gas as an alternative energy source

Natural gas is the most convenient form of primary energy. This conventional natural gas is going to last around 55 years. The onshore source of conventional natural gas is almost explored over last century. There is very less possibility to find an enormous reserve of natural gas that can provide fuel to continue for many years. Additionally, renewable technologies for clean energies such as solar, the wind are not picking up with the rate of economic development and are not convenient to use in comparison to the fossil fuels (Tokic, 2013, p. 5).

Natural gas resource is produced from conventional and unconventional geologic formations. It is easier to produce from conventional formations. However, it is complicated and more difficult to produce from unconventional geologic formations. Shale gas is an unconventional resource of natural gas (Khan, 2012). Figure 4 shows the schematic of the location of shale gas. Shale gas is natural gas that is confined in shale formations. The shale formations are sedimentary rock. These shale formations function as a reservoir and as source rock for shale gas. Shale gas is trapped in these rocks of low permeability (non-porous) and hence does not flow easily. The gas is held in natural fractures, pore spaces as free gas and some are absorbed into the organic material of shale. The absorbed gas is released when pressure drops after production of free gas. The method of recovery of shale gas is complex and quite different from that of the conventional porous reservoir of natural gas (Boyer, Kieschnick, Suarez-Rivera, Lewis, & Waters, 2006).

Production of shale gas can significantly increase the supply of global energy source. Thus with the production of shale gas the price of natural gas can come down. Many energy deficit countries including the US have sufficient reserve of shale gas. These countries can become self-reliant on domestic gas and can even become independent from import of energy. British Petroleum (2015, p. 45) estimated that the US could become energy independent by 2030. The energy independence of the US will also reduce geopolitical tensions with respect to Middle Eastern oil producing countries. Middle Eastern countries and countries like Russia are likely to become less strategically and economically important as oil and gas prices drop, and their demand decreases (Tokic, 2013, p. 7).

Figure 4. Schematic of location of shale gas



Source: K.A. Khan, *Conventional and Unconventional Reservoirs*, 2012, p. 4.

As natural gas is the cleanest of all fossil fuels, substitution of crude oil and coal with natural gas have a positive effect on the global environment. In future, renewable energy is expected to be evenly distributed globally, and all countries are likely to become self-sufficient as fossil fuels will phase out with time. Countries self-sufficient with alternative renewable energy will not have to rely on trade with other countries to obtain energy. Shale gas can be considered as is a bridge between conventional fossil fuels and sustainable renewable energy, till the later takes over as the primary source of energy. Shale gas, as an alternative to conventional natural gas, can supply sufficient requirement of energy for a considerable period (Tokic, 2013, p. 2).

2.2 Reserve and production of shale gas

Oil and gas reserves are measured as technically recoverable resources (hereinafter: TRR) and economically recoverable resources. TRR is the volume of resources that can be recovered using current exploration and production technology without regard to the cost of production and price of produced gas. As there is an improvement of technology, the volume of technically recoverable resources changes or gets adjusted (USEIA, 2013a, p. 10; Society of Petroleum Engineers, 1997).

Economically recoverable resources are resources that can be profitably produced under current market conditions. It depends on the cost of production and price of produced gas. Proved reserves are those reserves of oil and gas, which can be estimated with reasonable certainty to be commercially recoverable (USEIA, 2013a, p. 10; Society of Petroleum Engineers, 1997).

In 2013, the USEIA assessed shale gas reserves for 137 shale formations in 41 countries in addition to the reserves of the US. Many countries are yet to be estimated for the reserve of shale gas. Globally 32% of the total estimated natural gas resources are in shale formations. Table 3 indicates shale gas resource of top ten countries, India and Europe. China has largest reserve of shale gas in the world. Argentina, Algeria and North America have significant quantities of shale gas too. However, the reserve of shale gas is dependent on the availability of accurate information based on technology improvement, rigorous application of requirements and better geological data (USEIA, 2013a, p. 3-13).

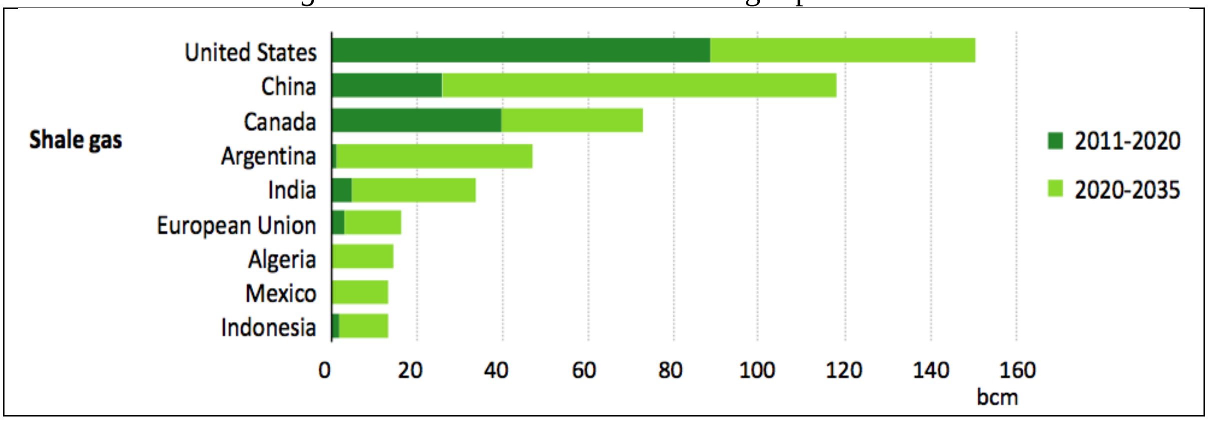
Table 3. Shale gas reserve of major countries, 2013

Sl. No.	Country or region	Shale gas		
		Trillion cubic feet (Tcf)	Trillion cubic meters	Reserve in %
1	China	1115	31.57	15.27
2	Argentina	802	22.71	10.99
3	Algeria	707	20.02	9.69
4	US	665	18.83	9.11
5	Canada	573	16.23	7.85
6	Mexico	545	15.43	7.47
7	Australia	437	12.37	5.99
8	South Africa	390	11.04	5.34
9	Russia	285	8.07	3.90
10	Brazil	245	6.94	3.36
11	India	96	2.72	1.32
12	Europe (excluding Russia)	470	13.31	6.44
	World Total	7299	206.68	100.00

Source: USEIA, *Technically Recoverable Shale Oil and Shale Gas Resources*, 2013, p. 6-10.

The US and Canada are the pioneers in exploration and production of shale gas. Recently China and Argentina started producing commercial volumes of either shale gas or oil. Other countries such as Algeria, India, Mexico, Poland, Romania, Russia, Saudi Arabia, Turkey, Ukraine and the United Kingdom have either expressed interest or started exploration in shale formations. They are still short of reaching commercial productions. The economic recovery of shale gas from the reserve depends on the production costs, the volume of production and production price of shale gas (USEIA, 2013a, p. 12-13). As per the International Energy Agency (2014), the top five countries in shale gas production in future will be the US, China, Canada, Argentina, and India (Figure 5).

Figure 5. Growth in unconventional gas production



Source: C Festa, *Golden Rules for a Golden Age of Gas*, 2014, P. 5.

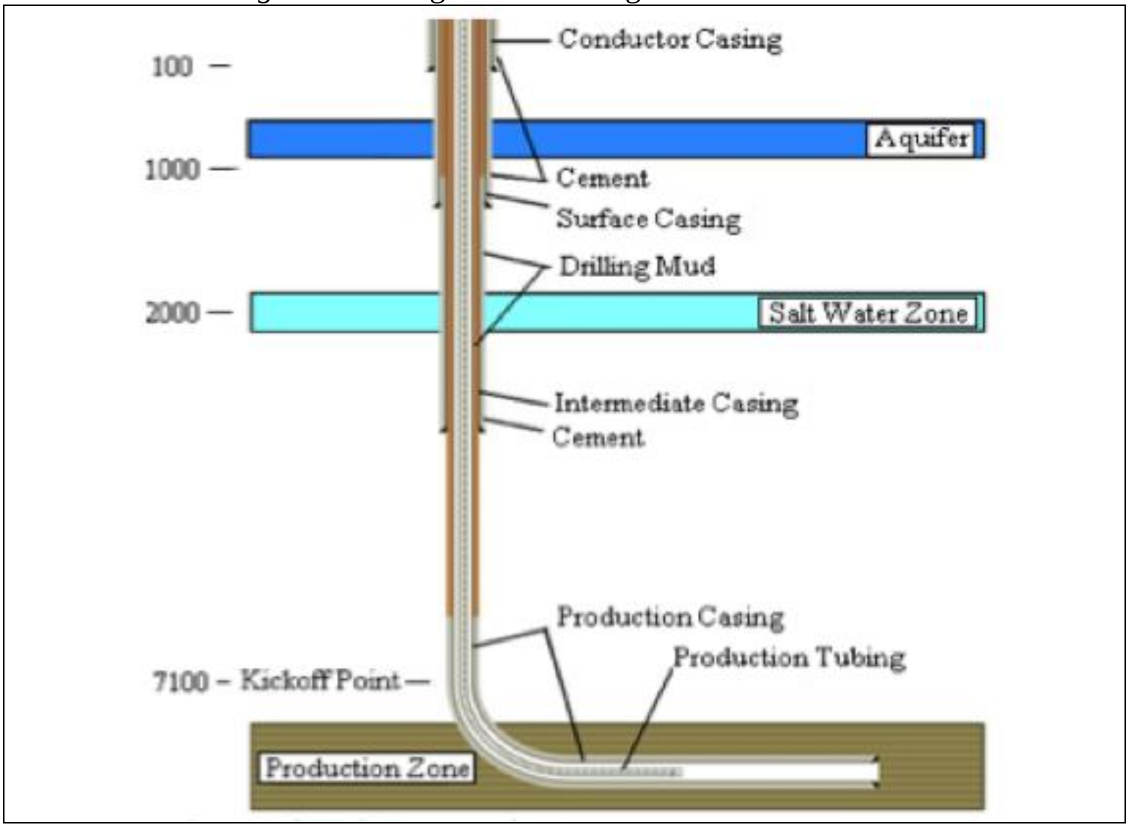
As per British Petroleum (2015, p. 11), world primary energy production is expected to grow at 1.4% p.a. from 2013 to 2035. With the improvement in technology and productivity, shale gas is expected to contribute significantly towards total energy production.

2.3 Developments in shale gas extraction technology

Shale gas was first extracted in 1821 in the US from shallow, low-pressure fractures. A limited quantity of shale gas was produced from shallow, fractured shale formations. Subsequently, horizontal drilling started in the 1930s. In 1947, first hydraulic fracturing was carried out in the US. Both technologies were used increase production from conventional wells. The shale gas in the US was only 1.6% of natural gas production in 2000 (Wang & Krupnick, 2013).

In the early 2000s, technological innovations in oil and gas industry pushed the shale gas production up and shale gas production became profitable (Wang & Krupnick, 2013, p. 3). The application of the innovations, research and development (hereinafter: R&D) increased the production of shale gas in the US up to 39%, Canada up to 15% of their respective total natural gas production in 2012. The innovations and R&D were carried out in directional and horizontal drilling, hydraulic fracturing and 3D micro-seismic imaging (USEIA, 2013c).

Figure 6. Casing and cementing of a horizontal well

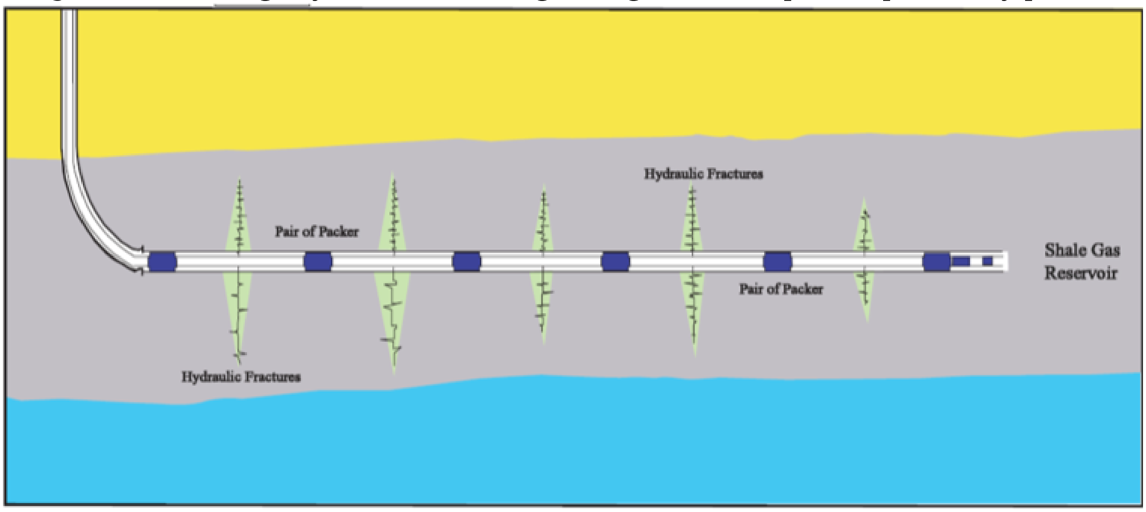


Source: U.S. Department of Energy, *Modern Shale Gas Development in the United States: A Primer*, 2009, p. 52, Exhibit 30.

Directional and horizontal drilling gives more exposure to the formation than the vertical drilling. The well is initially drilled vertically and then gradually drilling takes 90-degree turn in the horizontal direction in the shale gas reserve formation. Drilling continues in the horizontal direction depending upon the length of the shale formation. Multiple drillings can be carried out from single drill site pad location to improve the efficiency of operation and reduce environmental impact. Directional drilling can be performed at any angle depending upon the shale gas reserve formation. By making the wells horizontal, much more volume of the reservoir can be accessed with single horizontal drilling. The reduced number of horizontal wells plus drilling of many wells from same pad has reduced surface disturbances and environmental impact (Clark, Burnham, Harto, & Horner, 2012, p. 2).

During vertical and directional horizontal drilling, the drilled borehole is isolated from surrounding rocks and earth layers by metallic casings pipes (Figure 6). The gap between casing and earth and rocks is pumped with cement. Casing and cementing prevents contamination of gas or any other fluid with fresh water in the surrounding area. It also prevents the escape of gas from the well through the annulus (space between the casing and borehole) to the earth surface and aquifers. The section of the well in the shale formation is then perforated with the perforating gun using explosives, thus creating small holes in the casing (Figure 7). The perforated holes extend a short distance into the shale formation, which allow fracking fluids to be pumped into the shale rock (Clark et al., 2012, p. 2).

Figure 7. Multistage hydraulic fracturing through different ports separated by packers

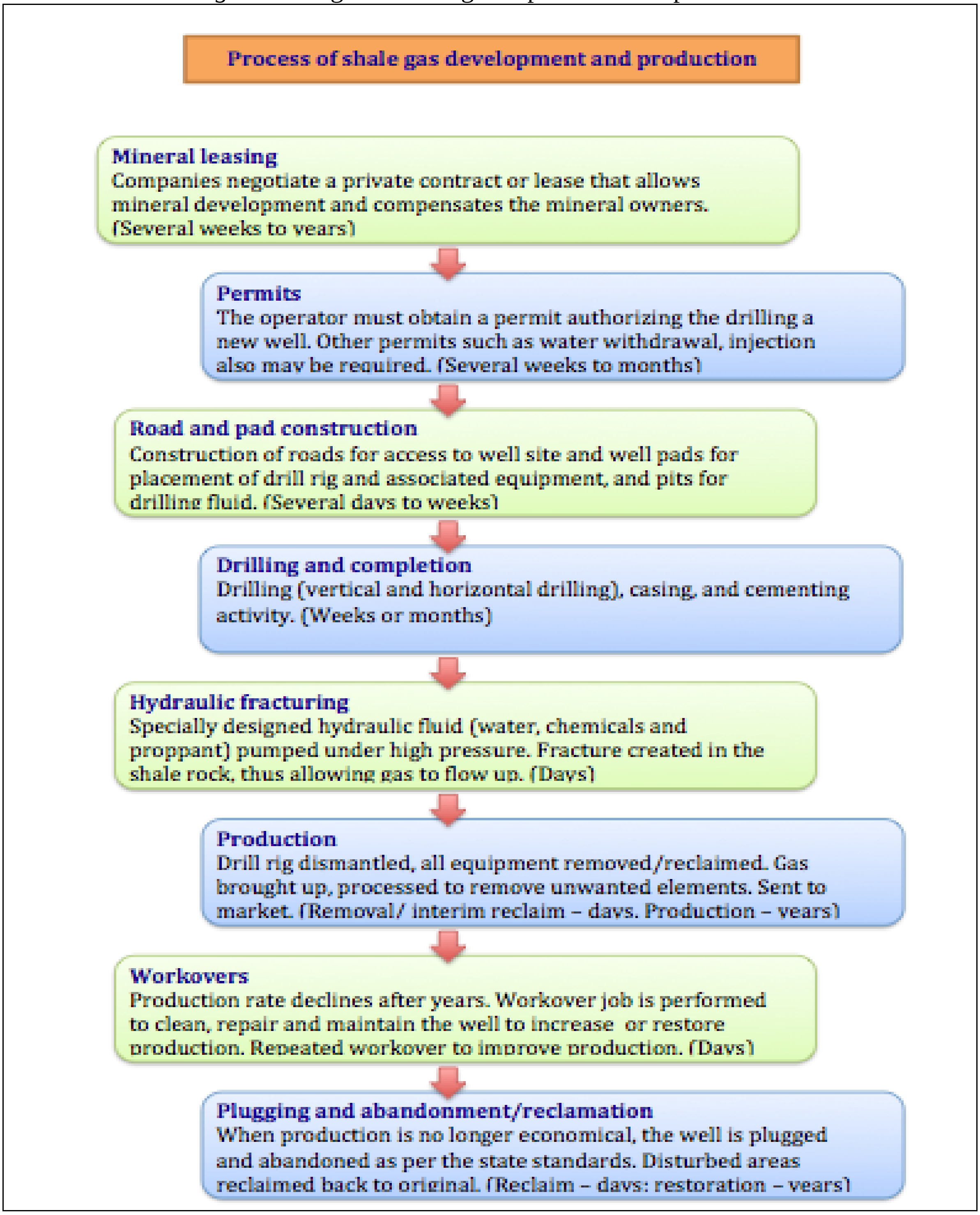


Source: A.M. Abdulaziz, *Microseismic Imaging of Hydraulically Induced-Fractures in Gas Reservoirs: A Case Study in Barnett Shale Gas Reservoir Texas USA*, 2013, P. 362, Figure 1.

The perforation allows little gas to flow into the well. Fine fracture networks are to be created in the shale rock formation so that maximum gas can flow into the well. In the process of hydraulic fracturing, a large volume of fluid is pumped at very high pressure through the perforations of a section of casing, to create a fine network of fractures. The fluid used for pumping consists of 98-99.5 % water, 0.5-2% fracture fluid and proppant. Fracture fluid is used to enhance the fluid properties like reduction of fluid friction, clean perforation for easy gas flow, corrosion and scale inhibitors and biocides to reduce biological growth. Proppant is made of solid material, usually sand, or hard ceramic materials to keep the fine fractures open. Hydraulic fracture of 300 m (approx.) of pipeline section is carried out at a time, and that pipe length is plugged. Then next 300 m is hydraulically fractured and similarly plugged and so on. It is started at the tip end and subsequently proceeded towards the vertical end of the pipe. When the full horizontal length is hydraulically fractured, all plugs are removed by drilling. The water used in fracturing is collected for either reuse or water is disposed of after treatment as per proper procedure (Clark et al., 2012).

After hydraulic fracturing job, the fracturing fluid ‘flow-back’ from the shale formation to the surface along with existing water in shale formation known as ‘produced water’. Produced water can have high concentrations of salt, naturally occurring radioactive materials (hereinafter: NORM), and contaminants like arsenic, benzene and mercury. If the concentrations of NORM, arsenic, benzene and mercury are above the regulatory limit, then the produced water must be disposed of as per proper procedure. Flow-back water has higher flow rate for a shorter period, whereas produced water has lower flow rate but continues over a longer period (Zoback, Kitasei, & Copithorne, 2010, p. 10).

Figure 8. Stages of shale gas exploration and production



Source: U.S. Department of Energy, *Modern Shale Gas Development in the United States: A Primer*, 2009, p. 44, Exhibit 28.

The fractures during hydraulic fracturing activity may extend beyond shale formations up to water aquifers. It will allow natural gases, contaminants of formation water and fracking fluids to travel into the drinking water supplies. This may happen when the depth of shale formation is shallow (Zoback et al., 2010, p. 7). Micro-seismic imaging technology is used for in situ monitoring of fracture growth during hydraulic fracture stimulations. It enables mapping active fracture networks and fracture growth during fracture operations for shale gas stimulations (Abdulaziz, 2013, p. 361).

After hydraulic fracturing is complete, gas flows out of the well to the surface. The gas thus produced, is processed to remove impurities, and compressed to send to the next destination. It is observed that shale gas wells experience quicker production declines than conventional natural gas production. The wellhead is removed when there is no economic rate of production of gas and the wellbore is plugged. The drill site is restored to its original condition and abandoned and finally handed over to the holder of the land's surface rights (Zoback et al., 2010, p. 5). The different stages of shale gas exploration and production is indicated briefly in Figure 8.

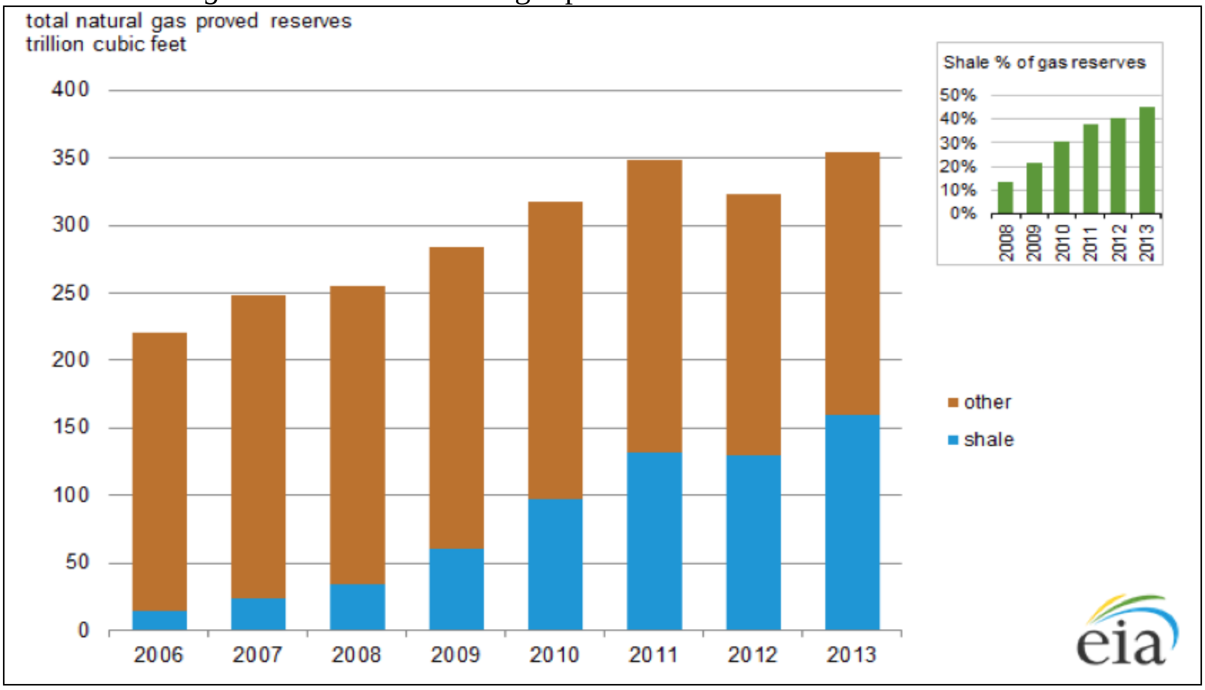
2.4 Shale gas in the United States of America

2.4.1 Exploration and Production

The exploration, development and production of domestic shale gas is one of the most rapidly expanding gas business in the US today. Shale gas has become a game changer for the US. The US has been producing shale gas for several decades. The growth of shale gas was observed after the mid-2000s, due to the development of technologies and innovation, the decline in domestic conventional natural gas production and an increase in natural gas price. Shale gas grew at more than 45% per year between 2005 and 2010 (Berkowitz, 2012).

In 2014, shale gas accounted for more than 40% of total US gas production. The US shale gas production in 2012 was about 10.4 Tcf; in 2040, it is expected to increase to 19.8 Tcf (USEIA, 2014c, p. 6-7; Mason, Muehlenbachs, & Olmstead, 2015). Shale gas is expected to remain the principal source of growth in overall gas supply in the US in the coming decades (Birol, Besson, & Gould, 2012). The US is expected to switch over from being a net importer of energy to a net exporter by the year 2017. Net export of the US is believed to be from 3 Tcf to 13.1 Tcf in 2040 (Tubb, 2015, p. ES-4). Being the leader of shale gas North America is expected to produce 75% of global shale gas in 2035 (British Petroleum, 2015).

Figure 9. US total natural gas proved reserves between 2006-2013



Source: USEIA, *US Crude Oil, Natural Gas, and Natural Gas Proved Reserves*, 2014, p. 7, Figure 12.

As per the USEIA (2013a, p. 10) estimates, the US had 665 trillion cubic feet of technically recoverable unproved shale gas resources in 2013. Figure 9 shows the growth of shale gas reserves between 2006 and 2013. The proven reserve of shale gas in the US is 159.1 Tcf. in 2013. The US shale gas reserve was more than 40 percent of total natural gas reserve in 2013.

Table 4 shows properties of shale gas basins in the US. Texas has the largest reserve of proven shale gas, followed by Pennsylvania. Texas has the shale plays like Barnett, Eagle Ford, Haynesville/Bossier and Woodford. Pennsylvania with Marcellus shale, have registered higher growth in shale gas reserve than Texas (USEIA, 2014c).

Table 4. Shale gas basin properties in the US

Gas shale basin	Barnett	Fayette ville	Haynes ville	Marcellus	Wood ford	Antrim	New Albany
Estimated basin area (sq. miles)	5000	9000	9000	95,000	11,000	12,000	43,500
Depth (ft)	6500 - 8500	1000 - 7000	10500 - 13500	4000 - 8500	6000 - 11,000	600 - 2200	500 - 2000
Net thickness (ft)	100-600	20 - 200	200-300	50 - 200	120-220	70-120	50-100
Depth to base of tractable water (ft)	1200	500	400	850	400	300	400
Rock column thickness (ft)	5300 - 7300	500 - 6500	10,100-13,100	2125 - 7650	5600 - 10600	300 - 1900	100 - 1600
Total organic Carbon (%)	4.5	4 – 9.8	0.5– 4.0	3 – 12	1 – 14	1 – 20	1 – 25

Source: U.S. Department of Energy, *Modern Shale Gas Development in the United States: A Primer*, 2009, p. 17, Exhibit 11.

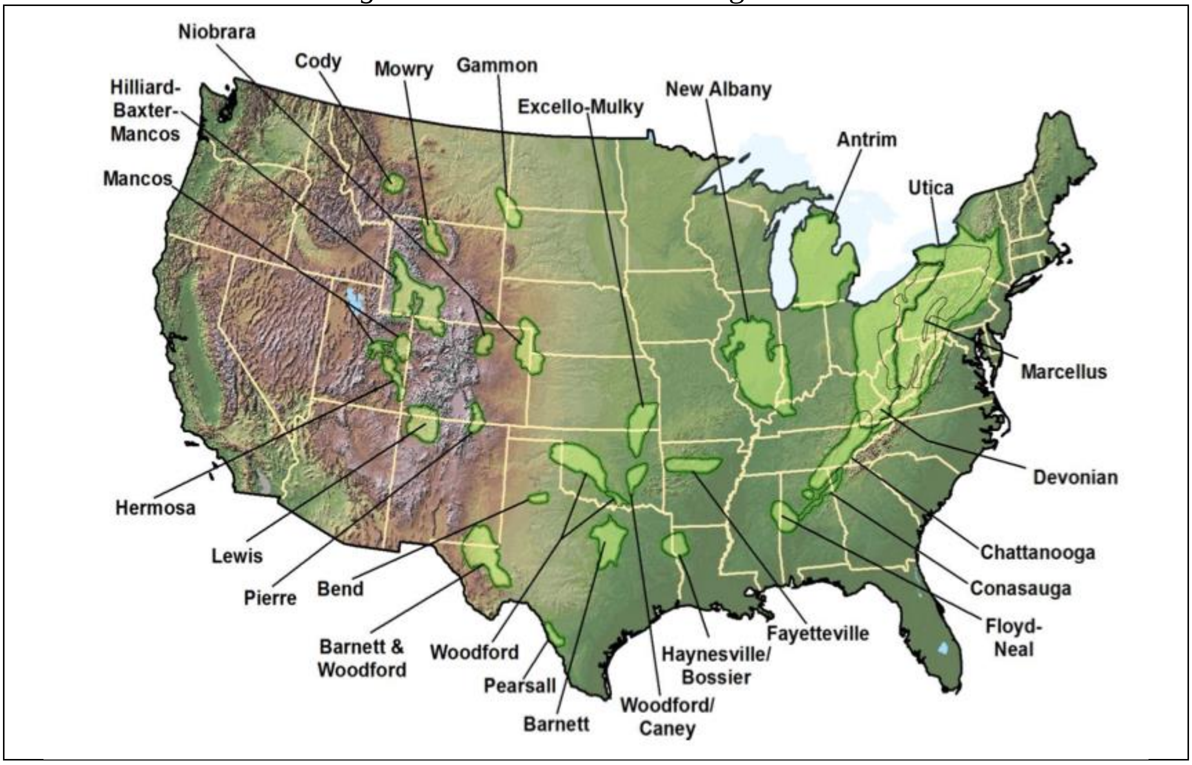
In 2013, six shale plays namely, Marcellus shale, Barnett shale, Haynesville / Bossier shale, Eagle Ford shale, Fayetteville shale, and Woodford shale accounted for 94% of the US shale gas proved reserve (USEIA, 2014c, p. 7).

Table 5. Production and reserve of shale gas basins of the US in 2012 and 2013

			2012 (in Tcf)		2013 (in Tcf)		Change 2013-2012 (in Tcf)	
Basin	Shale gas basins	State(s)	Production	Reserves	Production	Reserves	Production	Reserves
Appalachian	Marcellus	PA,WV, OH,NY	2.4	42.8	3.7	64.9	1.3	22.1
Arkoma	Faetteville	AR	1.0	9.7	1.0	12.2	0.0	2.5
Arkoma, Anadarko	Woodford	TX,OK	0.6	12.6	0.7	12.5	0.1	-0.1
Fort Worth	Barnett	TX	2.1	23.7	2.0	26.0	-0.1	2.3
Texas-Louisiana Salt	Haynesville / Bossier	TX,LA	2.7	17.7	1.9	16.1	-0.8	-1.6
Western Gulf	Eagle Ford	TX	1.0	16.2	1.4	17.4	0.4	1.2
Subtotal			9.8	129.4	11.4	159.1	1.0	29.7
Other basins			0.6	6.7	0.7	10.0	0.1	3.3
All US			10.4	129.4	11.4	159.1	1.0	29.7

Source: USEIA, *US Crude Oil, Natural Gas, and Natural Gas Proved Reserves*, 2014, p. 7, Table 4.

Figure 10. United States shale gas basins



Source: U.S. Department of Energy, *Modern Shale Gas Development in the United States: A Primer*, 2009, p. 8, Exhibit 7.

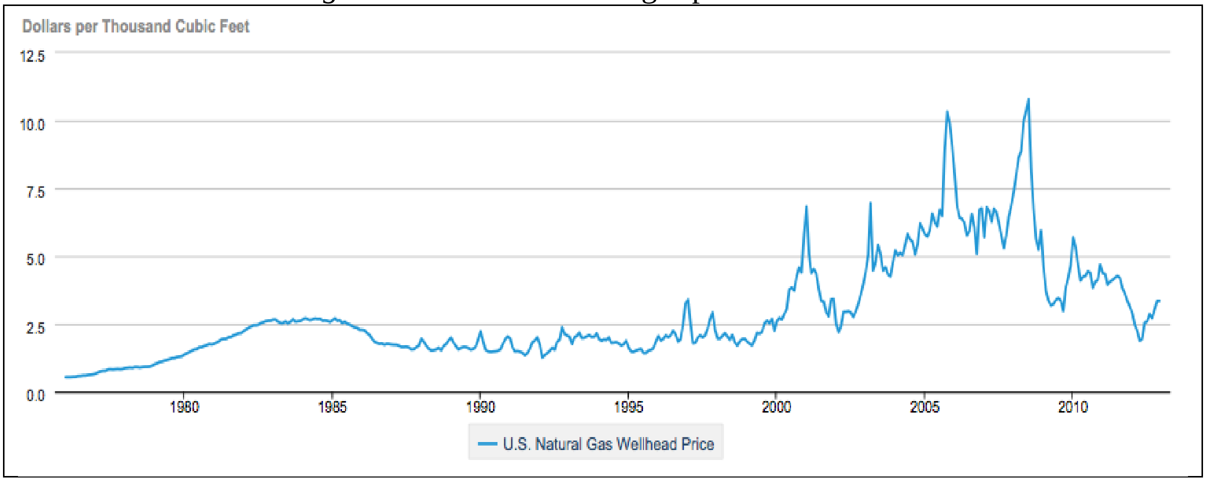
Table 5 shows production and reserve of shale gas basins in 2012 and 2013. Marcellus shale is the largest shale play, followed by Barnett shale. The US shale gas boom started with Barnett shale. Each of the shale gas basins in the US is different and has a unique set of exploration criteria and operational challenges. Therefore, they have unique development challenges for shale gas. For example, Antrim and New Albany shales are at shallow depth, and they produce a significant quantity of formation water. Fayetteville shale is present in the rural area. Development of Barnett shale is located in the urban and suburban area of Forth Worth, Texas (USEIA, 2014c, p. 7; US Department of Energy, 2009, p. 16-23). Figure 10 shows the locations of shale gas basins in the US.

Due to technological development and continuing exploration activities, the proven reserves of shale gas went up to 159.1 Tcf in 2013 from 129.4 Tcf in 2012. There was a marginal increase in production in 2013, at 11.4 Tcf, from 10.4 Tcf in 2012. The rise in reserve and production was mainly due to significant activities of Marcellus shale play in the states of Pennsylvania, West Virginia, Ohio and New York (USEIA, 2014c, p. 6-7).

2.4.2 Shale gas economics

In the last decade, there was a substantial increase in economically recoverable reserves and production of shale gas in the US. The production and utilization of shale gas have potential benefits and associated expenditures. Figure 11 indicates the US natural gas price at the place of production (wellhead) between 1980 and 2012. The US had a high natural gas price between 2003 and 2008, because of decline in production of conventional natural gas and high economical growth. Due to increase in gas price, there was a high growth of shale gas production and the producers realised a significant profit. As the supply of natural gas increased due to shale gas production, gas price went down to around \$3/MMBtu (Million British thermal unit) (Wang & Krupnick, 2013; Purwar, n.d., p. 17).

Figure 11. The US natural gas price at wellhead



Source: USEIA, *US Natural Gas Wellhead Price*, 2015.

Shale gas has put the US in the path of energy independence. The US enjoys second lowest energy cost after Middle Eastern countries. At present, more industries in the US are using natural gas. Every sector of manufacturing, consumers and workers were benefitted due to shale gas boom. Considering present reserve to production ratio, natural gas in the US is estimated to sustain gas for more than 100 years. The economic benefits of shale gas derived in the US are discussed below (Purwar, n.d., p. 5-10):

- Natural gas is an important feedstock for many industries. The abundant natural gas revived US manufacturing industries and they grew stronger than pre-shale gas boom. Increased supply of natural gas at a lower price supports a higher level of industrial output. There is a reduction in manufacturing cost. The chemical industry, metal industry, petrochemical industry, etc. were benefitted due to availability and low price of gas. Shale gas improved the US competitiveness and resulted in higher GDP growth (Tubb, 2015).

- Combined power and heat generation in the industrial and domestic sector can use more gas. Gas began to replace coal in power plants. The capacity addition of coal-based projects decreased and mining of coals reduced. The increase in gas-based electricity generation has made power generation cleaner, cheaper and more efficient.

- The shale gas industry and its associated activities generated more than 600,000 jobs in 2010, and it is expected to grow to 870,000 by 2015. The number of jobs is likely to be more than 1.6 million by 2035 (Pipeline & Gas Journal, 2012. p. 22-22,24).

- In near future, the US can export LNG to European countries and Asian countries like Japan and South Korea. These countries import natural gas at several times higher price than the US price. The US can export natural gas to these countries at a better price than its domestic price. However, the manufacturers and chemical industries are not willing to allow exporting natural gas, as it will increase the domestic gas price.

- The availability of shale gas has reduced the demand for oil and gas from the Organisation of Petroleum Exporting countries (hereinafter: OPEC). As a result, the global oil price fluctuating around $50 per barrel in 2015 (Trading Economics, 2015). The price will be affected more, as China, Argentina, India, Australia, Poland and Ukraine start producing shale gas in large scale.

- Like many other countries, the US was also a victim for a long time on OPEC's cartelization. As the largest consumer of oil, this affected the economy of the US. The US even created a strategic reserve of oil (currently have 100 billion barrels of oil), to avoid the impact of the artificial hike in price by OPEC. With the increase in production of shale gas and associated oil, the US is no longer dependent on imports.

- The shale contribution to the US GDP was more than $76.9 billion in 2010. In 2015 GDP contribution is expected to be $118 billion and it will double to $231.1 billion in 2035 (Pipeline & Gas Journal, 2012, p. 22-22, 24).

In addition to innovation and technology, the economic success of shale gas exploration and production is dependent on characteristics of the shale gas formations, the price of natural gas, and other externalities. These are discussed in the subsequent paragraphs (Wang & Krupnick, 2013, p. 29-34):

- The price of natural gas and characteristic of shale gas basin is an important factor in determining the viability of a shale gas project. For example, in the US, Barnett core area can achieve a 10 percent rate of return if the natural gas price is only $4/Mcf (Million cubic feet), but, Eagle Ford play can achieve 10 percent rate of return if the natural gas price is over $7/Mcf.

- Shale gas development in the US mainly taken place in areas of private lands and mineral ownership. The cost of production of shale gas decreased when the price of leasing large area of land was low. The early operators could obtain more financial profits because of the land price rather than the innovations. With technology innovations, the profit margin can be still more.

- Capital market played a significant role in the development of shale gas in the US. During shale gas boom, firms invested large amounts in natural gas companies for shale gas exploration and production.

- There are various other factors favourable for the development of shale gas in the US. They are availability of road infrastructure, pipelines for natural gas transportation, availability of underground injection wells for disposal of waste water, favourable shale basin topography, shale plays in low population density, sound history of conventional oil and gas development, and oil and gas service companies.

- It was observed by economists that, one percent increase in the price of natural gas estimated to increase the new number of wells drilled by 2.70 percent. This estimate and future price data from NY Mercantile Exchange are used to forecast the number of wells drilled in Pennsylvania in the next decade, and suggest that the number of wells drilled will increase from 1000 in 2010 to 2800 in 2020. The increase in job creation and more amount of taxes are expected (Purwar, n.d., p. 17).

- The increase in production lowers the price of shale gas in the US. With the lowering of the gas price the profitability of shale gas projects goes down.

2.4.3 Environmental challenges

Shale gas production is complex. In addition to the technological requirements, production of shale gas requires large quantity of water resources, significant possibility to polluting land, water and air, if not taken care. It may trigger seismic activities. Following environmental challenges are discussed (Zoback et al., 2010, p. 1-15):

The depth of New Albany and Antrim formations are shallow. So hydraulic fracturing may lead to ground water contamination. In those cases, a carefully designed hydraulic fracture can control the fissures and stop the groundwater contamination. Seismic monitoring ensures that the hydraulic fracturing induce micro-seismic activity within the shale rock formations. In 2009, only 3% of approximately 75000 hydraulic fracturing stages were seismically monitored. To stop groundwater contamination frequent micro-seismic monitoring activities need to be carried out. The companies follow the standards and recommended practices developed by American Petroleum Institute (hereinafter: API), or other recognized organisations to eliminate the defects of cementing process. Many states in the US have different tests to be carried out as per the regulations for checking cementing process.

During the use and processing of chemicals at drilling sites, solid and liquid wastes are produced. In a survey in 2009, New York State Development of Environmental Conservation identified the possibility of using around 200 chemical additives in hydraulic fracturing. These chemicals and various combinations of these chemicals are hazardous. The effort is made for public disclosure of the chemicals of fracture fluid so that the effect of these chemicals can be studied, and corrective and preventive actions are taken. Many companies in the US are carrying out R&D for development of environmentally friendly and hazard free chemicals to be used for fracture fluids.

In Marcellus Shale, approximately 25 percent of water injected during hydraulic fracturing may flow back to the surface. The flow-back water and produced water requires proper disposal. Different methods are used for dealing the flow-back water in various states. Primary disposal method utilized is the injection into disposal wells to the underground saline aquifers. The injection is regulated as per Safe Drinking Water Act, and the number of adequate disposal wells is limited. Though there are thousands of injection wells, suitable well for disposal is limited by political and geological constraints. In one of the options in the US, the flow-back water is diverted to municipal wastewater treatment facilities, from there the treated water is discharged into nearby water bodies such as rivers and streams. However, there is a constraint to handle increasing additional volume of flow-back water and produced water by these treatment plants, and they are not designed to handle the chemicals from flow-back water and produced water.

Research and development are required for chemical treatment technologies, which will enable companies to re-use the fracturing fluids. Recycling reduces the water requirement for hydraulic fracturing of next well and lessens the load on water treatment plant (Zoback et al., 2010). New water treatment technologies are being developed and used to treat shale gas produced water. The treated water can be reused as fracturing makeup water, irrigation water and in some cases even drinking water (US Department of Energy, 2009, p. ES4).

The flow-back and produced water is usually stored temporarily in the drill sites before it is sent to water treatment plants. They are mostly stored in lined evaporation pits. However, heavy rain can cause the pit to overflow and can contaminate the surrounding areas. Some companies use steel tanks to store produced and flow-back water to avoid this. Leakages during transportation and storage of chemicals and accidents also cause contamination. For example, spillage were observed in May and October 2009 by Department of Environment Protection in Pennsylvania from a leakage in a pipeline carrying wastewater to disposal site polluting and damaging the area.

Mild earthquakes are observed near the localities having shale gas drilling and hydraulic fracturing activities. Earthquakes of intensity 3.3 on Richter scale or less happened at earthquake free zone Cleburne, Texas in 2008 and 2009. The seismologists did not find any conclusive linkage between earthquakes and hydraulic fracturing, but they related the events to the disposal of fracturing fluid in over 200 saltwater disposal wells in that area. The magnitudes of micro-seismic events due to hydraulic fracturing are too small to be detected on earth surface. Seismic monitoring of hydraulic fracture jobs is important to monitor the effects of disposal of hydraulic fracturing fluids underground.

The drilling operation for shale gas involves a lot of over ground operations. The wellhead pads, the road leading to new wellhead areas, installation for collection of natural gas from different wellheads and the temporary collection of flow-back water require huge land (in hectares) to be developed. Drilling of multiple wells from the same well pad area maximizes the efficiency of land use and operations. Thus, impact on the environment and local communities is minimised. Permission procedures require specifying needs of each stakeholder and for ensuring minimal damage and maximum restoration of the used land.

The exploration and production of shale gas include a variety of potential air emission sources. The sources may be drilling rig operation engines and equipment, diesel powered fracturing pumps, well completion process, venting or flaring of natural gas, transportation trucks and vehicular traffic and unpaved/damaged roads. The sources like various pumps, compressors, evaporation pits, chemicals, fracturing fluids, etc. emit pollutants to the air. Natural gas contains mainly methane. It is environmentally more active than other gases. Methane is released into the atmosphere during drilling and production process.

The drilling operation of one well takes several weeks, with 24 hours service. There is noise pollution in the vicinity, which can be taken care by the construction of sound barriers. Further, more transportation activities put additional load on public resources.

The abundance of natural gas at a cheaper rate, have and adverse impact on the renewable energy industry. The renewable energy projects cannot compete with the low cost, high energy natural gas (Purwar, n.d., p. 7).

Drilling operation of one well usually requires one million gallons of water whereas hydraulic fracturing process of one well requires 2 to 8 million gallons of water depending upon the shale formation. For developing a region may require drilling of thousands of wells, which demand large volume of water. Therefore, it is important to reduce the use of water for hydraulic fracturing; recycling of water; or using excess water during peak seasons.

2.4.4 Shale gas policy

In 1970s energy crisis, the US faced shortage of energy. Domestic gas production declined. Natural Gas Policy Act (hereinafter: NGPA) was formed in 1978 to promote the development of new sources of natural gas. NGPA introduced incentive pricing for developing new natural gas in place of existing wellhead price controls. The government established R&D programmes on unconventional natural gas. Several major studies by Federal Power Commission, Energy Research and Development Administration (ERDA), and the US Department of Energy (DOE) suggested that, the resource base of unconventional natural gas could be very large and that efforts to develop unconventional resources should be encouraged and subsidized. These policies were the basis of shale gas growth in the US. The budget for fossil energy research programmes were increased ten folds between 1974 to 1979 (Wang & Krupnick, 2013, p. 7-8).

The major natural gas policies to promote development of unconventional natural gas are discussed below (Wang & Krupnick, 2013, p. 8-15):

Incentive pricing: NGPA introduced incentive pricing for natural gas from Devonian(-age) shale, coal seams, and any other gas which incurred high extraction costs. The wellhead prices for these formations were deregulated in 1979, which created a huge advantage for developing gas resources. In the early 1980s, the deregulated high-cost natural gas was selling at more than twice the price of regulated natural gas. The Federal Energy Regulatory Commission (FERC) designated tight gas also a high-cost gas, but it was allowed for highest regulated price ceiling under NGPA. Mitchell Energy, the pioneer operator for shale gas, filed the Barnett shale (Mississippian-age) as a tight gas formation probably because NGPA only considered Devonian shale for incentive pricing.

Tax credits: Due to the oil crisis in 1979, the Crude Oil Windfall Profit Tax Act in 1980 was introduced. Among other regulations, this act provides tax credits for supplying unconventional fuels. This tax credit applied to unconventional gas from Devonian shale, coal seams, and tight gas, biomass, geo-pressured brines, oil from shale or tar sands, synthetic fuels from coal, and some other fuels. Unconventional gas wells spudded between January 1, 1980, and December 31, 1992, were eligible for the tax credits, and production from eligible wells continued to receive credit until December 31, 2002. The initial tax credit was $0.52/Mcf, and subsequently it was increased to $0.94/Mcf in 1992. Kuuskraa and Guthrie (2002) indicated that, increased recovery from wells, lower development costs, while providing incentives through tax credits stimulated the development of unconventional gas.

R&D programs: Energy Research Development Administration (ERDA) initiated a research programme on unconventional natural gas in 1976. The US Department of Energy continued it later. US Department of Energy's (DOE) technology centers, national laboratories, universities, and private firms implemented the R&D projects of the program. This programme had three components: The Eastern Gas Shales Programme, the Western Gas Sands Programme, and the Methane Recovery from Coalbeds Programme. Most important technological innovations in the 1980s and 1990s concerning shale gas are (Wang & Krupnick, 2013, p. 9-15):

- Horizontal drilling. Commercial horizontal drilling were started between 1980 to 1983, and in late 1980s horizontal drillings achieved commercial viability for oil formations and subsequently applied to gas shales.
- Massive Hydraulic Fracturing (MHF). Large scale massive hydraulic fracturing was introduced to shale gas formations.
- 3D seismic imaging measures acoustic reflections from an energy source. 3-D seismic imaging provides a better picture of the structure and properties of subsurface rocks. It significantly improves the ability to locate new hydrocarbon deposits, determine the characteristics of the reservoir for optimal development, and determine the best approach for producing a reservoir.
- Micro-seismic fracturing mapping. It has a key role in optimizing the way the shale gas wells are hydraulically stimulated. It is a passive method that it listens for seismic energy occurring underground. By using sensors in a monitoring well to record the minor seismic events generated during fracturing of a nearby well, micro-seismic fracturing mapping can reveal height, length, orientation and other attributes of induced fractures.

Gas Research Institute also managed and funded the research projects on natural gas. Gas Research Institute established by gas industry began in 1976, for planning, managing and financing R&D programs in all segments of the natural gas industry, including production, transmission, storage and end-use.

Natural gas pipeline infrastructure: The US already had an extensive gas pipeline network before shale gas boom. The policy of open access to interstate natural gas pipeline and storage facilities was introduced in the 1980s and early 1990s. This open-access policy helped to create a more competitive wholesale natural gas market (Wang & Krupnick, 2013, p. 31).

Environment protection: In the US, there is an extensive framework of federal, state and local requirements for managing every aspect of the development of natural gas. Federal environmental regulations are evolved for applying to shale gas development. State agencies implement and enforce federal laws, rules and regulations of oil and gas development with federal supervision. The federal laws are controlled by the US Environmental Protection Agency (hereinafter: US EPA), development of land is managed by Bureau of Land Management and the US Forest Service. The following federal environmental regulations also apply to shale gas development (US Department of Energy, 2009, p. 25-42).

- Clean Water Act. It is a regulation of contaminated storm water run-off and surface discharges of water from drilling sites during drilling and production (Zoback et al., 2010).
- Emergency Planning and Community Right-to-know Act (EPCRA). Posting of material safety data sheets indicating the properties and health effects of chemicals stored, weighing more than 10000 pounds (Zoback et al., 2010, p. 10).
- Safe Drinking Water Act authorizes the US EPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. It is also regulation of underground injection of wastewater from gas wells.
- National Environmental Policy Act (NEPA) requires environmental impact analysis.
- Regulations of impacts on air quality (such as Clean air act, Air quality regulations, Air permits) regulate the emission of pollutants.
- Regulation of impacts to land (such as, Resource Conservation and Recovery Act, Endangered Species Act, State endangered species protections) regulate shale gas operations, include solid waste disposal and surface disturbances that may impact land and the habitats.

States have their laws, which add additional levels of environment protection and requirements appropriate to respective states. States have the power to permit, regulate, and enforce all activities – starting with drilling, hydraulic fracturing, production operations, management and disposal of wastes, and abandonment and plugging of the well. State regulatory bodies enforce state environmental laws as well as rules and regulations of oil and gas production. However, there are significant variations in the application of the rules and regulations from state to state (US Department of Energy, 2009, p. ES-3). The companies need permission before drilling, wellhead erection, hydraulic fracturing, waste handling, well plugging, construction of tanks and pits, chemical handling procedures and wastewater spills (Zoback et al., 2010, p. 13).

These agencies may be under various departments of divisions within state's organisations. Each state tries to create a structure, which serves best to its citizens. However, each state producing oil and gas has one agency with the primary responsibility for permitting wells and overseeing general operations. This agency may work with other agencies within the state, but they can serve as a good source of information about various agencies that may have jurisdiction over oil and gas activities (US Department of Energy, 2009, p. 25-27).

In addition to federal and state requirements, other levels of government may impose additional requirements. Additional operational requirements may be set by local entities such as cities, counties, tribes and regional water authorities, which may affect location, operation of wells or permits and approvals. These comprehensive set of federal and state laws and programs regulate all aspects of shale gas exploration and production activities (US Department of Energy, 2009, p. 27-29).

The state and federal requirements along with technologies and practices developed by industry try to reduce environmental impacts from shale gas operations. The state and federal rules and requirements guard and serve to reduce environmental impact from shale gas operations. In addition to this, the industry is trying to innovate and improve technologies and practice for reducing environmental impacts from shale gas operations. Drilling and hydraulic fracturing multiple wells from a single well pad reduce environmental impact. Engineering controls and appropriate personal protective equipment are used to reduce exposure to crystalline silica to a worker. Proper selection of site, design and construction of gas production and fluid disposal wells can reduce consumption of water. Groundwater quality monitoring and disclosure of fracturing fluid chemicals control the quality of operations (Clark et al., 2012).

2.5 Shale gas in the European Union

The EU is dependent on import of energy. There is a decline in domestic coal, oil and gas production, so demand for imported energy is on the rise. The EU imports 50% of its total energy. In 2012, EU imported 66% of its total natural gas consumption. The main suppliers of natural gas are Russia (25%), Norway (23%), Algeria (10%), and Qatar (9%). Some countries like Finland, Slovakia, Bulgaria and Baltic states are dependent on a single supplier and countries like the Czech Republic and Austria depend on concentrated imported gas supplies (European Commission, 2014c, p. 5-8; Bădileanu et al., 2015, p. 98). The EU is expected to import 80% of their natural gas consumption in the year 2030 (Belkin, Nichol, & Woehrel, 2013). The dependency makes them vulnerable to supply disruptions, whether caused by political or commercial disputes, or infrastructure failure. The conflict between Russia and Ukraine on gas in 2009 left many EU countries with severe shortages (European Commission, 2014b). Ongoing Russia-Ukraine crisis and Russian assertiveness on Eastern Europe countries have stimulated the European Council to seek greater diversification of energy supplies (Micco, 2014, p. 4-5).

2.5.1 Exploration and Production

The technically recoverable resources of shale gas of the EU countries are estimated as 470 Tcf. Table 6 shows technically recoverable resources of shale gas of top ten EU countries. Poland and France have a significant quantity of shale gas reserve. They are followed by Romania, Denmark, the Netherlands, and the United Kingdom.

The indigenous oil and gas production in the EU is declining. The EU is interested in producing shale gas to make up gas supply and to diversify gas supply sources. However, the initiative for the development of shale gas varies from country to country depending on energy mix of domestic fuels and imports, perceptions of the risks to energy security and the environment. There are some developments in exploration activities of shale gas, but production is yet to start in the EU countries. The EU has some favourable conditions for shale gas production like high natural gas price and good pipeline and storage network (Birol et al., 2012, p. 120-130).

Table 6. Technically recoverable resources of shale gas in the EU

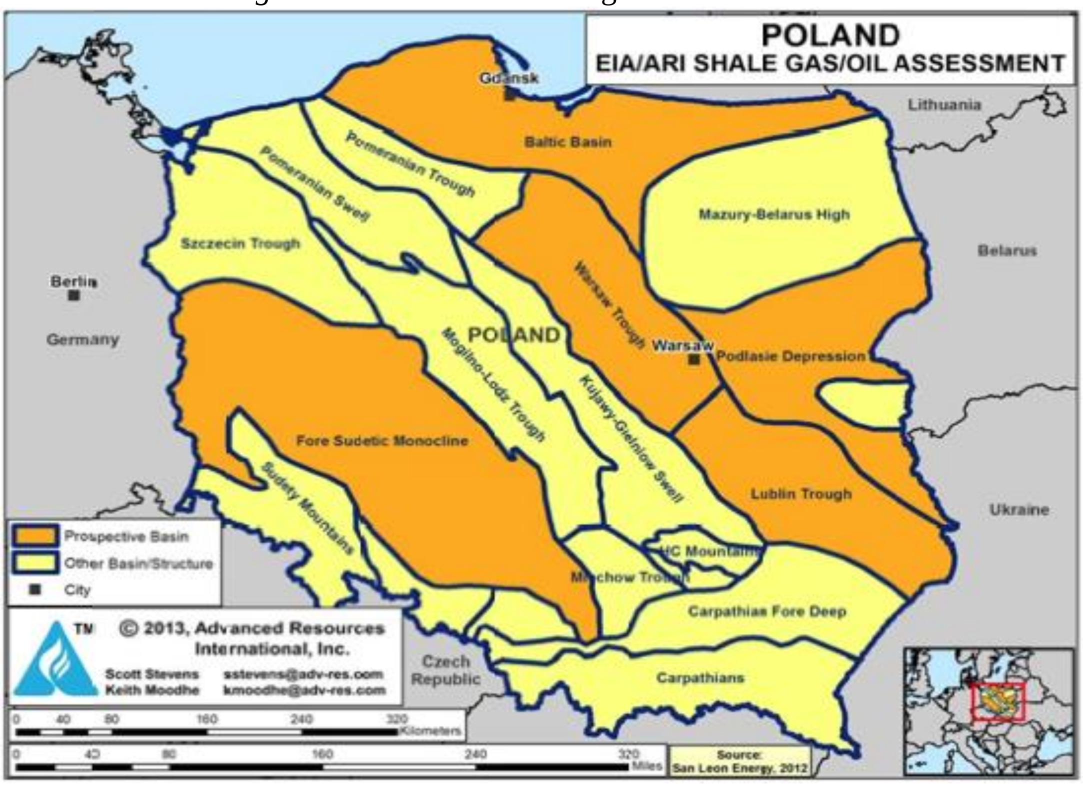
	Regions / country	TRR (in Tcf)	TRR (in %)
	Europe	470	100
1	Poland	148	31.49
2	France	137	29.15
3	Romania	51	10.85
4	Denmark	32	6.81
5	Netherlands	26	5.53
6	United Kingdom	26	5.53
7	Bulgaria	17	3.62
8	Germany	17	3.62
9	Sweden	10	2.13
10	Spain	8	1.70

Source: USEIA, *Technically Recoverable Shale Oil and Shale Gas Resources*, 2013, p. 6, Table 3.

2.5.1.1 Poland

Poland is the most advanced in terms of shale gas activities and attaining commercial production in the EU. Poland has oil and gas background, infrastructure, and low population density in major areas of its shale basins. The public acceptance for shale gas is higher, compared to other European countries (Birol et al., 2012, p. 120-130; Kuuskraa, Stevens, & Moodhe, 2013). With success in shale gas production, Poland will have the advantages of energy security, reduction in import of energy, reduction in usage of coal and improved emission quality. (Starmach, 2013) The demand for natural gas is expected to grow in Poland, particularly for power generation where of 90% of coal is used (USEIA, 2013a).

Figure 12. Location of shale gas basins in Poland



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. VIII-1, Figure VIII-1.

Figure 12 shows the location of the shale gas basins while Table 7 shows four important shale gas basins and their properties. The Baltic Basin is the most prospective region with a relatively simple structural setting. Podlasie and Lublin basins have potential but have complex shale structure. Fore-Sudetic Monocline is less recognized and has non-marine coaly shale potential (Kuuskraa et al., 2013). Poland has 148 Tcf of technically recoverable resources. However, Polish Geological Institute said that it needs more studies to confirm the geological characteristics of the shale gas basins before exploiting its potentially vast reserves (Robertson, 2011).

Table 7. Properties of shale gas basin in Poland

Gas shale basin	Baltic	Lublin	Podlasle	Fore Sudetic
Estimated basin area (sq. miles)	16,200	4,980	6,600	19,700
Depth (ft)	6,500-16,000	7,000-16,000	6,000-11,500	8,000–16,000
Net thickness (ft)	451	228	297	182
Total organic Carbon (%)	3.9	3	3	3
TRR (Tcf)	105	9	9	21

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. VIII-2, Table VIII-1.

Poland's shale gas industry is in early exploratory and pre-commercial phase. The Polish government has been supportive for shale gas. The government issued licenses for shale gas activities to many companies for five years duration. Some of these companies like ExxonMobil, Chevron, Eni, Talisman and Marathon Oil Corporation were active in the US until the beginning of 2015. Poland has been obtaining technical support from the US. The companies San Leon, BNK Petroleum and 3Legs Resources have been concentrating on development of shale gas in Poland. Sixty-six wells have been drilled up to January 2015, with 12 involving horizontal hydraulic fracking. But none of the wells is producing shale gas (Birol et al., 2012, p. 120-130; Neslen, 2015a; Reed, 2015). However, with the regulatory support, technological expertise and improved geological knowledge, Poland is expected to produce shale gas within next ten years.

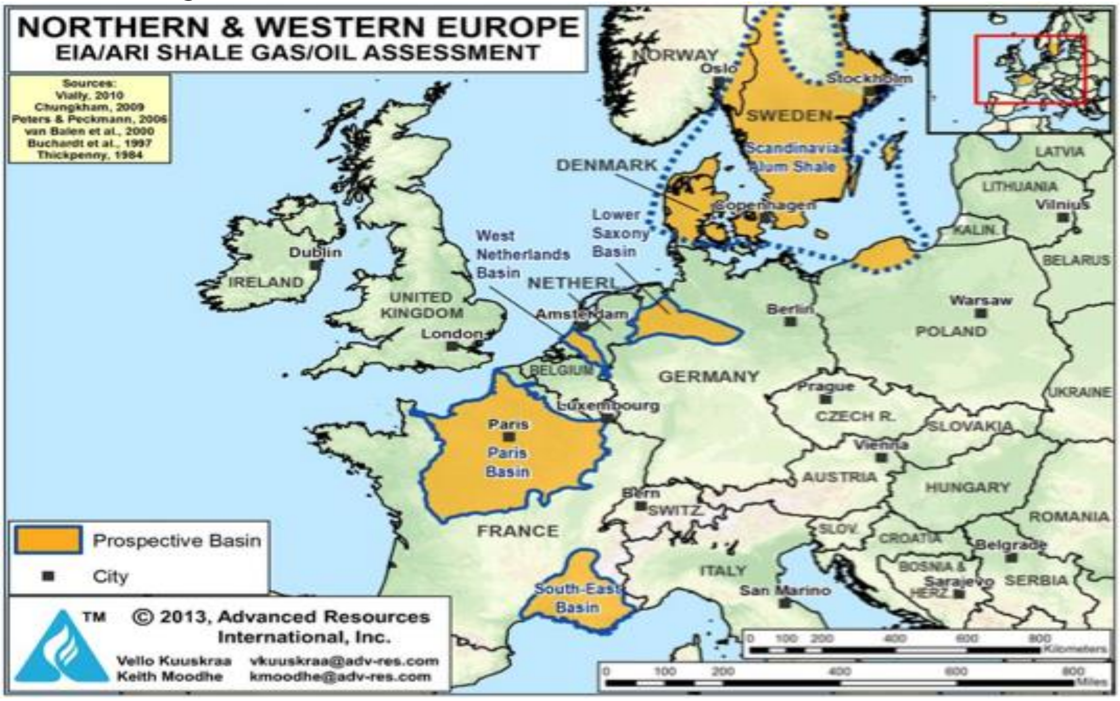
The Polish government made modifications and adjustments in the legislative system, licensing system and fiscal frameworks to incorporate many new market entrants and participants in unconventional gas exploration and production. In the initial years, licenses were granted based on first come first serve basis. After modifications, licenses for exploration were granted through tenders. The new law clearly defined the division between state and landowners right. In Poland (also in the EU), shale gas is the exclusive property of the state (Birol et al., 2012, p. 120-130). The government also planned favourable shale investment terms, by introducing higher taxes and mandating government back-in rights (Kuuskraa et al., 2013).

As on January 2015, Chevron Corporation, ExxonMobil, Total SA and Marathon Oil Corporation stopped exploring shale gas in Poland. They witnessed unfavourable geology, poor well test result, and growing public protest on environmental grounds (Williams, 2015; Thomas, 2015b). These companies also cited delay in the permit and unfavourable result of well testing as the reason for stopping shale gas operations. Many of these companies wanted to trim expenditure after 60% fall in oil prices in 2014-2015 (Neslen, 2015a; Reed, 2015). The Polish government has been trying to develop a legislative framework to create a more conducive environment for the industry. It is trying to simplify licensing procedures, along with geological and mining laws and taxation structure (Thomas, 2015b).

2.5.1.2. Northern and Western Europe

There are five major shale gas basins exist in Northern and Western Europe with an estimated technically recoverable resource (TRR) of 221 Tcf. (Table 8). Figure 13 shows the locations of the shale gas basins in Northern and Western Europe.

Figure 13. Shale Basins of Northern and Western EU countires



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XIII-1, Figure XIII-1.

Table 8. Properties of shale gas basins in Northern and Western Europe

Gas shale basin	Paris	South East Basin	Lower Saxony Basin	West Netherlands Basin	Alum Shale (Denmark, Sweden)
Basin area (sq. miles)	61,000	17,800	10,000	2,750	90,000
Depth (ft)	4,000 – 16,400	8,200 – 16,400	3,300 – 16,400	3,300 – 16,400	3,300 – 15,000
Net thickness (ft)	83 - 160	158	75 - 90	90 - 450	200
Total organic Carbon (%)	4.5 - 9	2	4.5 - 8	2.4 - 6	7.5
TRR (Tcf)	129.3	7.4	17.0	25.9	41.5

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XIII-4 – XIII-34.

France has second largest technically recoverable resources of 137 Tcf in the EU. Paris Basin and Southeast Basin have the largest share (Birol et al., 2012, p. 120-130). The government initially issued three licenses for shale gas exploration and drilling in Southeast Basin. However, in May 2011, the government announced a moratorium on its use because of strong public opposition on potential environmental impacts of hydraulic fracturing. The law later prohibited hydraulic fracturing. Public opposed that they were dependent on tourism because of the scenic beauty of the region, and they were not consulted before the start of activity in that area. The law, which is under review, says that public consultation is required only at the production stage, not before exploration stage.

Most exploration activities that were targeted lies in Paris Basin. Some companies started acquiring an eastern portion of Paris Basin having Permian-Carboniferous shale formation. The French Ministry of Energy and Environment awarded several exploration permits to companies for shale gas activities in South Basin. Many firms have been examining the shale gas potential (Kuuskraa et al., 2013).

The French government was divided on its approach to sustainable energy policy. One report required more study to understand the extent of the country's resource and technologies to safely develop it. The other report asserted that the national energy policy for meeting climate change objectives has no place for new hydrocarbon resources. It is expected that France may withdraw the ban on hydraulic fracturing. Production of shale gas is expected to increase after 2020 and may reach to 8 bcm in 2035 (Birol et al., 2012, p. 120-130).

In Germany, exploration permit for shale gas was issued to few companies, like ExxonMobil, Realm Energy and BNK Petroleum for Lower Saxony basin. After start of drilling series of wells in 2008, three wells showed potential for shale gas. There was increased opposition to hydraulic fracturing activities due to environmental reasons. The drilling operations halted following the declaration of the moratorium on hydraulic fracturing. In 2013, the German government issued draft legislation, which would allow development of shale gas and use of hydraulic fracturing under environmental safeguards (Kuuskraa et al., 2013).

In the Netherlands, three companies acquired shale gas leases in the West Netherlands Basin. However, no activity on shale gas developments is in progress so far (Kuuskraa et al., 2013).

Numerous companies applied for exploration of Alum Shale in Denmark and Sweden. Shell Oil and Total E&P Denmark were active in Sweden and Denmark respectively. Shell drilled three wells and found them uneconomic. Total had six years programme of exploration for confirmation of shale gas (Kuuskraa et al., 2013). Public opposition to hydraulic fracturing delayed shale gas plan and start of further activity was in threat (Birol et al., 2012, p. 120-130).

2.5.1.3. The United Kingdom

Production of gas from the North Sea continued to decline. Hence, shale gas is seen as one of the alternative energy solutions for future (Thomas, 2015b). The United Kingdom (hereinafter: UK) has substantial volumes of shale gas in the northern, central and southern portions of the country.

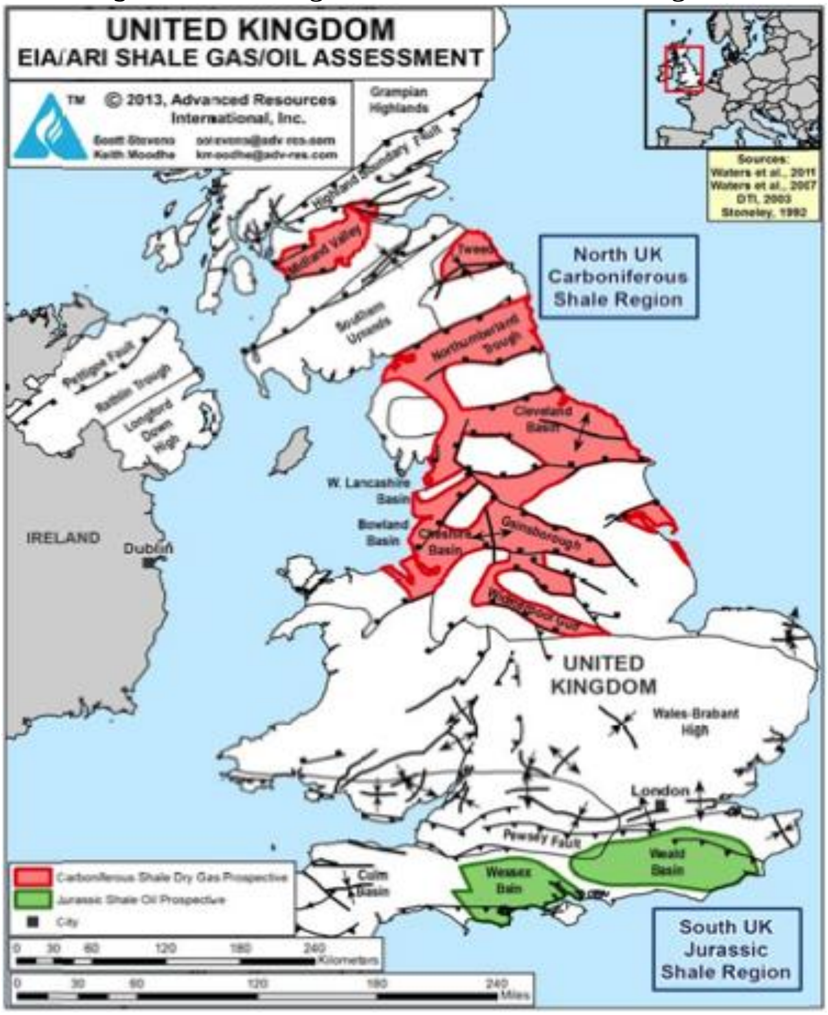
Table 9. Properties of shale gas basins in the United Kingdom

Gas shale basin	North UK	South UK
Estimated basin area (sq. miles)	10,200	3,470
Depth (ft)	5,000 – 13,000	4,000 – 6,000
Net thickness (ft)	410	149
Total organic Carbon (%)	3	3
TRR (Tcf)	25.1	0.6

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XI-2, Table XI-1.

Table 9 shows the properties of two major shale gas basins in the UK. The total reserves of these basins are 26 Tcf. The shale basin geology of the UK is considerably complicated, so drilling and completion costs for shale wells are expected to be higher than that of the US. The locations of the shale gas basins are indicated in Figure 14.

Figure 14. Shale gas basins in the United Kingdom



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XI-1, Figure XI-1.

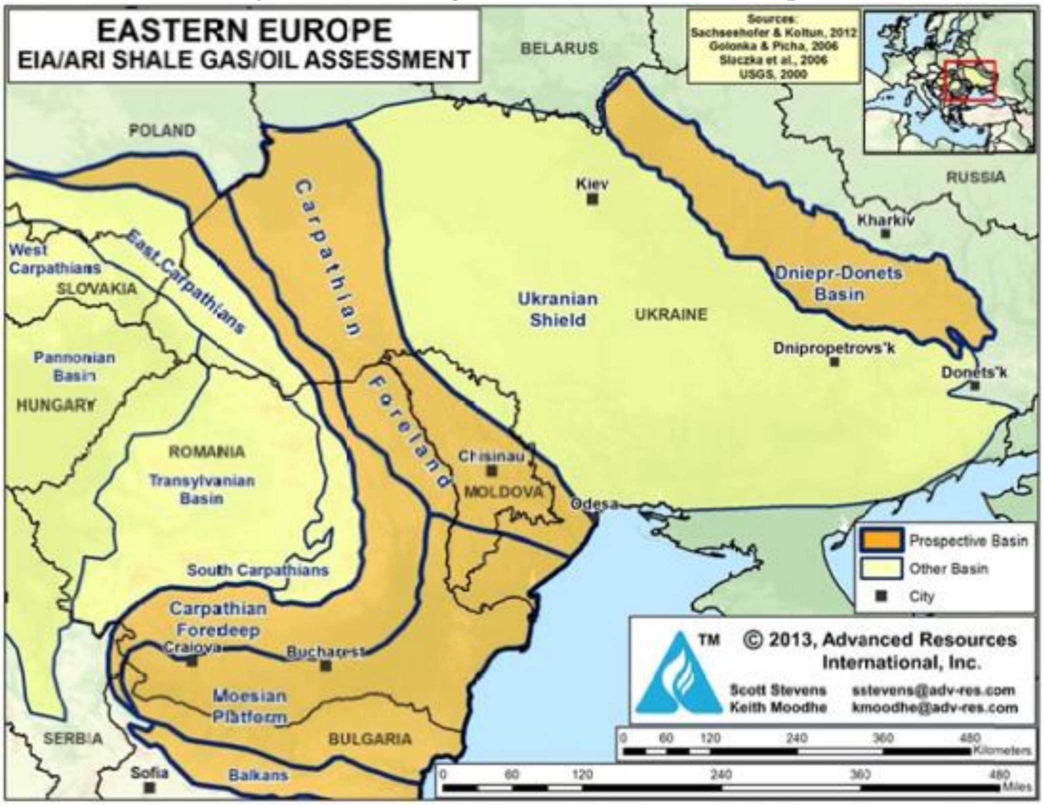
The UK is at an early phase of shale gas drilling and testing. They are yet to perform flow testing and horizontal shale drilling. Series of minor earthquakes were observed related to a nearby fault, due to which operations on shale gas activities were suspended. It was concluded in a report that, fracturing and subsequent earthquakes may be linked. In a parliamentary inquiry, it was observed that no evidence of risk due to hydraulic fracturing on water aquifers and concluded that a moratorium on shale gas was not justified or necessary in the UK. After eighteen months of the moratorium, the government decided that the environmental risks are small and manageable and again allowed drilling for shale gas in December 2012, but with stricter control. The UK Department of Energy and Climate Change recommended continuation of hydraulic fracturing operations and several safety provisions including more use of micro-seismic monitoring and new safeguard of operations in case of seismic activity (Thomas, 2015b; Kuuskraa et al., 2013). The government proposed to the UK Department of Energy and Climate Change to monitor drilling activity extreme carefully to assess its impact on air and water quality (Birol et al., 2012, p. 120-130).

The UK government is supportive of continuing shale gas exploration and development. The government is promoting companies to find out new innovative solutions in water treatment, water monitoring techniques, well drilling and design technology (Thomas, 2015b). The government planned to drill eleven wells for shale gas for the year 2015 (Vaughan, 2015).

2.5.1.4. Eastern Europe

Eastern Europe (Bulgaria and Romania) has significant prospective of shale gas resources in three sedimentary basins: Dniepr-Donets, Carpathian Foreland, and Moesian Platform (Figure 15). Total technically recoverable resource potential is estimated at 195 Tcf of shale gas (Table 10). Shale exploration in Romania is in progress. But there were strong public opposition in these countries on the environmental impact of hydraulic fracturing (Birol et al., 2012, p. 120-130). Bulgaria currently has a moratorium on shale development (Kuuskraa et al., 2013).

Figure 15. Shale gas basins of Eastern Europe



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. X-1, Figure X-1.

Table 10. Properties of shale gas basins in Eastern Europe

Gas shale basin	Carpathian Foreland	Dniepr-Donets	Moesian Platform
Basin area (sq. miles)	70,000	23,200	45,000
Depth (ft)	3,300-16,400	3,300-16,400	5,000-16,400
Net thickness (ft)	400	350	260-450
Total organic Carbon (%)	2	4.5	3
TRR (Tcf)	73 (Ukraine- 52, Romania- 21)	76 (Ukraine)	46 (Romania– 30, Bulgaria– 16)

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. X-2, Table X-1.

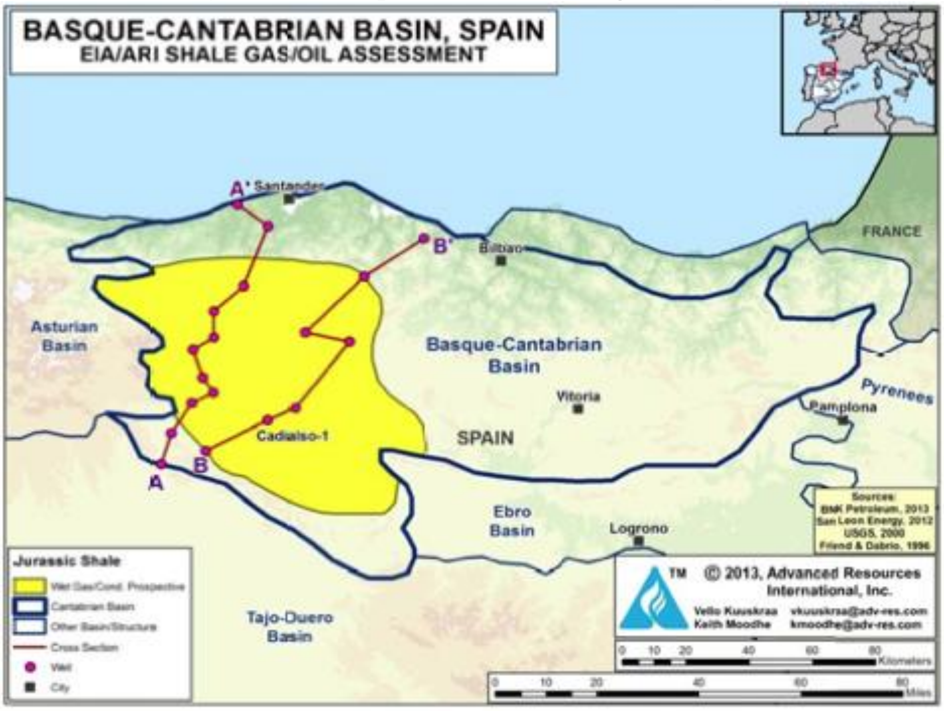
Chevron acquired Barlad shale gas permit in Carpathian Foreland basin in northeastern Romania, but the status of this block is unclear following shale ban. Chevron is in negotiations with the government to develop shale gas project in the Oleska block of Western Ukraine. ENI plans to explore shale gas in the Lviv Basin till 2015 (Kuuskraa et al., 2013).

License for shale gas exploration for Moesian Platform basin was awarded to several companies like Chevron, TransAtlantic Petroleum, and Park Place Energy. Presently there is a ban on shale gas activities in Bulgaria (Kuuskraa et al., 2013).

2.5.1.5. Spain

It is estimated that Spain has 8 Tcf of technically recoverable resource of shale gas in the Basque-Cantabrian Basin in the north (Figure 16). Several companies like San Leon Energy and BNK Petroleum hold leases and are exploring the shale gas in Spain (Kuuskraa et al., 2013).

Figure 16. Prospective area shale gas in Spain



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XII-3, Figure XII-2.

2.5.2 Shale gas economics

The shale gas is at an early stage in the EU. The exploration activities are hampered by the complicated geological structure and public awareness of environmental effect. The information on shale gas is limited and uncertain (European Commission, 2014c, p. 103-105). The shale formations in Europe are deeper than the US. Exploration and production activities are complex and expensive (Starmach, 2013). The production cost will come down, when the understanding of the geology improves, technology advances and the economies of scale is achieved. International Energy Agency estimates that average production costs of shale gas in Europe are estimated to be between \$8/MMBtu and \$12/MMBtu (in the US it is between \$3/MMBtu to \$7/MMBtu). The cost will be still higher if the cost of acquisition of land or leases is considered. However, as the gas price in the EU is more than the estimated production cost, shale gas projects can be economically viable (Ernst & Young, 2011). Oxford Institute for Energy Studies predicted that Europe might have a natural gas supply shortfall of 1.8 Tcf/year by 2020 (Robertson, 2011). There is urgent need for development and production of shale gas.

This unconventional gas will need to compete with existing energy sources in the EU. The investment and infrastructure of existing energy sources by many stakeholders are massive. Russia is less enthused about the development of shale gas in the EU, as they export huge volume of gas to Europe. Russia has been campaigning about the doubts of the viability of shale gas and environmental effects of hydraulic fracturing in many regions (Ernst & Young, 2011).

Europe is lacking in several areas for faster development of shale gas. There is a shortage of support for oil and gas service industries, suitable equipment, infrastructure, geological data and skilled manpower. For example, Europe has around 80 onshore rigs operating for oil and gas exploration, whereas the US has around 2000. The increase in of the number of drilling rigs will incur significant capital investments (Ernst & Young, 2011). In many situations, the cost of leasing of land is higher, and land may not be easily available. Another factor, which retards the shale gas activity, is that the underground resources are the property of the respective country, not landowners.

2.5.3 Environmental challenges

Potential environmental challenges of current extraction technologies for shale gas are often viewed as the main threat to future of shale gas industry. Most significant environmental concern regarding shale gas is associated with water. They are (Kavalov & Pelletier, 2012):

- Large freshwater demand. It could become critical in areas that are already experiencing water deficits. So far there is no industrial scale production of shale gas, so it is hard to predict the quantity of water. The water consumption may be higher when the geology is more complex, and depth is more.
- contamination of fresh water by methane and fracture fluid and produced water
- underground and surface pollution by hazardous chemicals, heavy metals, or radioactive elements
- wastewater handling, treatment, and disposal.

Other potential environmental conflicts of exploration and production of shale gas include (Kavalov & Pelletier, 2012):

- visual landscape disturbance
- impacts of biodiversity and natural conservation, particularly potential conflicts with Natura 2000[1]
- higher noise levels
- worsened local air quality
- seismic concerns.

Shale gases are distributed across larger areas. Europe is more densely populated, with average 113 persons per km^2. As more area is required for shale gas drilling activities, high population density may present a major barrier to the large-scale development. The factors mentioned above will be a multiplying effect in Europe.

According to a poll conducted by Eurostat in January 2013, less than 10% of Europeans are of the opinion that extracting unconventional fossil fuels should be among the EU's energy priority. Poland and Hungary are among the biggest enthusiasts, with only 16% strongly opposed shale gas extraction occurring in their communities. The people from France, Austria, Germany and Bulgaria opposed the most (50%) (Starmach, 2013).

[1] Natura 2000 is the nature and biodiversity policy of EU.

The regulations applicable to upstream oil and gas in the EU are determined at the national level. Member nations define their own energy mix and make decisions concerning domestic resource development. At the EU level, there is a standard set of rules to secure transparent and unbiased access to the opportunities for exploration and exploitation of hydrocarbons. The major area on which the regulation is applicable throughout the EU is environmental protection of the following (Birol et al., 2012, p. 120-130):

- water protection and management
- use of chemicals
- the protection of natural habitats and wildlife
- requirements environmental impact assessment
- penalties for environmental damage.

2.5.4 Shale gas policy

The European Commission issued energy strategy in May 2014 to ensure a stable, abundant and secure supply of energy. It addressed medium term measure for increasing energy production and diversifying supply countries and routes. It includes deployment of renewables, sustainable production of fossil fuels, and safe nuclear energy where the option is chosen (European Commission, 2014b).

To confirm that exploration and production of shale gas using hydraulic fracturing are carried out in a safe, responsible and environmentally friendly method, the Commission has issued a Recommendation to the member countries. This Recommendation is to be used as guidelines while creating legislation by member countries. The Recommendation provides guidelines on the following aspects (European Commission, 2014a):

- strategic planning, clear rules and environmental impact assessment to reduce environmental impact
- exploration and production permit and guidelines
- suitable selection of the site for exploration and production
- baseline study on the environment such as water, air, soil, seismicity, land use, biodiversity and existing oil and gas activity
- safe installation and design condition
- integrated approach to infrastructure development for shale gas activity
- operational requirements such use of best technologies, water management plan, air pollution management plan, contingency plan and risk management plan
- minimise use of chemicals and water consumption
- monitoring the requirements of the operation, surrounding environment and underground by using the baseline studies as a reference and ensure that reporting of results to the authorities
- environmental liability and financial guarantee provisions
- adequate administrative capacity with resources to control the shale gas operators
- compare the environmental status of the environment with the baseline study
- dissemination of information on the plan of shale gas activity and use of chemicals and water to the public
- review of the principles by Commission set by the member countries based on the Recommendation.

Some countries are exploring unconventional fossil fuels such as shale gas for sustainable production and diversifying the supply of gas. Poland and the UK have an ongoing programme of drilling and hydraulic fracturing. So far, a total of five countries (the UK, Denmark, the Netherlands, Poland, and Romania) have stated that they have licensed hydraulic fracturing or plan to do so. Another six (Austria, Germany, Hungary, Lithuania, Portugal, and Spain) are still considering the possibility of exploring for shale gas. France and Bulgaria have banned hydraulic fracturing (Thomas, 2015b).

Poland offers best prospects for viable shale gas industry and desires to start commercial production by 2015. Shale leasing and development began in 2007 when the Ministry of Environment implemented favourable policies for shale gas development, including a simple tax and royalty fiscal scheme. In 2014, the Polish government announced that shale gas extraction would exempt from tax until 2020 (Belkin, at al., 2013; Shale gas Europe, 2015). Polish government were also discussing modifications to the shale fiscal terms that may increase profit taxes on shale gas production to 40% or more while establishing government-owned equity to gain a minority stake in shale gas development projects. The intention was to reduce industry investment in shale exploration and reduce risk (Kuuskraa et al., 2013).

The offshore production of energy from the North Sea is declining. Britain needs new sources of oil and gas to reduce the burden of fuel imports, especially from Russia. In the wake of Ukraine crisis, the UK government has firmly committed itself to shale gas. The government wants to have similar benefit enjoyed by the US (Reed, 2014). The UK government is a firm supporter of shale gas. In 2012, the UK government allowed resumption of exploration of shale gas and recommended measures to mitigate any risk of seismic tremors. The UK is serious about environmental protection and interest of community groups and requires strict regulations for gaining permission to drilling activities. The government would take special precautions in the sensitive areas like national parks (Shale gas Europe, 2015). The government is trying to speed up exploration through a combination of streamlining of regulation and offering rewards for local communities and reduce hurdles that companies need to clear before drilling.

After Japan quake in 2011, Germany initiated energy transition process, accordingly planned to shut down all nuclear power plants by 2022, and natural gas would replace nuclear energy (Vetter, 2015). In 2015, Germany proposed a draft law that would allow commercial shale gas frecking at depths over 3,000 meters (Neslen, 2015b). German government concluded that hydraulic fracturing should not be banned and should not take place in water protection zones. Environmental impact assessments and display of chemicals of fracturing fluid are mandatory in Germany (Shale gas Europe, 2015).

Spain confirmed their willingness to pursue hydraulic fracturing by complying environmental regulations and mandatory environmental impact assessment for all shale gas projects. Romanian government came out in support of shale gas, as the country needs energy independence and reduction in gas price. The government sought for more exploration to determine the size of shale gas reserves (Shale gas Europe, 2015).

2.6 Shale gas in China

China is world’s largest consumer of energy. Rapid development with the largest population (1.36 billion in 2013) of China is the prime reason for huge consumption of energy. China consumes the maximum of coal (66%) in their energy mix, which is much ahead of consumption of petroleum and other liquid. Natural gas consumption is only 5%. The demand for natural gas is increasing. The consumption of natural gas is anticipated to reach 10% in 2020. In 2013, China imported 32% of their natural gas demand (USEIA, 2015c). To meet the demand, China has to increase the import of natural gas or increase domestic natural gas production. The best option to meet demand is to enhance domestic production of conventional and unconventional natural gas.

Shale gas, as an important component of unconventional gas, can fulfill the significant requirement of natural gas in China and reduce import burden. In addition, domestic shale gas can meet the demand for natural gas in the long term, promote the development of relevant industries and increase economic growth, reduce consumption of polluting coal and greenhouse emission, and increase the number of jobs (Yu, 2015).

2.6.1 Exploration and Production

China has the largest reserve of technically recoverable resources of shale gas. As per the USEIA (2013a) estimate, China has 1115 Tcf of technically recoverable resources (TRR) of shale gas. The reserves are located mainly in the shale gas basins of Sichuan, Tarim, Junggar, Songliaoi, Yangtze platform, Jianghan and Subei. Table 11 shows the properties of the shale gas basins while Figure 17 shows the locations of the shale gas basins in China. Initial drilling and examinations confirmed that geology of shale gas formations is complicated. Some of the basins are seismically active and hence are challenging for shale gas exploration and development (Kuuskraa et al., 2013).

Table 11. Properties of shale gas basins in China

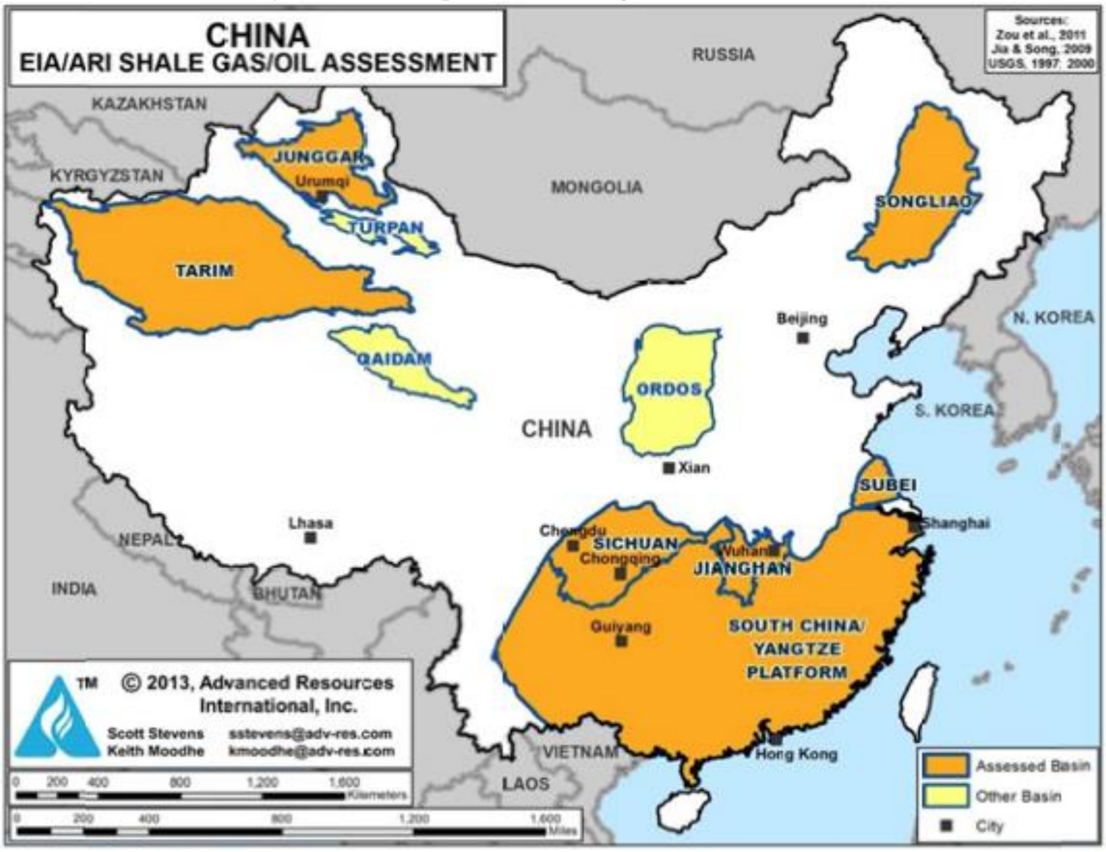
Gas shale basin	Sichuan	Tarim	Junggar	Songliao	Yangtze Platform	Jianghan	Subei
Estimated basin area (sq. miles)	74,500	234,200	62,100	108,000	611,000	14,400	55,000
Depth (ft)	9,700-13,200	10,790-16,400	5,000-16,400	3,300-8,200	10,000-16,400	5,500-13,120	3,300-16,400
Net thickness (ft)	250-275	160-240	410	500	275-400	175-267	150-300
Estimated basin area (sq. miles)	74,500	234,200	62,100	108,000	611,000	14,400	55,000
Depth (ft)	9,700-13,200	10,790-16,400	5,000-16,400	3,300-8,200	10,000-16,400	5,500-13,120	3,300-16,400
Net thickness (ft)	250-275	160-240	410	500	275-400	175-267	150-300

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XX-3 – XX-5.

The shale gas business in China is in early stage and maturing slowly. The industry has constraints and challenges like acquiring technologies for horizontal drilling and hydraulic fracturing, availability of water, transportation, regulatory hurdles and environmental issues (Kuuskraa et al., 2013).

South China has Sichuan, Yangtze platform, Jianghan and Subei basins. Major areas of these basins have existing gas pipelines and proximity to towns and cities. Sichuan basin has the highest reserve among all basins of China. The Sichuan region is abundant with surface water resources. This basin is seismically very active and has mountainous terrain. Due to these, shale gas activities are slow, and the cost of exploration and production are high in this region. PetroChina and Sinopec, along with foreign companies Shell, Chevron, ConocoPhillips, Statoil, and Total have expressed interest in this region. PetroChina and Sinopec are operating shale gas activities in this region with Shell. One of the first horizontal wells drilled by PetroChina produced around 580 million cubic feet/day during the 60-day test. The result was not inspiring, though, to have industry stability requires hundreds of shale gas wells to be drilled. The region of Yangtze platform, Jianghan, and Subei basins are considered prospective, structurally complex with the poor data control (Kuuskraa et al., 2013).

Figure 17. Prospective shale gas basins of China



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XX-1, Figure XX-1.

Tarim basin is one of the largest onshore basins in China. No shale gas activity is reported from Tarim basin. This remote region is in the North-western part of China and falls in the desert area. The shale gas basin is very deep there. This region being an existing oil field, has experienced horizontal drilling. This experience will be an advantage for shale gas activity in future (Kuuskraa et al., 2013).

Junggar basin has thick layer, high formation pressure and has high carbon content. Hence, considered as the best geology for shale gas. There are many cities in this region. Therefore, infrastructure is good in this region. The climate is better for agriculture. No shale gas activity reported in this area. Songliao basin has thick layer, high formation pressure, has high carbon content and naturally fractured. However, this region is seismically active. No shale gas activity reported in this area (Kuuskraa et al., 2013).

The progress of production of shale gas is so far slow in China. The shale gas production is mostly from Sichuan basin. Sinopec is producing from the Fuling block and PetroChina from Changning-Weiyuan block (USEIA, 2015c). In 2014, production was 46 billion cubic feet (hereinafter: Bcf). China is the only country other than the US and Canada, who is commercially producing shale gas (USEIA, 2015b). Due to success in development in the Fuling gas field, production in that gas field is expected to be 353 Bcf by 2017. Considering geological risk, sources of water, and production behavior of shale gas from the basins, China set a target of shale gas production at 1060 Bcf in 2020. The Chinese government has full backing and support for shale gas industry for exploration and maximum production (USEIA, 2015c).

Chinese companies had invested in the US shale gas exploration and production and have exposure to the shale gas activities. The national oil companies (hereinafter: NOC), PetroChina and Sinopec, hold a vast majority of natural gas resources. The NOCs are collaborating with foreign firms to obtain technology and investment for shale gas. In addition, many small companies carrying out shale gas exploration activities in China (USEIA, 2015c).

British Petroleum predicted that, by 2035, China would become world’s second largest producer of shale gas. From 2025 to 2035, the average growth rate of shale gas production is expected to be 33% per year. This growth is due to massive reserve in China, aggressive shale gas policy by the government, and the achievements so far in shale gas exploration and production (Xinhua News Agency, 2015).

2.6.2 Shale gas economics

The shale gas exploration and production activities are in the initial stage in China. The correct picture of shale gas economics can be obtained once industry matures, and economies of scale gas are achieved.

The shale gas wells are generally situated away from conventional well locations in China. Many basins are located in the mountainous terrains or the terrains that are not easy to access. Infrastructures like road, well site construction, pipelines, access and disposal of water need huge capital investment and time to build. The additional pipelines will assist in the production and delivery of new gas finds to the destination (Yu, 2015).

The geological characteristics are complex. The shale rock formations are deep, and many basins are in heavily fault zones. Hence, exploration and production are technically complicated. The mountainous terrain and inferior infrastructure make the shale gas activity tougher. Due to these reasons, drilling and hydraulic fracturing costs are high and take more time. Average drilling time of shale gas in China is 250 days, whereas it requires 10 to 20 days to drill a shale gas well in the US. To drill in deep and difficult zones require sophisticated technologies, which are not easily available in China. These technologies need additional investment (Thomas, 2015a).

The areas are densely populated and intensely farmed. In some of the villages like Maoba, drill sites are placed at a distance of 110 meters from the houses. Noise, dust and environmental concerns like water pollution and air pollution affect the villagers, and they protest. The companies have been giving compensations to the local residents and local government officials for using their land, roads and other inconveniences (Spegele & Scheck, 2013).

The cost of drilling horizontal shale wells is high at the beginning of the shale gas activity. However, the rates come down as the industry matures, more sophisticated technology is available, infrastructure is developed, and economies of scale is achieved. At present, the average cost of drilling a horizontal shale gas well is 6 - 8 million US Dollar (hereinafter USD), which can go up to 11 million USD. In comparison, the average cost of drilling a shale gas well in the US is 0.4 to 0.6 million USD (Yu, 2015). Chinese government increased the natural gas price by 0.4 Yuan to 2.35 Yuan per cubic meter, in 2014 (1 Yuan = 0.16 USD) (Asia News Monitor, 2014). With the increase in price, the shale gas projects became more attractive and viable.

Accessing the geological information in China is difficult. The geological data, in the initial rounds of bidding, were poor. After winning the bidding, many companies lack fund for exploration and development of shale gas. The winners of the bid lacked oil and gas experience, technology capability and talent. They anticipated risk in huge capital investment. Because of the technical and financial problems the progress is slow (Yu, 2015).

2.6.3 Environmental challenges

Shale gas industry is new to China. The shale gas exploration and production introduce significant challenges related to water resources, ecological and environmental management and supervision. The Chinese government and industry need to take careful steps to gain the confidence of the people. The following challenges are briefly described (Yu, 2015):

Population density: China is world's most populous country. The average population density is 141 persons per km^2. The shale gas basins of South China, Sichuan, Yangtze platform, Jianghan and Subei basins are located in densely populated areas. People are involved in agricultural activities in plains and the hilly regions. Agriculture supports 20 percent of the world population. Therefore, any adverse impact on the environment due to pollution will affect many.

Scarcity of water: Shale gas drilling and hydraulic fracturing require a large volume of water. Based on the experience of depth and geology of shale formation in China, drilling activities of a well requires around 2 million to 5 million gallons of water. The requirement is much more (between 5 to 13 million gallons) when more gas output is desired. China needs huge volume of water to drill and hydraulic fracture thousands of shale gas wells to achieve the target set for 2020.

The distribution of water resources of China is not uniform. The regions that have abundant shale gas are water-scarce. Many of these areas experienced drought. Tarim basin, which is in one of the largest basins, is situated in the desert. During the shale gas exploration process, the situation may be worse. The regions may experience depletion of ground water resources from rivers, lakes and aquifers.

Deterioration of quality of water bodies and air: The requirement of water and chemicals is more in China because of the complex geological formation. Therefore, the quantity of flow-back and produced water will also be high. The control and management of the flow-back and produced water is a challenge in the densely populated country, where the vast area is under agriculture. The complex geological formation has high concentrations of toxic and inflammable gases like hydrogen sulphide. Highly concentrated drilling and hydraulic fracturing may release methane and toxic gases in the highly populated areas.

Seismically active zones: Shale gas basins, such as Sichuan, Tarim and Junggar lie in seismically hazard zones. Among them, Sichuan region has very active faults and incidentally this region has the largest reserve of shale gas. These areas require utmost care and study before carrying out shale gas directional drilling and massive hydraulic fracturing.

2.6.4 Shale gas policy

China has the largest quantity of shale gas. The Chinese government, and their oil and gas companies and institutions are much interested in exploration and production of shale gas. China tied up with foreign oil companies for the improvement of the policies of shale gas exploration and production. To augment exploration and production, China raised the conventional gas price and promoted private sector participation for shale gas. The Chinese government has been developing shale gas as an important national energy strategy of energy consumption, improve energy structure, and to ensure future energy security. Favourable regions are selected for shale gas explorations in China based on the resources, depth, surface, and storage conditions of shale gas formations (Yu, 2015).

Shale gas policies include the following four main aspects (Yu, 2015):

Industrial planning: The Chinese government put special priority on shale gas on legal, technological and commercial fronts (Kuuskraa et al., 2013). The government identified shale gas as a key energy mineral and fully promoted strategy surveys, exploration and development in key regions. In 2011, State Council approved to separate ownership of shale gas from conventional resources (Kuuskraa et al., 2013). In 2012, the 12th Five-year Plan of Shale Gas Development was introduced. This plan analysed development foundation, resource potential and current situation of exploration and development of shale gas, and the problems faced. The aim of the plan was the large-scale commercial development of shale (Kuuskraa et al., 2013). The 12th Five-year plan promised favourable fiscal incentives to producers, such as direct subsidies, preferential tax treatments and priority land use. The pricing regime for shale gas is market-based, which will encourage shale gas development. The government is willing to allow higher end-user prices, instead of current controlled prices for natural gas (Birol et al., 2012, p. 115-120).

R&D support: The objective was to promote the development of shale gas technology, solve key technical issues, and research concerning the enrichment mechanism and resource potential evaluation of shale gas. In 2011, a scientific project "The Key Technologies of Shale Gas Exploration and Development" was set up.

Tax concessions and subsidies: The Chinese government allocated special funds to support development and utilization of shale gas and subsidies for production companies. The aim was also to reduce the charge of mineral resources compensation fee and mineral rights utilization fee for shale gas exploration companies. Imported equipment of shale gas development were exempted from customs duty. The government also had planned to study the tax structure in favour of shale gas development.

Mineral management innovation: Chinese government set and increased priorities for the new mineral shale gas. The exploration and development of shale gas were listed in the encouraged category and investors were encouraged to invest in shale gas exploration. Exploration rights bidding introduced and mineral management mechanism was innovated in 2011. Market competition mechanism was introduced, adopted public tenders and invitational tenders. China has implemented bidding for shale gas. In China, under normal circumstances, only state-controlled companies can acquire the mineral rights (Birol et al., 2012, p. 115-120). Foreign companies are not allowed to participate in the bidding. However, winning parties are free to bring both local and foreign partners. Foreign companies can have minority partnerships with them; sometimes can have production sharing agreements. In regards to shale gas, China is planning to carry out some changes considering their ambitious plan and for obtaining advanced technology and investments from foreign partners (Birol et al., 2012, p. 115-120).

It is mandatory to carry out an environmental impact assessment and approved by local and national regulators, before submission of a field development plan. Drilling permits are issued based on the development plan.

There is scarcity water in many areas of shale gas basins. Chinese government determines water policies, regulations and plans. Water management and enforcement of regulations are done at local level. Many organisations are involved at national, regional and local levels to regulate water resources. National Standards finalises the maximum concentration of pollutants that can be discharged into water sources while Circular Water Law encourages reuse and recycling of waste and produced water (Birol et al., 2012, p. 115-120).

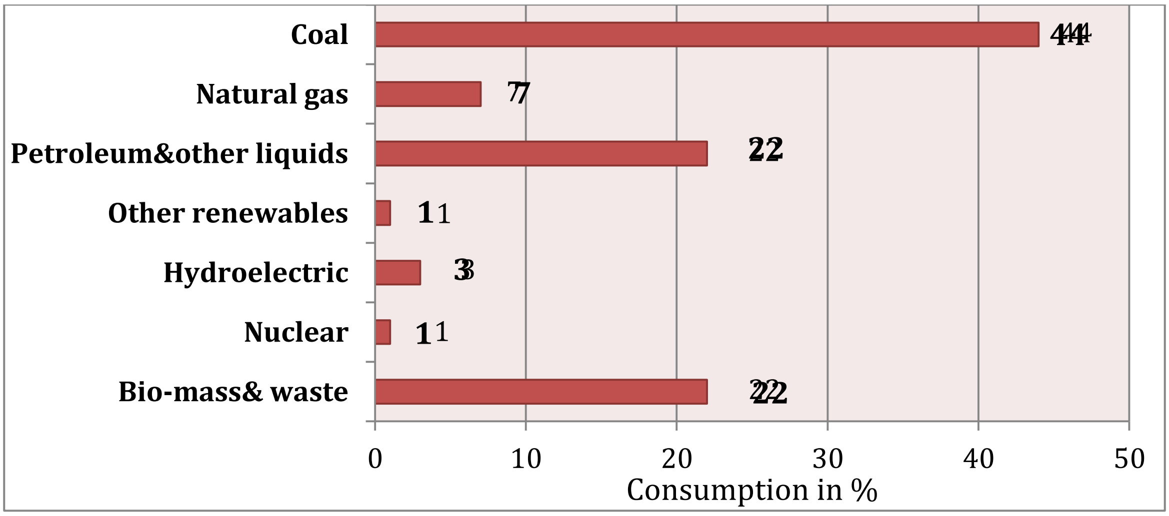
China is anxious to obtain the quick success and gain instant benefit without a long-term strategy. Shale gas exploration is technology intensive. It needs time to innovate, mature and sound technology for shale gas. China may need more time than it had anticipated as the shale gas geology is more complex, mountainous terrain, high population density, and lack of sufficient infrastructures like road and pipelines. China's gas pipeline network will necessarily have to expand to reach into unconventional gas production areas (Birol et al., 2012, p. 115-120). With the government's all-out effort, the results are expected faster than the usual time.

3 SHALE GAS IN INDIA

3.1 Energy position of India

India became the fourth-largest energy consumer in 2011 after China, the US and Russia, because of fast economic development and modernization. Since 2000, India has been maintaining an average economic growth rate of 7%. At present India's energy demand is growing at 2.8% per year (USEIA, 2014a).

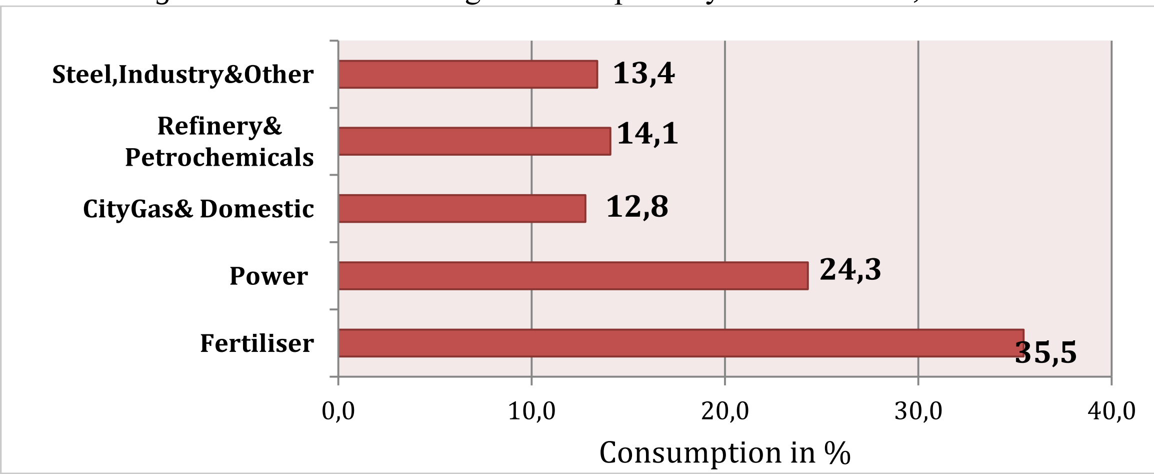
Figure 18. Total energy consumption in India in 2012



Source: USEIA, *India- Analysis,* 2014, p. 3.

Figure 18 shows consumption of various forms of energy in India in 2012. The use of energy mix in India consists of coal (44%), petroleum and other liquids (22%), biomass and waste (22%), natural gas (7%), hydroelectric (3%), nuclear (1%) and other renewables (1%) (USEIA, 2014a). The consumption of natural gas (7%) in India is much less compared to that of the US (44%) (US Department of Energy, 2009). Annual per capita natural gas consumption in India is 44 cubic meter, whereas the world average is 470 cubic meter (Ernst & Young, 2014). Figure 19 shows natural gas consumption in India by end-use sector in 2013-2014. Out of total natural gas consumption, 36% was in fertilizer sector, 24% in power sector, 13% in domestic use, 14% in petrochemical sector and 13% in steel, industries and others (MoPNG, n.d).

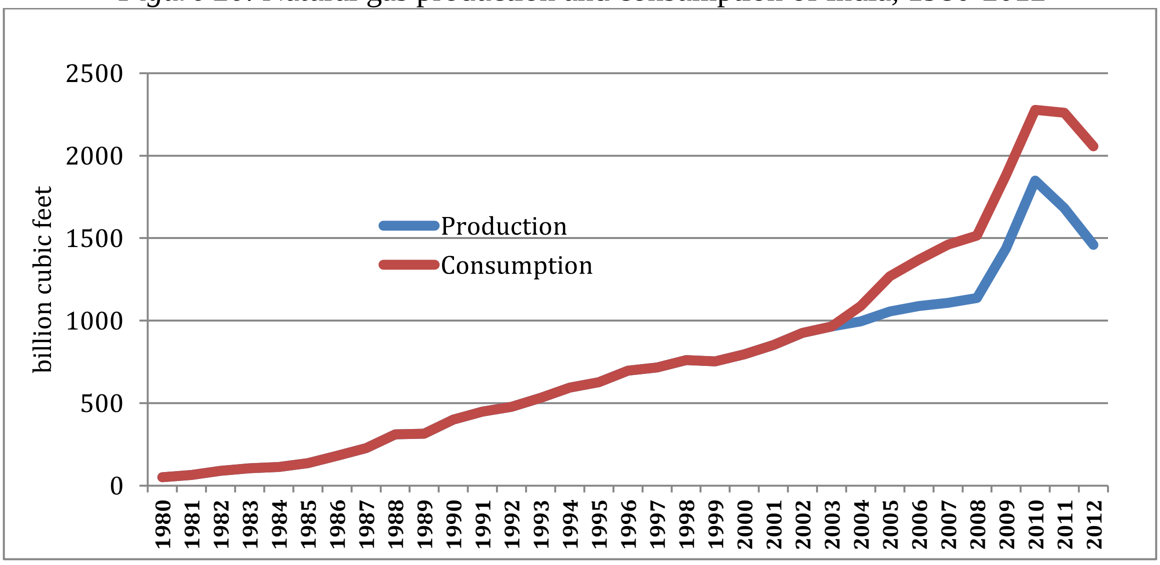
Figure 19. India's natural gas consumption by end-use sector, 2013-14



Source: Ministry of Petroleum and Natual Gas, *Natural gas scenario In India*, n.d.

Figure 20 shows the production and consumption of natural gas in India between 1980 and 2012. The demand for gas increased at a rate of 8% between 2000 to 2012. As the demand increased, India started importing natural gas in 2004 in the form of liquefied natural gas (LNG). In 2012, import went up to 29% of total consumption. Indian companies hold both long-term supply contracts for import and more expensive spot LNG contracts. In 2012, India consumed 2.1 Tcf of natural gas (USEIA, 2014a). As per the twelfth five-year plan, the demand for gas is expected to increase at the rate of 19.2% per annum to 6.0 Tcf by 2016-17 (Planning Commission-GOI, 2013). It is estimated that India and China will account for 50% of global demand for energy by the year 2040 because of economic growth, industrialization and urbanization (USEIA, 2013b). The energy import bill of India is expected to increase from $120 billion at present to $230 billion in the year 2023 (Press Trust of India, 2014a).

Figure 20. Natural gas production and consumption of India, 1980-2012



Source: USEIA, *India- Analysis*, 2014, p. 13.

In 2014, India had 47 Tcf of proved natural gas reserves located at onshore (34%) and offshore (66%). Total production was 1.25 Tcf in 2013-14 (MoPNG, n.d). Two biggest national oil companies (NOCs), viz., Oil and Natural Gas Corporation Limited (ONGC) and Oil India Limited (hereinafter: OIL) are the major players in the upstream sector. The government has also encouraged private and foreign companies in the upstream sector. Reliance India Limited (hereinafter: RIL) is the major private company in the gas upstream industry. RIL along with British Petroleum (BP) discovered gas in the KG-D6 basin on the east coast of India, which has reservoir capacity 3.1 Tcf (USEIA, 2014a). In the financial year 2013-14, the NOCs accounted for 73.2% of domestic natural gas production, while private/JV companies produced 26.8% (MoPNG, 2015a).

Gas Authority of India Limited (hereinafter: GAIL) and RIL are the major operating companies of the gas pipeline system. GAIL makes up over 70% of country's pipeline network. RIL is the biggest private player in gas transmission. Assam Gas Company Limited (AGCL) and Gujarat State Petronet Limited (GSPL) have strong pipeline network in the northeastern part of India and Gujarat respectively. Country's natural gas pipeline is 14,987 km (MoPNG, n.d). However, pipeline system lacks uniform pipeline networking in India, especially southern and eastern part of India. The government proposed to expand pipeline length to 18,000 miles by 2017 (USEIA, 2014a). Additional pipelines will assist in the production and delivery of new gas finds to the market.

India started importing LNG from Qatar in 2004. In 2013, India imported 638 Bcf or 6% of global trade. The imported LNG prices are around three times higher than domestic natural gas price. Petronet, a joint venture of ONGC, GAIL, Indian Oil Corporation (hereinafter: IOC) and several foreign firms, are the major importer of LNG supplies in India (USEIA, 2014a). India has four LNG terminals. India's regasification facility in these terminals was 1020 Bcf/year in 2014-15. The expansion of regasification capacity is in progress in these terminals (MoPNG, n.d). Ministry of Petroleum and Natural Gas (hereinafter: MoPNG) looks after natural gas exploration and production activities. Directorate of Hydrocarbons of MoPNG functions as an upstream regulator (USEIA, 2014a).

3.2 Shale gas reserve

India has many shale gas basins. As per the USEIA (2013) India has 96 Tcf (2.72 trillion cubic meters) of technically recoverable resource of shale gas and 3.8 billion barrels of oil in the four basins namely, Cambay, Krishna-Godavari (KG), Cauvery and Damodar Valley. Locations of these basins are shown in Figure 21 (Kuuskraa et al., 2013). However, Schlumberger has estimated shale gas resources of India between 300 to 2100 Tcf (MoPNG, 2015b).

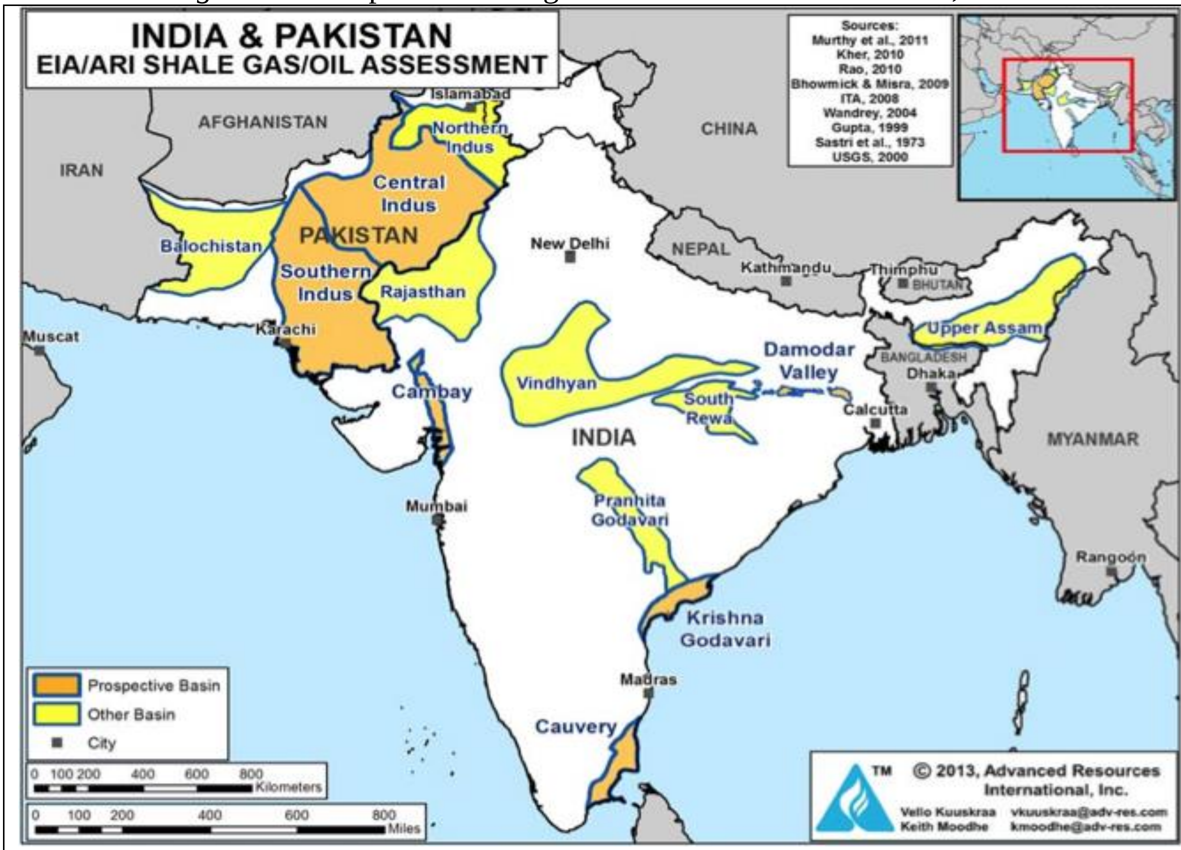
At present limited information is available on geologic settings and reservoir properties. Table 12 shows the properties and technically recoverable resources (TRR) of shale gas for four basins. The shale gas basins of India are highly complex. The basins such as Cambay and Cauvery have a series of extensively faulted structures (Kuuskraa et al., 2013).

Table 12. Shale gas basin properties in India

Gas shale basin	Cambay	Krishna-Godavari	Cauvery	Damodar Valley
Estimated basin area (sq. miles)	7,900	7,800	9,100	2,270
Depth (ft)	6,000-16,400	4,000-16,400	7,000-13,000	3,300-6,600
Net thickness (ft)	500	100-390	500	250
Total organic Carbon (%)	2.6	6	2.3	3.5
TRR (Tcf)	29.5	56.9	4.5	5.4

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XXIV-2, Table XXIV-1A.

Figure 21. Prospective shale gas and shale oil basins of India, 2013

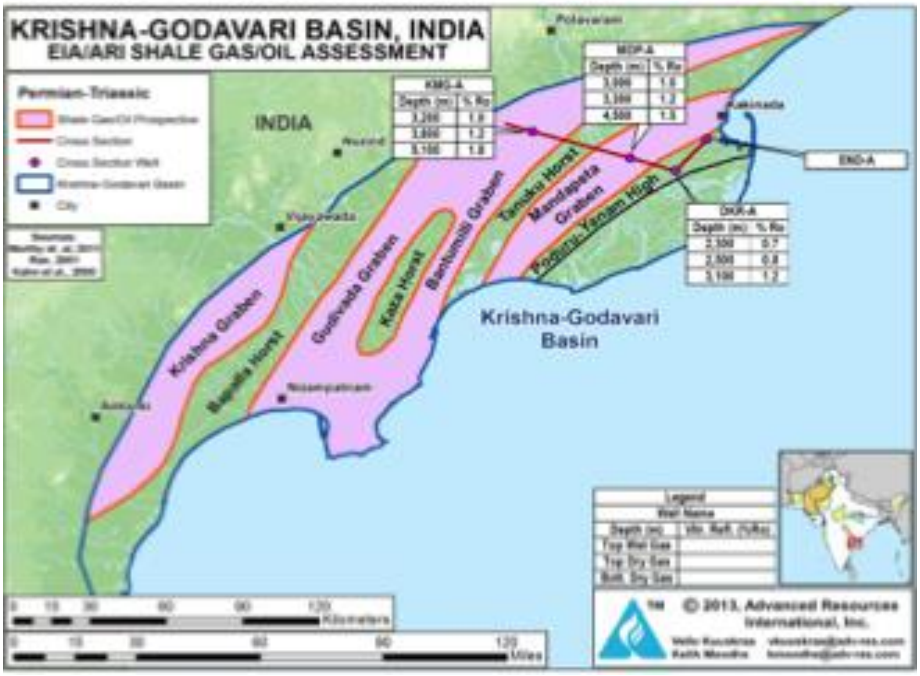


Map disclaimer: the map is considered only for the purpose of location of shale gas basins in India.

Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XXIV-1, Figure XXIV-1.

Krishna-Godavari Basin is in the eastern part of India (Figure 22). It has organic-rich shales. This basin has an estimated reserve of 57 Tcf of technically recoverable resource of shale gas (Kuuskraa et al., 2013).

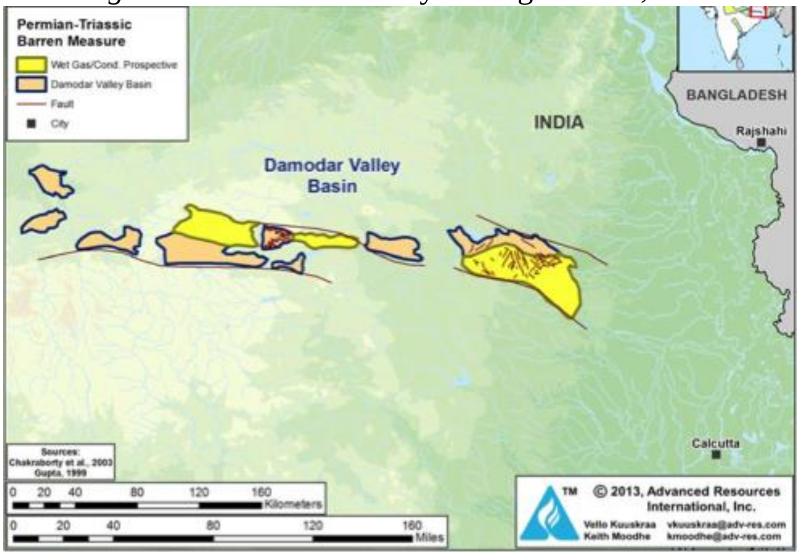
Figure 22. Krishna-Godavari shale gas basin, India



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XXIV-21, Figure XXIV-16.

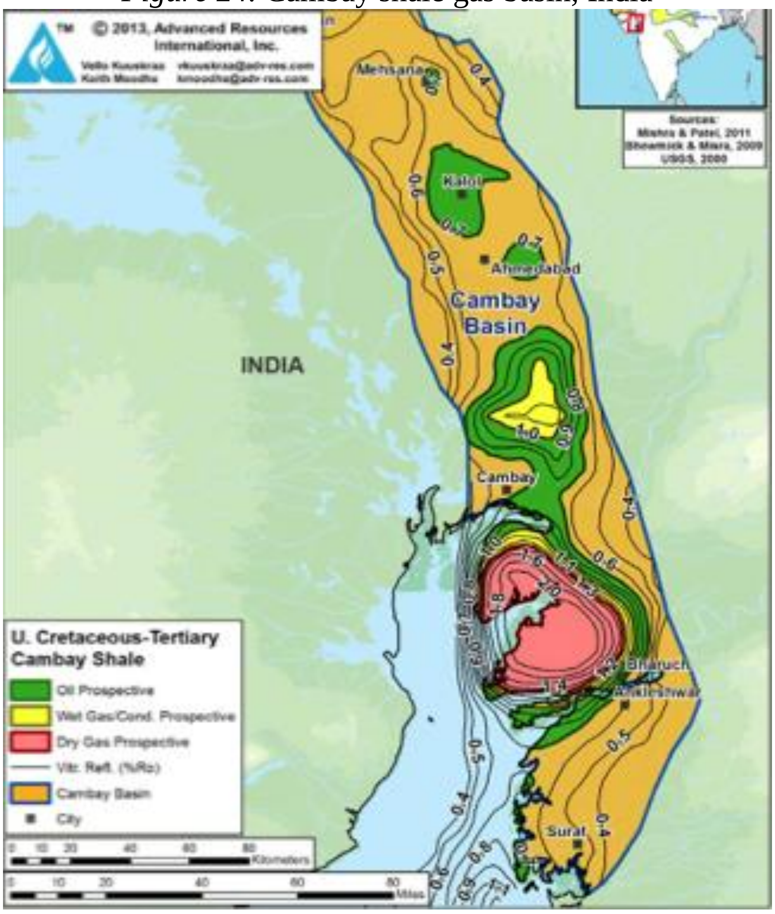
Damodar Valley basin is a group of basins in the eastern part of India (Figure 23). Along with Cambay basin, Damodar Valley basin was also set as a priority for shale gas. This basin has an estimated reserve of 5.4 Tcf of technically recoverable resource of shale gas (Kuuskraa et al., 2013).

Figure 23. Damodar Valley shale gas Basin, India



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XXIV-29, Figure XXIV-23.

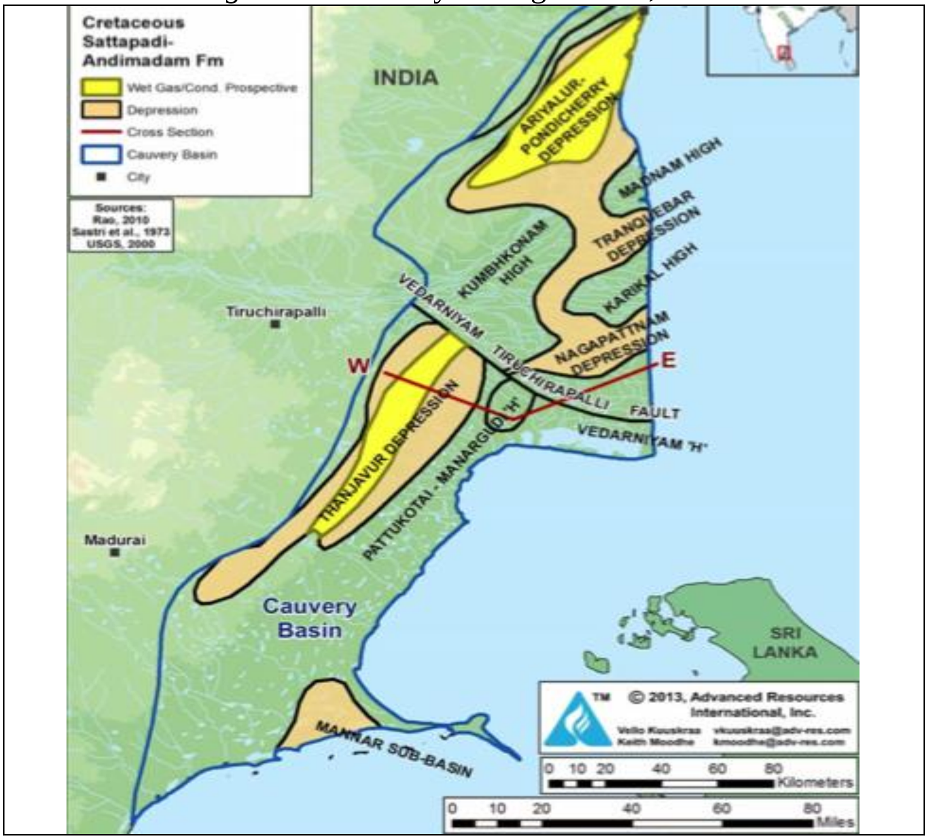
Figure 24. Cambay shale gas basin, India



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XXIV-14, Figure XXIV-10.

Cambay basin is an elongated one (Figure 24). It is located in northwest India, in the state of Gujarat. It has around 30 Tcf of technically recoverable resource of shale gas. Cauvery Basin is on the east coast of India (Figure 25). It has thick organic-rich resource rocks. This basin has an estimated reserve of 4.5 Tcf of technically recoverable shale gas (Kuuskraa et al., 2013).

Figure 25. Cauvery shale gas basin, India



Source: V.A. Kuuskraa, S.H. Stevens, & K. Moodhe, *EIA/ARI World Shale Gas and Shale Oil Resource Assessment*. 2013, p. XXIV-27, Figure XXIV-21.

In addition to major basins, there are several other basins such as Upper Assam, Vindhyan, Pranhita-Godavari, Rajasthan and South Rewa. Resource assessment of these basins was not carried out, as those shales were considered either thermally immature, or the data for conducting rigorous resource assessment were not available. Upper Assam basin an important onshore basin for oil and gas. The data of the estimation of shale gas is publicly not available. This region is seismically very active. Pranhita-Godavari basin is located in the eastern India, is thick and organic-rich shale. Vindhyan basin is located in north-central India. Rajasthan basin has a large onshore area in north-west India. Rajasthan basin is structurally complex and characterized by numerous small fault blocks. Limited data is publicly available (Kuuskraa et al., 2013).

3.3 Natural gas pricing in India

Natural gas price is regulated in India. The domestic price of natural gas is less than the import price of LNG. Major modifications from the existing pricing mechanism were done in 2014. The price mechanism before modification is discussed here to understand the background of the new pricing mechanism. In India, different producers were allotted different natural gas pricing schemes. The price of domestic gas to producers were set according to the terms of the fiscal regime that governs a producing field. There used to be three fiscal regimes for gas exploration and production in India (MoPNG, 2014a).

1. Administered Pricing Mechanism (hereinafter: APM). Gas produced from existing fields of nomination blocks of NOCs, viz. ONGC and OIL were covered under this mechanism. This gas is supplied mainly to fertilizer plants and power plants, at APM rates. The government fixed APM gas price for the country at \$4.2/MMBtu in 2010 (except Northeastern India, where it was \$2.52/MMBtu in 2010). The government of India kept the price of gas produced under APM low, as some of the critical industries were dependent on the gas such as fertiliser and power sector. The increase in the gas price affected the farmers and public, who were the customers of fertiliser and power sectors. The price of APM gas was fixed by the government from \$4.20 to \$5.25/MMBtu in 2010 for other customers who are not entitled to APM gas. Also, for the gas produced from new fields in the nominated blocks, the price of gas was fixed higher than the APM price.

2. Pre-NELP gas. Certain blocks where discoveries were made by NOCs were auctioned under a production-sharing contract (hereinafter: PSC) to private sector exploration and production companies to overcome funding constraints and lack of advanced technologies. The produced gas has to be sold to GAIL, a government nominated company, as per the pricing formula specified in the PSC. The pricing formula was linked to an internationally traded fuel oil basket, with a provision for revision after seven years from the date of first supply. Under these PSCs, Panna-Mukta-Tapti (PMT) and Ravva fields were operating with GAIL as government nominee. The price ranged from \$3.5 to \$5.73 /MMBtu in 2013-2014. Gas from Ravva field and part of PMT JV field were supplied at APM rate to consumers such as fertilizer and power sector.

3. The New Exploration Licensing Policy (NELP) was introduced in 1999. It replaced the Pre-NELP regime. It was based on production sharing contracts between exploration companies and government. Under NELP, the gas pricing was approved only in the case of RIL’s KG Basin discovery. The formula (1) adopted by government is:

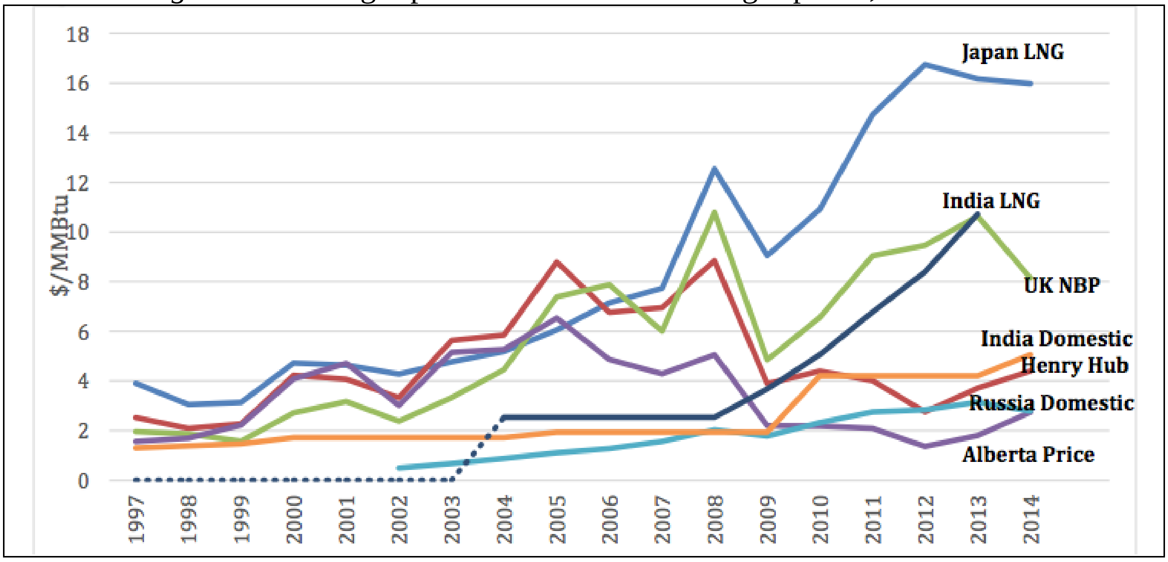
   $$SP\ (Rs/MMBtu) = 2.5 + (CP - 25)^{\mathbf{0.15}} \qquad \text{- - - - (1)}$$

   where SP is the selling price in \$/MMBtu at nearby delivery point. CP is the average price of Brent crude oil in \$/barrel for the previous year. CP was capped at \$60/mmbbl, with a floor of \$25/mmbbl. The selling price came to \$4.2/MMBtu in 2013-2014. This gas price was applied to all gas produced in APM gas fields awarded to NOCs (ONGC and OIL), NELP blocks, and in Pre-NELP blocks where PSCs provides for government approval of gas prices.

4. Pricing of imported LNG (MoPNG, 2014a)

   The price of imported LNG is not controlled by the government. They are market driven. The imported LNG can be divided into three categories. They are long term, medium term and short term and spot. The price of long term, medium term and short term LNG is based on the pricing formula accepted by the buyer and the seller. The price of spot LNG varies from cargo to cargo depending on the international demand-supply position. Long term imported contracted price of LNG costs around \$13/MMBtu in India in 2014 (Narayan, 2013). Figure 26 gives a comparison of the gas price of India with international gas prices.

Figure 26. India gas price versus international gas prices, 1997-2014



Source: A. Sen, *Gas Pricing Reform in India: Implications for the Indian Gas Landscape*, 2015, p. 15, Figure 3.

Gas price reform: The existing pricing policy required modification to provide an economic incentive for the projects, increase domestic gas production and reduce upstream project delays. Increased gas price improves the viability of marginal fields, and deep-water fields, however, affects sensitive industries like fertilisers and power sector. Therefore, pricing policy of India intended to support critical industries such as fertiliser and power sector, on which farmers and common population depend. The new domestic gas pricing policy was approved in 2014, and the following gas price formula (2) was adopted (Cabinet Committee on Economic Affairs, 2014):

$$P = \frac{V_{HH}\,P_{HH} + V_{AC}\,P_{AC} + V_{NBP}\,P_{NBP} + V_R\,P_R}{V_{HH} + V_{AC} + V_{NBP} + V_R} \qquad \text{- - - - (2)}$$

Where, V_{HH} =Total volume natural gas consumed in the US and Mexico; V_{AC} = Total volume natural gas consumed in Canada; V_{NBP} = Total volume natural gas consumed in EU and Former Soviet Union; V_R =Total volume natural gas consumed in Russia.
P_{HH} and P_{NBP} are annual average daily prices at Henry Hub and National Balancing point respectively, less transportation and treatment charges; P_{AC} and P_R are annual average daily prices at Alberta Hub and Russia respectively, less transportation and treatment charges.

The periodicity of price determination/notification is half yearly. The revised gas price, applies to gas produced from fields given to ONGC and OIL on nomination basis, NELP blocks, such Pre-NELP blocks where PSC provides for government approval of gas prices and coal bed methane blocks (Cabinet Committee on Economic Affairs India, 2014).

The government has increased the gas price from $4.20/MMBtu to $5.61/MMBtu in October 2014. This increase in gas price will boost gas production without having much impact on the fertilizer and power sector (Press Trust of India, 2014b). The final price of $5.18/MMBtu was set in March 2015, which is valid up to September 2015 (Press Trust of India, 2015).

3.4 Shale gas policy

The government expected that shale gas should be explored and produced on a fast track in the overall interest of energy security of the country. At the same time, the government wanted to implement regulatory policies to protect health and safety of the people, environment and carry out exploration and production activities by modern oilfield and petroleum industry practices. In October 2013, the government had issued "Policy Guidelines for Exploration and Exploitation of Shale Gas and Oil". Salient points are briefed below (MoPNG, 2013):

1. The government had granted permission for exploration, development and production of shale gas and oil to two NOCs namely ONGC and OIL. The government had given permission for the purpose of promoting shale gas and oil in existing on-land Petroleum Exploration Lease (hereinafter: PEL) or Petroleum Mining Lease (hereinafter: PML) areas under nomination acreages with those NOCs. The acreages of nomination blocks to be allotted to those NOCs in phases, as it may be difficult for them to take up exploration and production activities for all acreages simultaneously.

2. The income tax will be payable as per the applicable income tax provisions. However, there will be full exemption from basic customs duty and additional duty of customs for special goods required for these shale oil and gas activities allotted on nomination basis. All goods supplied against international competitive bidding for shale gas and oil activities are exempt from excise duties, subject to the condition that, such goods are exempt from basic customs duty and additional customs duty when imported to India.

3. Production, royalty, cess and taxes for shale oil and gas would be treated equivalent to the production of conventional oil and gas for all purposes of exploration license and mining lease.

4. The NOCs are required to adhere safe petroleum operations; sound health, safety and environment (hereinafter: HSE) practices; site restoration; and best industry practices. The NOCs shall handle all activities related to health, safety and environment (HSE) and site restoration. There will be audit by statutory authorities on the shale gas activities for compliance with all safety measures and industry standards. The requisite permissions and approvals are given at national/central level and state/regional level.

5. Groundwater is to be protected against contamination. Multiple casing programme with competent and reliable cementing (at least two casings) as per Good International Petroleum Industry Practices (hereinafter: GIPIP) are to be carried out. These casings shall be at a depth deeper by 100 m or as specified from time to time than the deepest fresh water aquifer. It is a mandatory requirement across all sub-surface fresh water aquifers identified by local bodies in all shale gas and oil wells, as well as effluent disposal wells.

6. The NOCs shall follow GIPIP of reputed international organisations such as American Petroleum Institute (API), Society of Petroleum Engineers (SPE) and International Organisation for Standardisation (ISO). The NOCs shall follow API guideline document HF3, January 2011, 'Practices for mitigating surface impacts associated with hydraulic fracturing'.

7. The company shall disclose the fracture fluid content, volume and chemical composition of both injection and flow-back fluids. Environmental impact analysis studies are required to be carried out through competent agencies.

8. The NOCs will take care of adequate availability of water for fracking. NOCs are required to take prior approval from Central Ground Water Authority (CGWA) and State Ground Water Authority (SWGA) and other regulatory institutions.

9. Approval from State Pollution Control Board (SPCB) is to be taken for proposed treatment and disposal of wastewater and ensuing required action. Continuous monitoring of flow-back water and disposal of wastewater is required. The use of various chemicals used must be transparent. The chemical composition of fracking fluid to be disclosed.

10. In the event any seismic activity occurs due to the fracking activity, the project will be reviewed by Directorate General of Hydrocarbons (DGH) in consultation with expert agencies.

11. Provision of Forest (Conservation) Act, 1980 will not be applicable as long as shale gas and oil exploration and production activities do not involve any clearing of forest or cutting of trees. Shale gas exploration and exploitation activities are not allowed in protected areas such as wildlife sanctuaries, national parks and other sample plots demarcated by the forest department. Prior permission from the central government is required for shale gas activities involving the clearing of forest areas, land inside within protected areas, land located within eco-sensitive zones around the boundaries of protected areas.

3.5 Exploration and development of shale gas so far

ONGC and OIL are carrying out pilot projects to assess shale gas potential in the country. In 2011, ONGC drilled its first R&D well, RNSG-1, north-west of Kolkata, in Damodar Valley up to a depth of 2000 meters, and discovered shale gas. As per the new shale gas Policy by the Government of India, ONGC and OIL were awarded 50 and five nomination blocks respectively for shale gas assessment within a three-year period in Phase-I. The identified blocks of ONGC in four basins are- 28 PMLs in Cambay, 3 PMLs in Assam & Assam-Arakan, 10 PMLs in Krishna-Godavari and 9 PMLs in Cauvery basins (ONGC, 2015).

ONGC planned to drill 57 pilot/assessment wells by April 2017. ONGC has taken up drilling of 14 wells for shale gas assessment in Cambay, Krishna Godavari (KG), Cauvery and Assam & Assam-Arakan Basins by the year 2014-15. Out of which drilling of eight wells were taken up during FY'15. ONGC drilled five exploratory wells in Cambay, Cauvery, KG and Upper Assam basin for shale gas potential assessment. Drilling is in progress for two more wells (JMSGA and GNSGA) in Cambay basin and one (WPGAA) in KG basin. In FY'16, ONGC has the plan to drill 19 wells including 11 exclusive shale gas wells and eight wells with dual objectives. Based on the data collected from wells JMSGA and GNSGA, two wells are planned to carry out drilling and hydraulic fracturing shortly. ONGC intended to carry out horizontal drilling, multi-stage hydraulic fracturing of many wells to establish the production potential and commercial viability of shale gas in different basins (ONGC, 2015).

OIL hired Schlumberger to carry out feasibility studies of shale gas potential in the Northeast region and Rajasthan (Arora et al., 2012).

On the other hand, RIL, GAIL, IOC, OIL and Adani Welspun Exploration Limited have invested in the US for shale gas (Watkins, 2011). In the 1st quarter 2015, RIL has produced more than 49 billion cubic feet equivalent of shale gas in the US with an investment of $8.5 billion in three joint ventures (Chatterjee, 2015). GAIL has signed an agreement with Cheniere Energy for the supply of 3.5 million tonnes per year of LNG (Watkins, 2011). The experience and familiarization of these companies with the US shale gas will help domestic exploration and production.

3.6 Shale gas economics

The shale gas industry is in the initial stage in India. Hence, the shale gas economics does not have a trend to analyse. Till the economies of scale are achieved, the drilling and hydraulic fracturing activities will be more expensive in India, comparative to the US.

In addition to economies of scale, the factors that affect cost of shale gas extraction are 1) complexity of the structure of shale, 2) environmental regulation, 3) availability of water resource, 4) technology and equipment availability, 5) availability of infrastructures such as roads and pipelines, and 6) progress in research and development. The performances of India on these factors are not bright. The shale structure is complex and has many faults. There is lack of water resource, technology and equipment, pipelines and roads. India is yet to institutionalise research and development on shale gas. Therefore, the cost of shale gas extraction is expected to be high at present in India.

Though the shale gas price in the US has reduced to around $3/MMBtu, this may not impact extraction cost of shale gas in India (Corbeau, 2010). The average production cost of shale gas in Europe is around twice that of the US. In China, drilling a horizontal shale gas well is expected to range from 6 to 11 million USD. The shale gas activity in India is still behind Europe, China and Argentina. It is anticipated that production cost in India will be similar to the production cost of Europe and China.

The natural gas price in India is $5.18/MMBtu for conventional natural gas. However, at this price, the shale gas project involving horizontal drilling and hydraulic fracturing may not be economically viable.

3.7 SWOT analysis of shale gas in India

There are many challenges and opportunities India will have in the process of exploration, development and production of shale gas. The concept of SWOT analysis is applied in finding out the strategic factors such as strengths, weaknesses, opportunities and threats of shale gas exploration and production activities in India.

3.7.1 Strengths

S1. India has a vast reserve of technically recoverable resources of shale gas. Further, there is a possibility that as shale gas activity progresses more shale gas reserves may be discovered. Schlumberger, the largest oilfield services company, has estimated shale gas resources of India between 300 to 2100 Tcf, which may be larger than China (MoPNG, 2015b).

S2. With the substantial reserve, there is a tremendous potential for exploration and production of shale gas in India.

S3. Gas is the most environment-friendly among the fossil fuels such as coal and oil. Hence, the emissions to the environment will be significantly less with the use of shale gas along with renewable energy sources.

S4. Shale gas can serve the country for a longer period. Shale gas can supply additional 45 years of natural gas to India considering the pessimistic reserve and present consumption rate.

S5. The government awarded acreage on nomination basis for exploration, development and production of shale gas to experienced National Oil Companies (NOCs), such as ONGC and OIL. They were awarded in existing on-land Petroleum Exploration Lease (PEL) or Petroleum Mining Lease (PML) areas. These companies regularly carry out directional drilling and hydraulic fracturing for vertical wells of conventional oil and natural gas. They have an advantage in upgrading the technologies for the exploration of shale gas.

S6. Oil and gas industry started in India in 1889 (Biswas, 2012). India has a sound history of oil and gas development. People are aware of oil and gas exploration and production activities. The drilling activities of shale gas will not be a surprise to them. Moratorium on shale gas exploration is unlikely.

S7. The USEIA had identified basins such as Cambay, Krishna-Godavari, Cauvery, Damodar Valley, Upper Assam and Rajasthan basins having shale gas. ONGC and OIL are familiar with these basins, as exploration and production of conventional oil and gas are in progress in these basins.

S8. Many Indian companies have considerable experience in shale gas exploration and production in North America. Indian companies GAIL, OIL, RIL and ESSAR, invested in shale in North America.

S9. India has vast technical manpower. The general population of India is young, and 65% are below 35 years of age.

S10. India has many ports. These ports will facilitate transportation of heavy equipment required for shale gas horizontal drilling and fracturing operations.

S11. Many big global service companies of oil and gas, such as Schlumberger, Halliburton, and Baker Hughes have been operating in India. Schlumberger is in collaboration with both of ONGC and OIL for different oil and gas activities including shale gas.

3.7.2 Weaknesses

W1. Lack of fund for investment. Thousands of wells are required to be drilled and hydraulically fractured for the development of shale gas basins in India. It is expected that the drilling cost of a shale gas well will be at least similar to drilling cost of China ($6 to $11 million). Drilling thousands of shale gas wells require an enormous amount of money. Therefore financing the shale gas activities will be a challenging task.

W2. India does not have indigenous technology on hydraulic fracturing, chemicals, and wastewater management that are needed for shale gas. Hydraulic fracturing technologies used in the US and other countries may require improvement based on conditions/geology, depth and thickness of shales in India. The composition of fracturing fluid, flow-back and produced water will depend on the geology of shale, and will affect water treatment and water management. India is yet to institutionalise innovation and research & development on fracturing technology, chemicals and water management. There is a requirement of the study of the science of shale fracturing.

W3. Lack of infrastructure/access roads and pipelines. As the sites for exploration will be new, there is less possibility of an approach road to the new sites. Lack of approach road will add to delay of the shale gas project. The pipeline density in India is 0.003 km/km^2, which is very small compared to the US (0.05 km/km^2), China (0.004 km/km^2) and Pakistan (0.01 km/km^2) (FICCI & Ernst & Young, 2011). Low pipeline density of India, will be a bottleneck for delivery and marketing of the shale gas from the drilled well sites.

W4. Lack of technology in water management and treatment. Water is scarce, and there is a shortage of water for usage for shale gas activities. Rajasthan basin is in the desert area. Further, water is depleting from surface water and aquifers. Drilling operation usually requires one million gallons and hydraulic fracturing operation requires 2 to 8 million gallons of water. When we desire more output, the requirement of water is much more.

The requirement of water will be huge to explore thousands of wells for shale gas production. During drilling activities, the volume of flow-back water and produced water is also large to handle. Availability of underground injection wells for disposal of wastewater is also a concern.

W5. The population density in India is 383 persons per km^2 (as per 2011 census). It is high compared to the US, Europe and China. Any adverse actions like shortage of water, water pollution, seismic events, and so on, will have a multiplying effect in India due to high population density. Moreover, there is a lack of awareness of public on environmental issues.

W6. Shale gas projects require longer lead-time than conventional oil and gas drilling activity due to the complicated activities.

3.7.3 Opportunities

O1. There is a tremendous potential for the domestic natural gas market, as there is a huge gap between demand and domestic supply. To meet the demand, India is importing LNG at approximately three times the domestic price of natural gas. Natural gas is crucial for fertilizer sector, power generation, domestic use and feedstock for chemical industries.

O2. It is evident from the shale gas policy that, the government supports the production of shale gas. In the shale gas policy, customs duty and excise tax are exempted on imported equipment of shale gas activities. At present India has a stable and strong government. The government support is likely to increase with an increase in production.

O3. The exploration and production of shale gas started around 80 years back in the US. Since then, there were a lot of research and development and innovations in the technology to explore and produce shale gas. The experience of the US, Canada and China is an added advantage for countries like India to progress in shale gas.

O4. India has strong NOCs to invest and explore in shale gas. The government has selected two NOCs (ONGC and OIL) to initiate activities for shale gas. The financial positions of these companies are very sound. ONGC is ranked as the Top Energy Company in India, 5th in Asia and 21st worldwide in Platts Top 250 Global Energy Rankings. ONGC is the only Indian energy company in Fortune's Most Admired List 2014 under 'Mining, Crude Oil Production' category (7th worldwide) (ONGC, 2015). OIL is the second largest oil and gas upstream public sector company in India.

O5. International cooperation. To promote international cooperation, ONGC is operating with foreign companies such as ConocoPhillips and Schlumberger for shale gas exploration and development activities.

O6. Production of shale gas will reduce the gap between energy demand and domestic supply. Thus, India will import less LNG and oil and reduce energy import bill. More natural gas will benefit industries, manufacturers, consumers and workers and will help Indian economy to grow. There will be more jobs, both direct and indirect.

O7. As India starts producing shale gas and gains expertise, the NOCs and other private companies can expand globally, invest in other countries and receive gas for the country.

O8. Availability of more natural gas can reduce utilization of coal and oil for power generation. The increase in gas-based power generation will make the environment cleaner, more efficient and livable.

O9. Renewable energy supplies from solar, water and the wind are the cleanest forms of energy. However, the development of the renewable form of energy is yet to pick up. Shale gas can bridge the gap between conventional non-renewable and renewable energy supply.

O10. Along with shale gas exploration and production, many supporting ancillary industries are expected to emerge and grow. The development of ancillary industries will help economic growth.

3.7.4 Threats

T1. At present, the reserves are yet to produce shale gas in India. The reserve of shale gas estimated by the USEIA is not certain. The reserve can be confirmed by carrying out proper tests in the shale gas basins. Additionally, shale gas reserve connected to drilled well may deplete faster because of low porosity of shale rock.

T2. Shale gas industry in India is in the initial stage. The shale gas policy approved by the government is a preliminary one. As per the policy, private companies cannot participate now in shale gas exploration and production. There is no tax exemption on shale gas produced. The permission procedures for the acquisition of land and forest area are lengthy.

T3. Gas pricing mechanism is not lucrative for shale gas projects. There may be changes in gas prices due to global demand-supply, change in government, and geopolitical developments in South Asia, Mid-east and other regions.

T4. The invention and innovation of technologies in the field of renewable energy may reduce the demand for exploration of fossil fuels like shale gas.

T5. Environmental risk, seismic risk and health safety and environment (HSE) impacts. Hydraulic fracturing may create water pollution of surface water and aquifers. Surface water can be polluted due to improper handling of chemicals, wrong storage of flow-back water and produced water, storm water run over the drill site and release of untreated water. The drilling and production activities may create air pollution due to fugitive emission and release of greenhouse gases. The NOCs are required to carry out an environmental impact assessment for the exploration and production activities of shale gas and comply with the recommendations. Shale gas activities are not allowed in forest reserve areas/sanctuaries/identified areas. Frequent drought, floods and cyclones are observed in the basin regions.

T6. The shale gas geology of India is complex. There is limited geological information. The basins like Upper Assam, Cambay and Cauvery, fall in seismically active zones.

T7. The government is the owner of minerals in India, and the land owner does not have any right to the minerals. As the landowner does not get any incentive, there may be protests and subsequently delay in construction/installation of roads, drill pads and pipelines due to land issues.

The above strengths, weaknesses, opportunities and weaknesses are summarised in the following Table 13.

Table 13. SWOT matrix

Strengths	Weaknesses
S1. Huge reserve of shale gas S2. Huge potential for exploration and production of shale gas S3. Gas is most environment-friendly among the fossil fuels S4. Shale gas can serve country for many years S5. NOCs will lead exploration and production of shale gas S6. India has sound history of oil and gas industry S7. NOCs are familiar with shale gas basins S8. Indian companies have significant shale gas experience in the US S9. Huge technical and young manpower S10. Many ports for transportation S11. Many big global service companies operating in India	W1. Lack of fund for investment W2. Lack of indigenous technology W3. Lack of infrastructure/access roads and pipelines W4. Lack of technology on water management and treatment W5. High population density W6. Shale gas projects require longer lead time
Opportunities	**Threats**
O1. The demand-supply gap natural gas is large O2. Government supports production of shale gas O3. Experience of the US, Canada and China is an advantage O4. India has strong NOCs to invest O5. Cooperation with international companies O6. Production will reduce demand-supply gap of natural gas O7. India can invest in other countries O8. Reduce utilization of coal and oil O9. Bridge the gap between conventional non-renewable and renewable energy O10. Many supporting ancillary industries are expected to emerge and grow	T1. Reserve of shale gas estimated by the US EIA is not certain T2. Shale gas industry and policy is at initial stage T3. Gas pricing mechanism is not lucrative T4. Invention of renewable energy technologies may reduce the demand T5. Environmental risk, seismic risk and HSE issues T6. The shale gas geology of India is complex T7. Owners of private land cannot claim the property rights

3.8 Strategy formulation of shale gas industry in India

Strategy formulation is the development of long-range plans for effective management of opportunities and threats, in the light of strengths and weaknesses. SWOT is employed to generate some alternative strategies. The concept of TWOS (threat, weakness, opportunity and strength) matrix (Table 14) is utilized to illustrate how opportunities and threat can be matched to strengths and weaknesses to obtain an outcome of four sets of possible alternative strategies (Wheelen & Hunger, 2012). The strategies developed are described in the subsequent paragraphs.

Table 14. TOWS strategy matrix for shale gas in India

	Strengths	Weaknesses
Opportunities	**S-O Strategy** 1. Shale gas can be identified as special category of energy 2. Encourage NOCs for aggressive shale activity 3. Set target of shale gas production with NOCs 4. Encourage to find more shale gas reserves 5. Intensive education and training 6. Utilisation of young technical manpower 7. Encourage NOCs to start activities in other countries	**W-O Strategy** 1. Prioritise construction of pipelines and roads 2. Reinforce the investment 3. Consider tax exemption for initial fixed number 4. Encourage collaboration of NOCs with foreign companies 5. Priority and importance to be given to HSE 6. Display details of the chemicals 7. Import technological equipment and materials 8. Water management plan 9. Contingency plans for natural calamities 10. Innovation, R&D on hydraulic fracturing, chemicals, water management for Indian condition
Threats	**S-T Strategy** 1. Shale gas reserve shall be verified and confirmed 2. Revise and strengthen the shale gas policy 3. Pricing strategy of shale gas to be different from conventional natural gas pricing 4. Modification of land acquisition act 5. Formulate rules and regulations for water, air, noise and land pollution	**W-T Strategy** 1. Maintain public confidence 2. R&D to substitute of water for hydraulic fracturing 3. Carefully select the location of drilling activity 4. Select location considering tectonic faults 5. Prevent gas leaks underground to aquifers 6. Efficient use of water resource 7. Avoid surface water pollution, air pollution 8. Invite more companies to attract more investment 9. NOCs to increase R&D activities

3.8.1 Strength-Opportunity strategy

Strength-opportunity strategy (S-O strategy) is the strategy based on the strength of the industry taking advantages over the opportunities. Table 14 indicates the list of S-O strategies when the existing strengths can be exploited in the areas of opportunities. These strategies are briefly described below.

1. Shale gas can be identified as a special category of energy. The government can consider developing shale gas as an important national energy strategy of energy consumption.
2. Encourage NOCs for aggressive shale gas exploration and production in the shale gas basins.
3. The setting of a production target of shale gas production with NOCs in Tcf/per year for the year 2020/2025/2030.
4. Encourage the NOCs to find more shale gas reserves. At present the companies like ONGC, OIL are adding reserve of conventional natural gas every year. Similarly, there shall be an effort to find and add reserve of shale gas.
5. There should be intensive education and training in shale gas exploration and production technologies. Education and training are essential to strengthen the foundation for shale gas development.
6. The huge and young available technical manpower can be utilised for shale gas exploration and production.
7. The NOCs can be encouraged to start exploration and development activities in shale gas rich countries other than North America.

3.8.2 Weakness-Opportunity strategy

Weakness-opportunity strategy (W-O strategy) is based on the advantages of opportunities overcoming the weaknesses of the industry. Table 14 indicates the list of W-O strategies when the advantage of opportunities is used to make new strengths. These strategies are briefly described below.

1. Prioritise construction of infrastructure like pipelines and roads for the faster realization of shale gas. Pipelines network requires an extension to reach into unconventional production areas. The construction of infrastructure will benefit other industries, increase the number of job creation and improve the economy.
2. Reinforce the investment required for shale gas exploration, development and production. Attract funds from various sources, as there is a requirement of massive investment in shale gas activities.
3. Consider tax exemption for initial fixed number of (say five) years of production of shale gas to attract more investors. It will encourage the increase of output of shale gas.
4. Promote collaboration of NOCs with foreign companies. The foreign companies can provide access, learning and absorption of hydraulic fracturing technology and chemicals used. In addition, there will be opportunities for investment by the foreign companies in India.
5. Priority and importance to be given to health, safety and environment (HSE) so that public confidence is maintained. There should be a stringent audit on HSE aspect and an emergency contingency plan for HSE.
6. Details of the chemicals should be displayed along with their effects and emergency contingency plan. The chemicals should be protected against spillage and mixing.
7. Encourage importing technological equipment and materials for hydraulic fracturing, chemicals and wastewater management. At the same time, the technology and knowledge should be absorbed and modified as per the Indian shale conditions.
8. Devise water management plan for usage, treatment and recycling. This will reduce the use of water. The use of excess water during peak water seasons can be considered.
9. Contingency plan for natural calamities like drought, flood, cyclone, etc. should be ready.

10. There should be planning and investment to institutionalise innovation, research and development on hydraulic fracturing, chemicals and water management. R&D for environment-friendly and hazard free chemicals will resolve many issues of water management.

3.8.3 Strength-Threat strategy

Strength-threat strategy (S-T strategy) is based on the strength of the industry taking care of the threats perceived. Table 14 indicates the list of S-T strategies when existing strengths are utilised to overcome the threats. These strategies are briefly described below.

1. The shale gas reserve in the four basins, viz. Cambay, Krishna-Godavari, Cauvery and Damodar Valley basins should be verified and confirmed with the help of expertise of the NOCs and external expert agencies. The other basins such as Upper Assam, Vindhyan, Pranhita-Godavari, Rajasthan and South Rewa should also be studied and reserves verified.
2. The shale gas policy of India should be revised and strengthened. It is to be ensured that, the policy is more implementable and favourable for the development of shale gas. Shale gas exploration and extraction is complex, and India is in the initial stage of exploration. The policy may be revised to have relaxed financial terms, or more pragmatic land acquisition policy so that shale gas exploration can be economically viable. The government may pay particular priority for shale gas in the legal, technological and commercial fronts.
3. Different pricing strategy for shale gas. To attract more investment and technology, gas prices may be initially set at a higher rate than the government set natural gas price for a certain period, say for five years. The government may allow market-based pricing or allow higher end-user prices for shale gas instead of current controlled prices of conventional natural gas. The objective is to extract shale gas with an economically viable project.
4. The land acquisition acts require modification while considering recovery of mineral resources and interest of farmers, ecological and environmental effects. The permission procedures need to be simplified.
5. The rules and regulations for water, air, noise and land pollution due to hydraulic fracturing should be formulated and implemented in a stringent manner. Drilling of multiple wells from the same site should be encouraged to minimize the footprint of operations.

3.8.4 Weakness-Threat strategy

Weakness-threat strategy (W-T strategy) is based on the effort to overcome the threats as well as taking care of the weaknesses of the industry. Table 14 indicates the list of W-T strategies when the effort is made to create new strengths to defend threats. These strategies are briefly described below.

1. There should be an effort to maintain public confidence. Educate, disclose and involve the local public in the shale gas activities.
2. Research and development should be conducted to find the substitute of water for hydraulic fracturing.
3. Carefully choose the location of drilling activity considering agricultural area and locality. Optimum area should be selected for drill pad and for drilling activities.

4. Select location considering tectonic faults and monitor the activities in the high-risk areas. In the event of seismic activity due to shale gas activity, the immediate action plan should be ready.
5. Prevent gas leaks underground to aquifers; eliminate gas leak, emission of greenhouse gases to atmosphere and gas flaring. Carefully designed hydraulic fracturing supported by micro-seismic monitoring activities will control fissures and stop groundwater contamination. Correct cementing of annulus spaces is also important to prevent ground water contamination.
6. Water resource should be used efficiently.
7. Detailed work procedure is required to avoid surface water pollution, air pollution, and their corrective action. Avoiding surface water pollution requires proper transportation, storage and handling of chemicals, storage and disposal of flow-back fluid and produced water.
8. Opening the shale gas to more companies will attract more investment. Prepare a procedure to allocate acreage for future shale gas exploration and production to NOCs as well as private enterprises, which are socially and environmentally responsible.
9. Encourage domestic companies to continue with research and development on shale gas exploration and production activities.

CONCLUSION

India faces a huge gap between the demand and supply of natural gas and hence relies on the heavy import of natural gas. To reduce the demand-supply gap, there needs to be a surge in domestic production. As there is a substantial quantity of shale gas reserve available, domestic shale gas production can help India meet its natural gas demand and reduce import bills of natural gas. Development of this sector will contribute to more economic activity such as rise in investments, more employment, and expansion of downstream sectors/industries all leading to increased GDP growth.

Shale gas industry is more complex than conventional oil and gas exploration and production. Capital investments and cost of shale gas production is very high. As shale gas industry in India is in the preliminary stage, and domestic technologies are not available, the production of shale gas is bound to be more expensive initially. Hence, the success of shale gas in India will depend primarily on the gas pricing policy and availability of technology. The gas pricing and shale gas policy needs modification so that shale gas exploration, development and production projects in India become more economically viable. In addition to gas pricing and shale gas policy, the success of shale gas will also depend on the availability of fracturing technology; use of chemicals suitable for the geology of shale gas basins of India; and wastewater management plan. The Indian geology and the environment are different from the US. Additionally different shale gas basins have varied geological conditions making it more complicated. Hence, the hydraulic fracture technology and usage of chemicals needs to be suitably adapted to Indian geological and environmental condition. Innovation, research and development need much more emphasis on the success of shale gas industry. Collaboration with foreign counterparts will help to understand and improve technology and adapt it to Indian conditions. Education and training on shale gas will also strengthen the foundation of shale gas development. The domestic oil companies need encouragement to initiate more research and development activities in this area.

Shale gas exploration and production are a capital-intensive business. The NOCs (ONGC and OIL) presently involved in shale gas activities are financially sound. However, substantial investment is required for horizontal drilling and fracturing of thousands of shale gas wells, so that the production of shale gas becomes economically viable. Government support and collaboration with foreign companies can generate investment capital for this activity.

Water resource management plays a critical role, as water is scarce in India. Further as there are environmental impacts of shale gas production especially in a populated country like India, shale gas industry should progress in such a way that adverse effects are minimum. With adequate safeguards in place, shale gas should be exploited responsively to protect both environment and human health. In this journey of the success of shale gas, the society and public at large should be of paramount importance along with other stakeholders including the government and the National Oil Companies. The environmental issues and the adverse impact if any on society should be handled carefully for the long-term success of exploration and production of shale gas in India.

The analysis and strategies formulated in this Master Thesis research paper intend to give guidelines that can take the industry towards exploitation of known reserve of shale gas and also open up new shale gas reserves for further exploitation. The domestic production and supply of shale gas will support other forms of energy supply such as non-renewable and renewable types of energy to meet the energy demand of the country. Thus, shale gas can make India more self-reliant in terms of energy needs and save huge import bill at the same time being environment-friendly.

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