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GENERIC ENVIRONMENTAL IMPLICATIONS OF SHALE GAS PRODUCTION

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CERTIFICATION OF APPROVAL

GENERIC ENVIRONMENTAL IMPLICATIONS OF SHALE GAS PRODUCTION

BY:

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Approved by,

____
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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SAIDAH NAFISAH KHALID

ABSTRACT

Shale gas has been one of the sources of natural gas, in small but continuous volumes since the earliest years of development. Nowadays, modern shale gas development has become a technological play, in which the development is facilitated by the technological advances in the oil and gas industry has made in hydraulic fracturing and horizontal drilling over the last two decades. However, the risks remain since shale gas development around the world has met with fierce opposition from local residents and environmental groups due to environmental concerns over the hydraulic fracturing process. If mismanaged, hydraulic fracturing fluid which may contain potentially hazardous chemicals can be released by spills, leaks, faulty well construction, or other exposure pathways. The purpose of this paper is to identify the generic environmental implications of the shale gas extraction and the types of mitigation techniques exist for such cases in the countries with technically recoverable shale gas resources in the world by studying the related articles, book and previous journals. In conducting this project, a few research methodologies such as case study, analysis and evaluation are identified to be carried out to ensure this project to be successfully completed in achieving its objectives.

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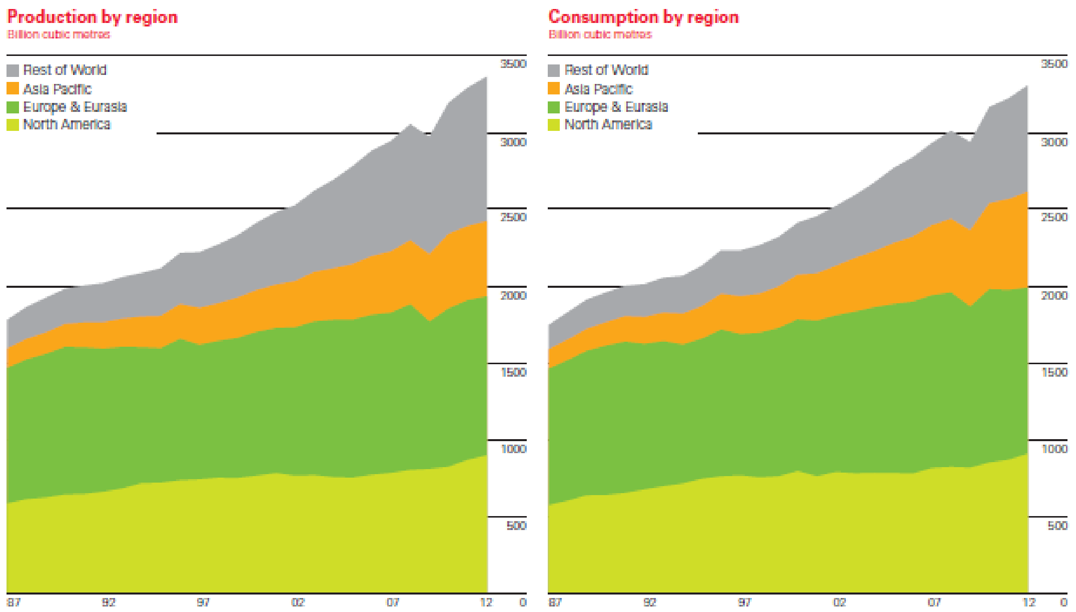
CHAPTER 1

INTRODUCTION

1.1 Background of Study

Natural gas is one of the world highest demands of energy resources. Recent study in 2013 has shown that the world natural gas consumption grew by 2.2%, below the historical average of 2.7%. Consumption growth was above average in South & Central America, Africa, and North America, where the US recorded the largest increment in the world. In Asia, China, Australia and Japan were responsible for the next-largest growth increments. Globally, natural gas accounted for 23.9% of primary energy consumption. Global natural gas production grew by 1.9%. The US once again recorded the largest volumetric increase and remained the world's largest producer. Qatar and Saudi Arabia also saw significant production increases, while had the world's largest decline in volumetric terms. Figure 1 shows the trend of production and consumption of world natural gas by region [1].



World natural gas production increased by 1.9% in 2012. The US once again recorded the largest national increase. Production grew in every region except Europe & Eurasia, where declines in Russia and the UK offset a gain in Norway. Natural gas consumption increased by a below-average 2.2%. As was the case with production, the US recorded the largest national increase and consumption rose in every region except Europe & Eurasia; EU consumption fell to the lowest level since 2000.

Figure 1: World production and consumption of natural gas

Natural gas that is economical to extract and easily accessible is considered conventional. Conventional gas is trapped in permeable material beneath impermeable rock. Natural gas found in other geological settings is not always so easy or practical to extract is called unconventional. New technologies and processes are always being developed to make this unconventional gas more accessible and economically viable. Essentially, there are six main categories of unconventional natural gas. These are: deep gas, tight gas, gas-containing shales, coalbed methane, geopressurized zones, and Arctic and sub-sea hydrates. Figure 2 shows the schematic geology of natural gas resources [2].

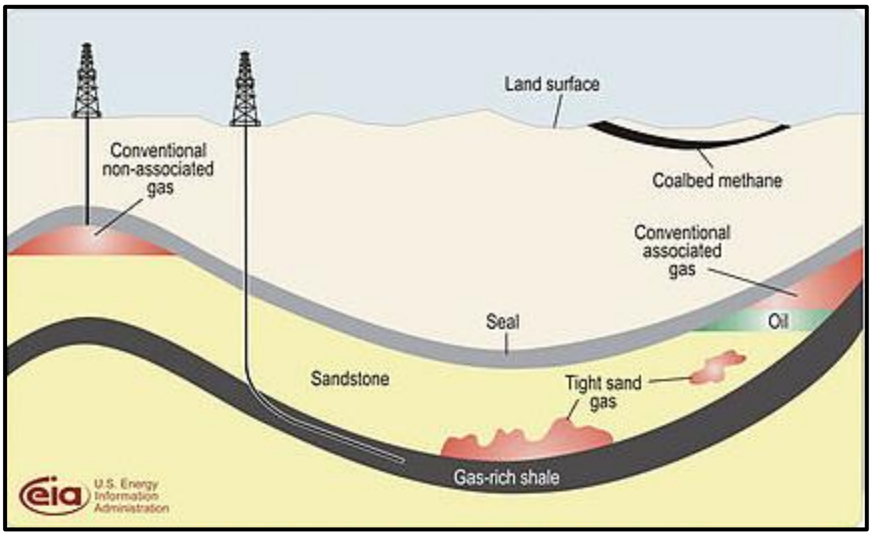


Figure 2: An illustration of shale gas compared to other types of gas deposits.

Natural gas from tight and shale gas reservoirs is becoming increasingly important in worldwide as all countries shift from coal-based energy to cleaner energy sources. Commercial production from shale gas reservoirs in Malaysia is yet to begin, but is expected to grow rapidly in the future. This paper will present briefly the shale gas production and its generic implications to the environment. The discussion in this paper includes the potential environmental issues that have been identified in shale gas plays in an un-mitigated nature.

1.2 Problem Statement

Development of shale gas resources requires an understanding of the environmental considerations associated with the drilling and production process. Many of the environmental considerations associated with the shale gas development are common to oil and gas activity (Arthur J et. al, 2010) [3].

There are some potential environmental concerns associated with the production of shale gas. The fracturing of wells requires large amounts of water. In some areas of the country, significant use of water for shale gas production may affect the availability of water for other uses and can affect aquatic habitats.

Another challenge of shale gas production is if mismanaged, hydraulic fracturing fluid which may contain potentially hazardous chemicals can be released by spills, leaks, faulty well construction, or other exposure pathways. Any such releases can contaminate surrounding areas.

Fracturing also produces large amounts of wastewater, which may contain dissolved chemicals and other contaminants that could require treatment before disposal or reuse. Because of the quantities of water used and the complexities inherent in treating some of the wastewater components, treatment and disposal are an important and challenging issue.

1.3 Aim and Objectives

The aims and objectives of this project are:

a) To identify the countries with technically recoverable shale gas resources in the world.
b) To study the techniques used to hydraulically fracture the wells completed in shale gas reservoir.
c) To evaluate the environmental implications of hydraulic fracturing in shale gas reservoirs.
d) To develop environmental case studies from shale gas consumers in order to be implemented at the potential shale basin in Sabah, Malaysia.

1.4 Scope of Study

The main focus of this project will be on generic environmental effects of shale gas production. By studying the extraction of shale gas, the leaking of extraction chemicals and waste into water supplies, the leaking of greenhouse gasses during extraction, and the pollution caused by the improper processing of natural gas are identified. The detail scope of study is as followed:

a) To study on the books, previous journals and related articles.
b) To identify the potential shale gas reservoir or formation in Malaysia.
c) To evaluate the efficiency of the hydraulic fracturing to extract the shale gas from the subsurface.
d) To analyse the general environmental effects of shale gas to the countries with technically recoverable shale gas resources.
e) To prepare the database of the environmental impacts.

CHAPTER 2

LITERATURE REVIEW

2.1 Shale Gas Resources and Reserves

Shale gas, sometimes together with shale oil, occurs in very fine-grained low permeability organic-rich sediments, such as shales mudstones and silty mudstones, usually in deeper parts of basins. Gas was formed when the organic matter within shales was subjected to high temperatures and pressures, but unlike in conventional deposits, the gas or oil remained within the impermeable shale. In other words the shale is both the source rock and the reservoir rock. In terms of its chemical composition, shale gas is typically dry gas composed primarily of methane (90% or more methane) [3]. The important geological, geochemical and geotechnical criteria that are widely used to define a successful shale gas play are shown in *Appendix 1.*

Shale reservoirs are typically characterized by extremely low permeabilities and this necessitates the use of hydraulic fracturing treatments and horizontal well completions to contact larger volumes of the reservoir and to allow the gas, or oil, to flow from the rock. The creation of hydraulic fractures is accomplished by injecting high pressure fracturing fluids into the well and through selected perforations into the formation. For shale wells, these fluids, known as slickwater, are predominantly fresh water treated with viscosity reducers and characterized by low proppant concentrations (Yinan, 2013) [4].

Shales have been the sources of natural gas in small but continuous volumes since the earliest years of development. Nowadays, modern shale gas development has become a technological play, in which the development is facilitated by the technological advances the oil and gas industry has made in hydraulic fracturing and horizontal drilling over the last two decades (Daniel J, et al, 2009). Figure 3 shows the map of basin with assessed shale oil and shale gas formation, as of May 2013 [5].

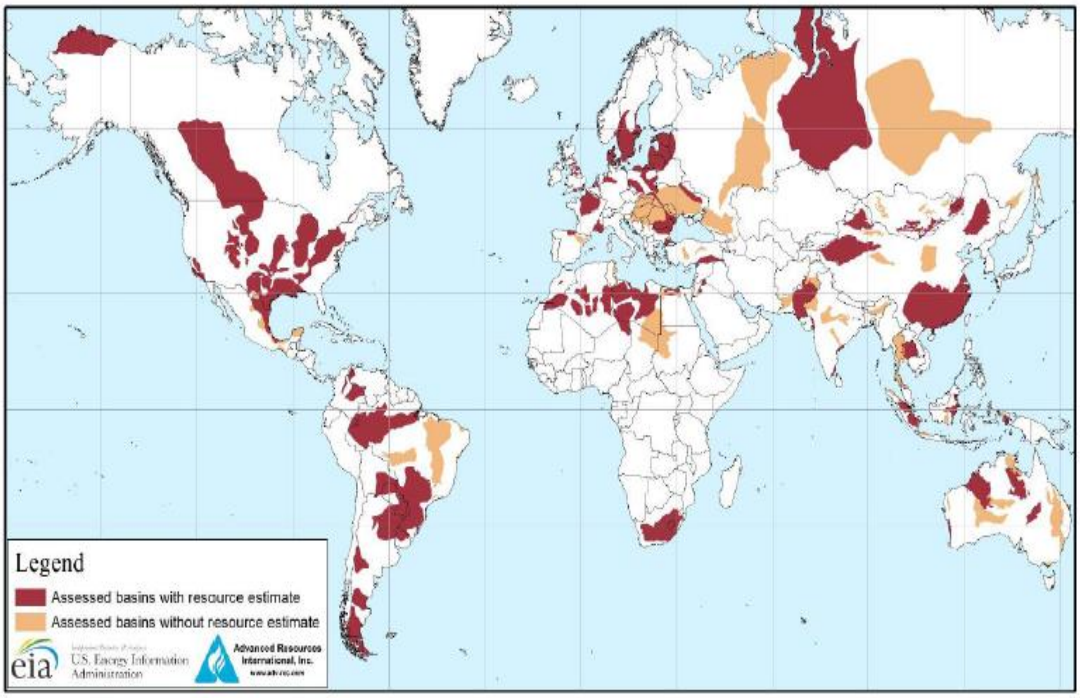


Figure 3: Map of basin with assessed shale oil and shale gas formation, as of May 2013

The development of the shale gas industry in the United States over the past decade has had a major impact on the energy market in that country and on its economy. The Asia Pacific countries like Australia, Indonesia, China, and Thailand have had some early success, and work together on tight gas. Thus, more exploration activities are expected over the next 1-2 years.

The distribution of potential shale gas plays covers the globe (Figure 4) [28], but it is only within North America that large-scale commercial extraction has been achieved to date. In the USA, ten shale gas plays hold the vast majority of the country's technically recoverable reserves, and these are the only shale gas plays currently being exploited (Jarvie 2012) [29].

Figure 4: Estimates of technically recoverable shale gas resources for selected shale formations in 32 countries (Bickle et al. 2012) [30].

In Malaysia, the shale gas has not been produced yet but is expected to grow rapidly in the future after the discovery of the shale formation in Sabah; Eucalyptus Campsite area, Maliau Basin, Sabah.

2.2 Hydrocarbon Generation Potential of the Shales around the Maliau Basin, Sabah

Maliau shales were deposited in a complex series of tectonically active basins across south central region of Sabah, during the adjacent area of Kapilit Formation (Early to Middle Miocene) (Figure 5). This basin is in fact a sedimentary formation comprised mainly of gently inclined beds of sandstone and mudstone. Contemporary basins relatively gentle slopes characterize the inner basin with general inclinations ranging from 15 degrees along the outer rim to almost flat at the center of the basin.

The marine shales attain thicknesses of up to 5495.41 ft (1,675 m) at Gunung Lotung and they contain sufficient organic matter to generate considerable amounts of hydrocarbons. Conventional oil and gas fields around this basin attest to their capability to produce hydrocarbons.

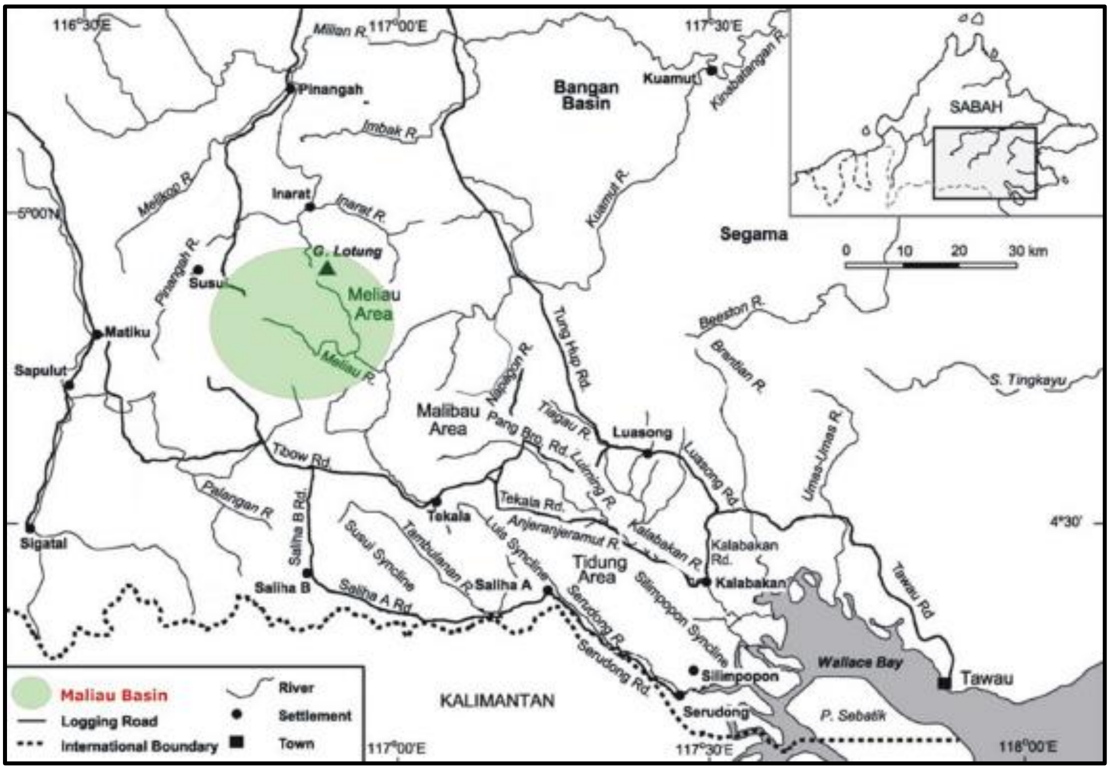


Figure 5: Location map of Maliau Basin

The maturity of the Maliau shales is a function of burial depth, heat flow and time, but subsequent uplift complicates this analysis. Where they have been buried to sufficient depth for the organic material to generate gas, the Maliau shales have the potential to form a shale gas resource analogous to the producing shale gas provinces of south central region of Sabah. Where the shales have been less-deeply buried, there is potential for a shale oil resource.

The shales are considered to be in the early to main stage of oil generation (vitrinite reflectance between 0.57% and 0.80%) at depths about 984.252 ft (300 m). The total volume of potentially productive shale in south central region of Sabah was estimated using organic petrological and organic geochemical methods to determine their hydrocarbon generating potential, maturity and depositional environment.

The volume of potentially productive shale was used as one of the input parameters for a screening analysis (Rock-Eval and TOC), petrographic (maceral distribution and VRo measurement) and biomarker analyses (GC and GCMS) in order to characterize the shales in term of organic richness, organic matter composition, thermal maturity and depositional environment. (Zulkifli Salleh, et al, 2008). [6]

Many central Kapilit Formation outcrop, core and cuttings samples of Maliau shales have undergone geochemical analysis, mainly when studying source rocks in conventional petroleum systems. Relatively little analysis has specifically targeted its shale gas plays. Data from Kapilit Formation well and outcrop locations (6 samples) were available.

2.2.1 Organic Carbon Content

There are only limited published data on organic carbon contents in the Maliau basin. This published data suggest that Maliau shales possess good to very good organic carbon richness as shown by TOC values (1.04wt% to 16.38 wt%), except for one sample which has poor organic carbon richness (0.44 wt%).

The shales also possess good to very good hydrocarbon generating potential values ranging from 5.03 to 37.27 mg HC/g rock, except for two samples which have poor hydrocarbon generating potential (<2.5 mg HC/g rock).

The observed range of TOC values in the Maliau Basin unit (1.04wt% to 16.38 wt%), is tabulated in the Table 1.

Table 1: Total organic carbon contents (TOC) for the Maliau Basin

Sample No	Formation	HI (mg/g)	TOC (wt.%)	S1 (mg/g)	S2 (mg/g)	Tmax (°C)
S1B	Kapilit	135	3.73	0.05	5.03	443
S4	Kapilit	95	0.44	0.01	0.42	447
S9	Kapilit	92	1.04	0.05	0.96	439
S13	Kapilit	161	5.74	1.21	9.24	425
S25	Kapilit	228	16.38	0.62	37.27	438
S26	Kapilit	143	12.95	0.16	18.57	441

2.2.2 Kerogen Type

Four basic categories of kerogen are recognised in organic matter (Tissot et al. 1974). Type I and II kerogens have the potential to generate both oil and gas. Type III kerogens mainly generate gas, with only a small amount of oil, while Type IV kerogens have little or no remaining potential to generate hydrocarbons.

The type of kerogen present is also an indication of the environment in which the interval was deposited. Algae seen in Type I samples indicate a lacustrine (or marine environment), whereas Type II is deposited exclusively in marine conditions and contains plant spores, exines, resins and bacterially degraded algal matter. During initial maturation, Type II source rocks generate mainly oil and only a limited amount of gas. As maturation proceeds through higher temperatures, secondary cracking in these source rocks cracks the generated oil into gas. Type III organic material is comprised of vitrinite and is typically woody material found in continental rocks deposited in rivers and deltas, but it can also be found in marine environments where it is washed in from a nearby shelf. Type IV contains inertinite, where oxidation of woody material has occurred, either before it is deposited or in situ.

Table 2: Organic matter typing data

Sample No	Type of Organic Matter (%)		
	Inertinite	Vitrinite	Liptinite
S1B	20	50	5
S4	30	60	10
S9	25	40	5
S13	20	40	15
S25	25	50	5
S26	35	50	5

In the shale samples, vitrinite and inertinite are the dominant macerals and constitute more than 70% of the total kerogen (Table 2). Zulkifli et al. (2008) reported Type III kerogen in the Maliau Basin and the sandstone dominated unit consists of thick sandstone bed, interbedded with thin mudstone on the Kapilit Formation. However, little additional data are available to establish the original composition of the kerogen in the Maliau Basin. Therefore, the identification of kerogen type using hydrogen index (HI) aimed to indicate their ability to generate liquid hydrocarbons present in the sample. HI for the shale samples are generally low (<200), except for one sample (S25) which gives HI of 228. Therefore, the HI values suggest that the shales contain mainly Type III organic matter which is capable of generating mainly gaseous hydrocarbons. A significant number of samples plot in the Type III field (Figure 6) which is in coastal plain or deltaic setting under oxic condition depositional environment of the Maliau unit. The plot of HI versus Tmax (Figure 7) shows that most of the shales plot below the Type III curve.

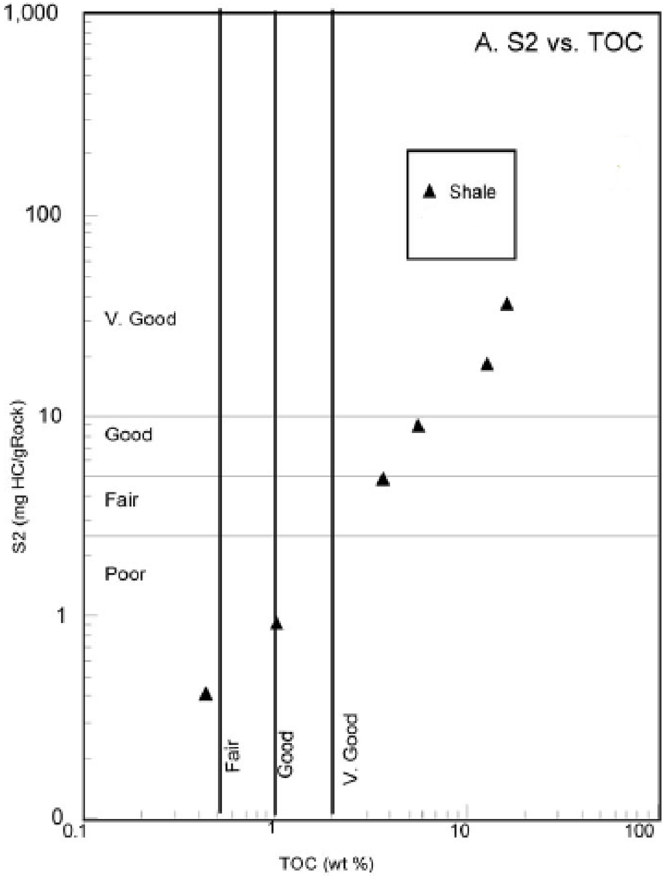


Figure 6: Hydrocarbon potential (S2) versus TOC plot for the Maliau Basin

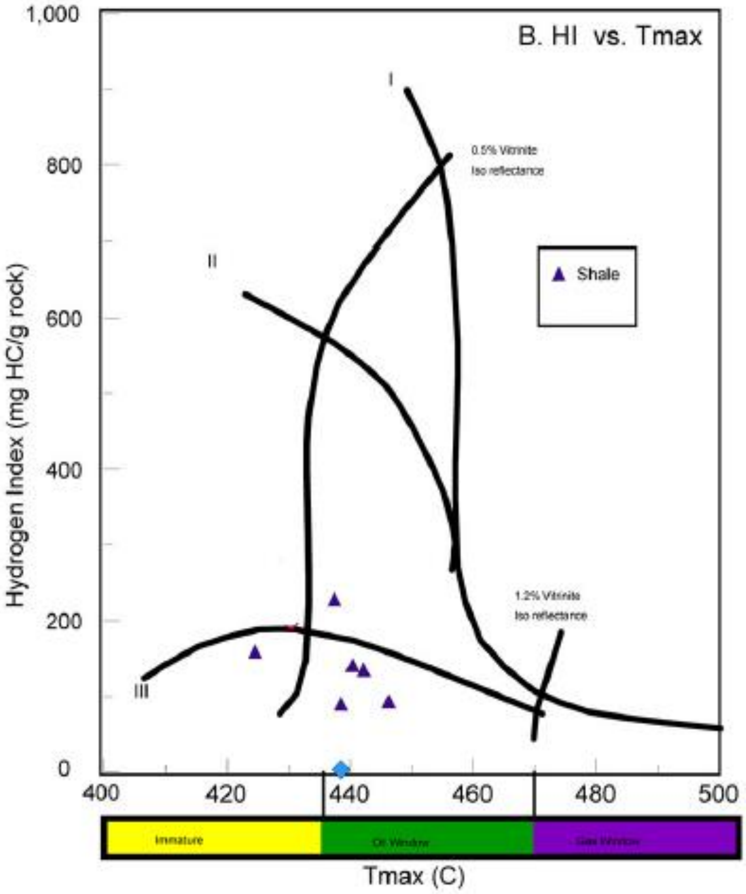


Figure 7: Hydrogen Index versus Tmax plot for all available data

The thermal generation of oil and gas from organic material generally takes place at temperatures between 50°C and 225°C. At lower temperatures, the organic material is immature and no oil or gas will be thermally generated from the source rock; at much higher temperatures, the organic material is overmature and all possible oil and gas will have been generated. For Maliau Basin, Tmax values (Figure 7) ranging from 425^{o}C to 447^{o}C considered as overmature suggesting that the samples in the early to main stage of oil generation. The timing of generation is dependent on the kerogen type and the exact composition of the organic material.

Vitrinite reflectance (Ro) and measurements of the temperature of maximum release of S2 hydrocarbons (Tmax) at outcrop and in boreholes provide a widely accepted proxy for thermal maturity and extent of hydrocarbon generation. The vitrinite reflectance data of the investigated samples was given from Rock Eval pyrolysis. Thermal Alteration Index (TAI) and various biomarker maturity ratios are also available to complement the vitrinite reflectance data. The Ro values for most of the samples range from 0.57% to 0.70%, indicating that the samples are in the early stage of oil generation, except for two shale samples (S1B and S26) which give higher Ro values (0.76% and 0.80%, respectively) suggesting that the samples are already in the main stage of oil generation.

2.3 Shale Gas Extraction Methods

Hydraulic fracturing is a formation stimulation practice used to create additional permeability in a producing formation. By creating additional permeability, hydraulic fracturing facilitates the migration of fluids to the wellbore for purposes of production. Hydraulic fracturing can be used to overcome barriers to the flow of fluids, one of the primary reasons development of gas shales has traditionally been limited. Barriers may include naturally low permeability common in shale formations or reduced permeability resulting from near wellbore permeability impairment caused during drilling activities. While aspects of hydraulic fracturing have been changing and maturing, this technology has been utilized by the industry to increase production to support the increasing demand for energy for over 60 years (Arthur, 2009) [3].

The process of hydraulic fracturing as typically used for shale gas development involves the pumping of tens of thousands of barrels of sand laden water into the target shale zone. Fluids pumped into the shale creates fractures or openings through which the sand flows, at the same time the sand acts to prop open the artificial fractures that have been created. Once the pumping of fluids has stopped the sand remains in-place allowing fluids (both gas and water) to flow back to the wellbore.

Hydraulic fracturing is the process of pumping water, mixed with a small proportion of sand and chemicals, underground at a high enough pressure to split and keep open the rock and release natural gas that would otherwise not be accessible. The technique of hydraulic fracturing is shown in Figure 8 [16].

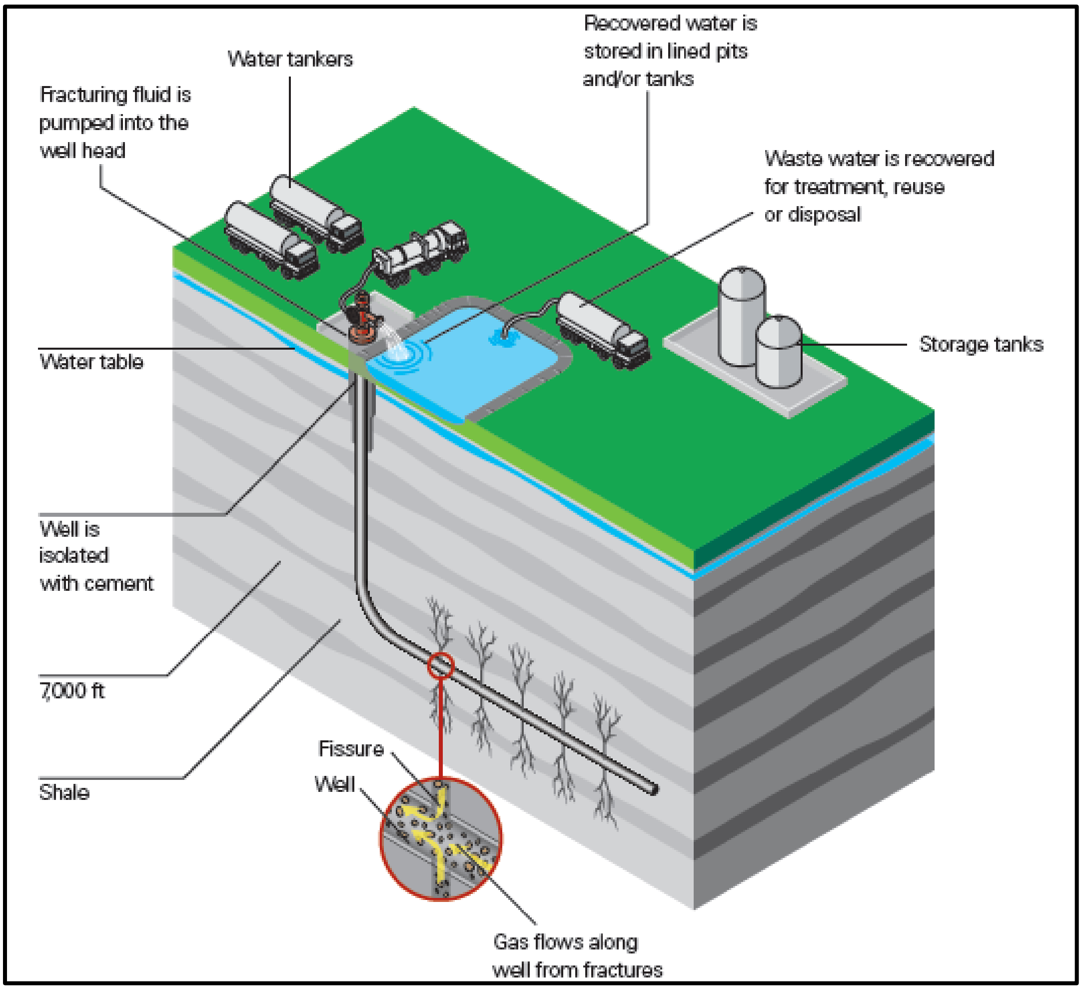


Figure 8: The technique of hydraulic fracturing

However, risks remain since shale gas development around the world has met with fierce opposition from local residents and environmental groups due to environmental concerns over the hydraulic fracturing, or "fracking" process.

Fracking involves drilling a well bore into the reservoir rock formation and then forcing water, sand and chemicals into the well at high pressure to create fractures or fissures in the rock. *Appendix 2* shows the composition and purposes of typical constituents of hydraulic fracturing fluid. Once the fracture is open, the released gas flows out of the fractures and into the well bore. In addition to shale gas, the process has recently been applied to extract gas from coal seam and tight sand deposits. With the impact of fracking operations still under study, the jury is out on the extent to which the process may be harmful to the environment.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter will cover a detail explanation on the methodology to ensure this project to be successfully completed in achieving its objectives.

3.1 Research Methodology

In conducting this project, a few methodologies are identified to be carried out. The methodologies identified are as followed:

3.1.1 Case study

Conduct a thorough study on the background, current condition and environmental interactions of the shale gas production at countries with technically recoverable shale gas resources by referring to numbers of related articles and journals.

3.1.2 Analysis

Collect and analyse classes of data which consist of the composition data of high consumption and production from the country, as well as the assessment of shale gas resources in the respective countries. Analyse the reason why Maliau Basin had been gazetted as a sanctuary area by Sabah government.

3.1.3 Evaluation

Determine whether the government in respective countries will be implementing the rules and regulations after discovering the environmental impacts of shale gas.

3.2 Project Activities

Proposal Preparation

- Do research on books, journal and articles.
- Understand on the objectives and scope of study of the project.

Project Study

- Suitable data findings on how shale gas affects the environment

Data Analyzing

- Discuss the effort that has been done by the countries with technically recoverable shale gas.

Report Writing

- Report the findings of the whole study and outcomes of the project.

3.3 Gantt Chart

Activities	**Week**														
	1	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
Briefing on Student Progress				🟩				Mid Semester Break							
Project Work Commences	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩						
Submission of Progress Report									🟥						
PRE-SEDEX										🟥					
SEDEX												🟥			
Submission of Final Draft Report													🟥		
Submission of Technical Report													🟥		
Final Oral Presentation															🟥
Submission of Hardbound Copies															🟥

Table 3: Final Year Project II Timeline

🟩 Process

🟥 Suggested Milestone

CHAPTER 4

RESULT & DISCUSSION

4.1 General Environmental Issues Associated with Shale Gas Development

Shale gas has received a good deal of attention recently for the potential negative impacts that its development may have on the environments and communities in which it occurs. Instances of water contamination, air pollution, and earthquakes have been blamed on gas extraction activities. A thorough understanding of the techniques used to extract gas from shale formations and the safeguards that exist to prevent environmental damage is critical to assessing the sources and magnitudes of risk involved in shale gas development. The potential environmental issues that have been identified in shale gas plays in an un-mitigated nature are hydraulic fracturing, urban development, wildlife, well site selection & construction, noise [7], traffic, air emissions, water sourcing, groundwater contamination, earthquakes as well as naturally occurring radioactive materials.

4.1.1 Hydraulic Fracturing

Hydraulic fracturing operations have been identified as a potential source of groundwater contamination, earthquakes, and surface contaminations and air emissions (Zoback et. al, 2010) [8]. Public especially in the United States believes that hydraulic fracturing is the primary environmental impacts associated with shale gas development at gas shale basins such as Barnett, Fayetteville and Haynessville [3]. Storage of fracturing additives on drilling sites has created concerns about the potential for surface water and soil to be impacted by accidental releases.

4.1.2 Urban Development

The widespread potential of shale gas development means that development is encroaching on urban and suburban areas in some plays [3]. Urban areas can present different environmental issues than rural areas. Issues including lighting of well pads, noise from well pads, traffic, dust, air emissions and water usage can all be predominant in urban areas. The encroachment of shale gas development on urban areas has resulted in the passing of shale gas development-related ordinances at the city and country level. These ordinances address environmental issues to shale gas development and often include additional permitting, approvals, and taxes placed on the development.

4.1.3 Wildlife

The disturbance of the land surface associated with development of shale gas has the potential to impact wildlife and wildlife habitat during the exploration, development, operations and abandonment phases. Technologies like horizontal wells and multi-well pads reduce the surface disturbance by combining resources, reducing the number of right of ways, utility corridors and other forms of surface disturbance. Habitat loss and growth fragmentation can have complex ecological impacts. According to Swarthmore, fragmentation can cause changes to environmental variables such as wind patterns, sunlight fluxes, water regime and nutrient levels, all of which can impact the growth and wildlife [9].

4.1.4 Well Site Selection & Construction

Low natural permeability of shale gas reservoirs requires vertical wells to be developed at a higher density than conventional gas reservoirs to drain the gas resources efficiently. Horizontal drilling provides a means to lessen the surface disturbances and associated concerns by reducing the number of well pads necessary to develop the resources.

Shale gas producers can drill up to 12 horizontal wells from one vertical well and six to eight horizontal wells from one vertical well can access the same or greater shale reservoir volume as more than 16 conventional vertical wells – each requiring its own well pad. When drilling conventional vertical wells, it is typical to install 16 well pads and drill 16 vertical wells per 2.6 square kilometres versus just one well pad in the same area when drilling horizontal wells and 16 conventional vertical wells would disturb approximately 0.3 square kilometres of surface land, while a four-well horizontal well pad for shale gas production would disturb only 0.03 square kilometres – more than 10 times less than the vertical wells – and access the same volume of shale gas. The use of multi-well pads decrease the number of roads, utility corridors and production facilities, potentially resulting in a reduction of habitat fragmentation, impacts of the public and the overall environmental footprint [10].

4.1.5 Noise

Noise during drilling can create an operational challenge for shale gas developers especially in urban areas. Well site preparation and access road construction utilizes bulldozers, backhoes and other construction equipment and thus generate noise similar to a construction site. The noise impacts associated with horizontal drilling occur over a longer time period than those of conventional gas drilling. High volume hydraulic fracturing operations also create significantly more noise than conventional natural gas operations due to the volumes and pressures required to stimulate the formation successfully [11].

4.1.6 Traffic

Shale gas development especially during drilling and completion phase, can create increased truck traffic volume. The large volumes of water necessary for drilling and hydraulic fracturing multiple wells per pad increases and concentrates traffic to a single location, rather than dispersing it over multiple sites as in conventional gas operation.

Total truck movements during the construction and development phases of a well are estimated at between 7,000 and 11,000 for a single ten-well pad. These movements are temporary in duration but would adversely affect both local and national roads and may have a significant effect in densely populated areas. These movements can be reduced by the use of temporary pipelines for transportation of water. During the most intensive phases of development, it is estimated that there could be around 250 truck trips per day onto an individual site – noticeable by local residents but sustained at these levels for a few days. The effects may include increased traffic on public roadways, affecting traffic flows and causing congestion, road safety issues, damage to roads, bridges and other infrastructure, and increased risk of spillages and accidents involving hazardous materials. The risk is considered to be moderate for an individual installation, and high for multiple installations [12]. Intensification of traffic can damage road surfaces if volume and weight loads are exceeded.

4.1.7 Air Emissions

Shale gas exploration and production are very similar to conventional natural gas operations in terms of air emissions. Air emissions during drilling and hydraulic fracturing operations are mostly from the engines powering the equipment and are similar to those emitted by highway trucks. These emissions occur for the relatively short time required to drill and fracture a well. Other air emissions can occur from venting or flaring of some natural gas and vehicular traffic with engine exhaust and dust from unpaved roads.

During completion of a well, emissions can occur during the flow-back following hydraulic fracture and may include vented gases and pollutants from flaring which are similar to those from the normal use of gas as a fuel. Once a well is producing, emission sources may include compressors or pumps and leaks from pipe connections and associated equipments. Emissions during production include both vented and fugitive hydrocarbon gas, and the normal pollutants from use of natural gas as a fuel. Greenhouse gas emissions during these phases include both methane and carbon dioxide [13]. Increased volumes of these gases create a harmful greenhouse effect, potentially raising the earth's temperatures and melting the polar ice caps. Another local air pollutant of growing concern is crystalline silica dust, which can be generated from the sand proppant. Silica dust can be generated in the mining and transporting of sand to the well site and in the process of moving and mixing sand into the hydraulic fracturing fluid on the well pad [14].

4.1.8 Water Sourcing

The drilling and hydraulic fracturing of a horizontal shale gas well requires millions of gallons of water. Surface water, private water, groundwater from water supply wells, urban water and reusable produced water are all common sources for shale gas development, but each source is complicated. Withdrawals from surface water and groundwater can create conflict with and problems for local populations may be inhibited by overdrafting or droughts.

Although water is used in several stages of the shale gas life cycle, the majority of water is typically consumed during the production stage. This is primarily due to the large volumes of water (2.3–5.5 million gallons) required to hydraulically fracture a well (Clark et al. 2011) [15]. Water in amounts of 190,000–310,000 gallons is also used to drill and cement a shale gas well during construction. After fracturing a well, anywhere from 5% to 20% of the original volume of the fluid will return to the surface within the first 10 days as flowback water. An additional volume of water, equivalent to anywhere from 10% to almost 300% of the injected volume, will return to the surface as produced water over the life of the well. It should be noted that there is no clear distinction between so-called flowback water and produced water, with the terms typically being defined by operators based upon the timing, flow rate, or sometimes composition of the water produced. The rate at which water returns to the surface is highly dependent upon the geology of the formation. Water management and reuse are local issues and often depend upon the quality and quantity of water and the availability and affordability of management options. Over a 30-year life cycle, assuming a typical well is hydraulically fractured three times during that time period, construction and production of shale gas typically consumes between 7,090,000 and 16,810,000 gallons of water per well [15].

4.1.9 Groundwater Contamination

4.1.9.1 Fracking process

Subsurface hydraulic fracturing operations in deep shale formations might create fractures that extend well beyond the target formation to water aquifers, allowing methane, contaminants naturally occurring in formation water, and fracturing fluids to migrate from the target formation into drinking water supplies (Zoback et al., 2010) [8]. Because the direct contamination of underground sources of drinking water from fractures created by hydraulic fracturing would require hydrofractures to propagate several thousand feet beyond the upward boundary of the target formation through many layers of rock, such contamination is highly unlikely to occur in deep shale formations during well-designed fracture jobs.

4.1.9.2 Accidental releases during preparation of fracturing fluids

The potential polluting activities are fuelling and tank refilling, bulk chemical or fluid storage, equipment cleaning, vehicle maintenance, pipe work, cement mixing areas and piping. On-site spills or leaks could potentially occur during transport to site and mixing and preparation. Chemicals to be used in fracturing fluids are commonly transported by road and are generally stored at drilling sites in tanks before they are mixed with water in preparation for a fracturing job. These could therefore be released by pipe work or regulator failures or by operator error (Wood et al., 2011) [27]. These fluids have the potential to contaminate surface water and groundwater in the same way as any other surface activity.

4.1.9.3 Fluid leak-offs, blowouts and casing failures

All natural gas wells are subjected to accidents such as blowouts, improper well construction and abandonment and associated contamination. Any structure that penetrates water aquifers, such as a well, has the potential to contaminate these water sources (Grubert and Kitasei, 2010) [26]. The loss of fracturing fluid through the artificially created fractures to other areas within the shale gas formation is termed as fluid leak off. This can constitute 70% of the injected volume if not controlled properly which could result in fluid migrating into drinking water aquifers (Energy and Climate Change Select Committee, 2011) [31].

Failure of the cement or casing surrounding the wellbore poses a risk to water supplies. If the annulus is improperly sealed, natural gas, fracturing fluids, and formation water containing high concentrations of dissolved solids may be communicated directly along the outside of the wellbore among the target formation, drinking water aquifers, and layers of rock in between.

4.1.9.4 Retention Pits

In rural areas, storage pits may be used to hold fresh water for drilling and hydraulic fracturing (Ground Water Protection Council and ALL Consulting, 2009) [32]. They are typically excavated containment ponds that, based on the local conditions and regulatory requirements, may be lined. Water storage pits are becoming an important tool in the shale gas industry because the drilling and hydraulic fracturing of these wells often requires significant volumes of water as the base fluid for both purposes. Pits can also be used to store additional make-up water for drilling fluids or to store water used in the hydraulic fracturing of wells.

In an urban setting, due to space limitations, steel storage tanks may be used. Tanks can also be used in a closed-loop drilling system. Closed-loop drilling allows for the re-use of drilling fluids and the use of lesser amounts of drilling fluids. Closed-loop drilling systems have also been used with water-based fluids in environmentally sensitive environments in combination with air-rotary drilling techniques. While closed-loop drilling has been used to address specific situations, the practice is not necessary for every well drilled. Drilling is a regulated practice managed at the state level, and while state oil and gas agencies have the ability to require operators to vary standard practices, the agencies typically do so only when it is necessary to protect the gas resources and the environment.

4.1.9.5 Flowback and produced water

Most of the concerns of water transport and disposal arise from flowback water which is produced by the fracturing process or produced water which comes from the formation during gas production, or the partial recovery of the fluids that are utilized to fracture stimulation a well.

Flowback of the fracturing fluid occurs over a few days to a few weeks following hydraulic fracturing, depending on the geology and geomechanics of the formation. The highest rate of flowback occurs on the first day, and the rate diminishes over time; the typical initial rate may be as high as 1000 m^3/d (Arthur et al., 2008) [3]. The majority of fracturing fluid is recovered in a matter of several hours to a couple of weeks. In various basins and shale gas plays, the volume of produced water may account for less than 30% to more than 70% of the original fracture fluid volume. In some cases, flow back of fracturing fluid in produced water can continue for several months after gas production has begun.

4.1.10 Earthquakes

Any process that injects pressurised water into rocks at depth will cause the rock to fracture and possibly produce minor earthquakes. It is well known that injection of water or other fluids during processes such as oil extraction, geothermal engineering and shale gas production, can result in earthquake activity. Indeed, microseismic activity induced by water injection in often used to monitor the extent and nature of the hydraulic fracturing. Typically, the earthquakes are too small to be felt, however, there are a number of examples of induced or triggered earthquakes which were large enough to be felt by people in United Kingdom [24]. The two small earthquakes felt in the Blackpool area in April-May 2011 are thought to have been associated with hydraulic fracturing carried out at 2-3 km depth by a company exploring for shale gas (Figure 9).

Figure 9: Damage have been caused by earthquake in UK

4.1.11 Naturally occurring radioactive material

Naturally occurring radioactive material can be brought to the surface in the natural gas production process. When such material is associated with oil and natural gas production, it begins as small amounts of uranium and thorium within the rock. These elements, along with some of their decay elements, notably Ra^{226} and Ra^{228}, can be brought to the surface in drill cuttings and produced water. $Radon^{222}$, a gaseous decay element of radium, can come to the surface along with shale gas (Ground Water Protection Council and ALL Consulting, 2009) [32]. The principal concerns are with accumulation in field equipment or in sludge or sediment within settling tanks.

4.2 Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs

The primary environmental impacts associated with hydraulic fracturing result from the use of toxic chemicals during the fracking process and the subsequent release of additional toxic chemicals and radioactive materials during well production. Fracking fluid flowback – the fluid produced from the well and separated from oil and gas – not only contains the chemical additives used in the drilling process but also contains heavy metals, radioactive materials, volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) such as benzene, toluene, ethylbenzene and xylene (BTEX). The potential impacts of hydraulic fracturing can be clearly shown at each stage of the hydraulic fracturing water cycle in Figure 10 [17].

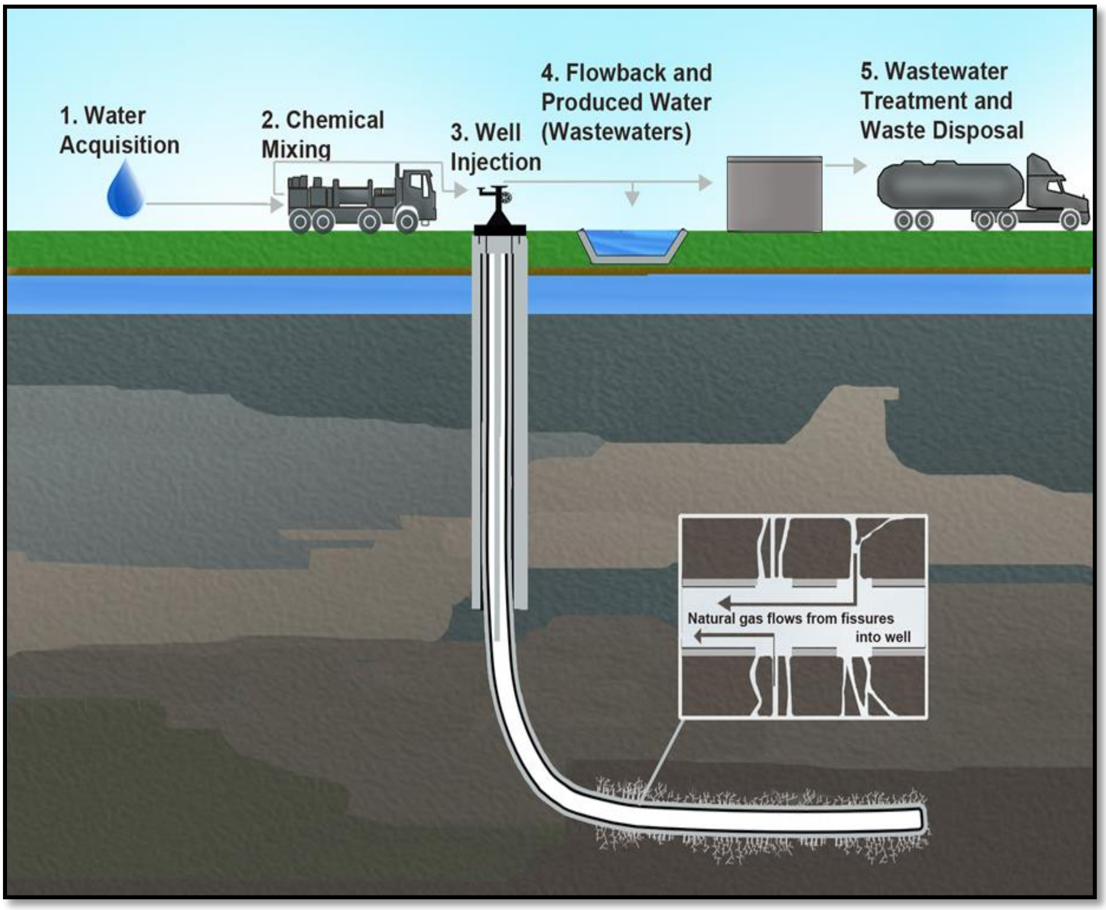


Figure 10: Hydraulic fracturing water cycle

Stage 1: Water Acquisition

Two to four million gallons of water is required to hydraulically fracture a single shale well. This source water is generally stored on site in tanks or surface impoundment pits. The removal of significant amounts of source water may impact water availability from local sources and adversely impact existing water quality [17].

Stage 2: Chemical Mixing

An average well requiring 3 million gallons of water requires the injection of 15,000 to 60,000 gallons of chemical additives into the well. Due to the large amount of chemical additives required, there is a risk of releasing to surface and ground water through on-site spills or leaks and a risk of releasing through chemical transportation accidents [17].

Stage 3: Well Injection

Shale formations commonly contain natural gas, carbon dioxide, hydrogen sulfide, organic acids, BTEX, VOCs, trace elements (mercury, lead and arsenic) and naturally occurring radioactive elements (radium, thorium and uranium). As a result, improper cementing or well casings risk the release of these substances into drinking water aquifers during the injection process [17].

Stage 4: Flowback and Produced Water

Following the fracking process, flowback containing the initial fracking fluids as well as naturally occurring toxic and radioactive substances return to the surface.. The recovered fluids are typically stored either in containment/evaporation pits or storage tanks. Here, improper well construction presents a risk of contamination to drinking water aquifers, while improper pit containment may result in contamination of surface waters [17].

Stage 5: Wastewater Treatment and Waste Disposal

The final stage of the lifecycle ends with treatment or disposal of flowback waters. Following treatment, water may be reused or discharged into surface waters. Currently, publicly owned treatment facilities are not designed to treat fracking wastewaters, especially the radioactive materials. The presence of excessive levels of radium, uranium and benzene in rivers and streams due to improper treatment at facilities prior to discharging wastewater into surface waters [17].

4.3 Shale Gas from the Perspective of United States, Australia, China and United Kingdom

A number of environmental issues related to the shale gas industry have arisen in the United States and similar questions have been raised about potential impacts in Australia, China as well as United Kingdom.

4.3.1 United States

In the United States, companies have unlocked access to rich shale gas reserves and there is tremendous activity as the country ramps up for full-scale production. Shale gas is in the midst of a boom across the country, with existing reserves being put into full production in Pennsylvania, Louisiana and Texas, and with new reserves being discovered, recently, for the Marcellus, Eagle Ford, and Utica reserves.

Many states such as New York, Texas and Pennsylvania, which have sizable plays near populated centers, are poised to potentially impose additional state-level regulation regarding water and air emissions on existing and new operations. In addition, the US EPA has been petitioned by environmental groups to regulate disclosure of chemicals used in the fracking process and is also in the process of drafting regulations for additional regulation of air emissions.

It is expected that the trend of new regulations and disclosure requirements will continue with respect to water usage and fracking chemicals, in addition to air emissions [18].

4.3.2 Australia

Australia’s shale gas is often located in remote locations, making it even more expensive to commercialize. While a combination of foreign and local companies are exploring for shale gas plays in various locations, there is currently no commercial production of shale gas.

Since most of Australia's conventional shale gas is remotely located, its production may face less environmental opposition than operations in the more populated areas where coal seam gas is currently being developed [19].

4.3.3 China

Natural gas production from tight and shale gas reservoirs is becoming increasingly important in China as the country shifts from coal-based energy to cleaner energy resources. Recent Chinese sources have estimated that the gas-in-place resources from tight and shale gas reservoirs in China are at least 12 and 31 Tcm respectively.

The challenge in China is the constraining water supplies for hydraulic fracturing. The unconventional gas industry will compete with other water usage such as farming, coal mining and power generation.

There is no environment standard in China controlling injection of produced water, and each case is handled individually, this subject will undoubtedly receive much close observation and attention by regulators. Re-use of produced water for hydraulic fracturing will probably be the most environmentally acceptable option [20].

4.3.4 United Kingdom

Unconventional gas development in the UK is at an early stage. Shale gas in the UK is not yet at the pilot production stage, while even in Poland, one of the most advanced nations in Europe with regards to shale gas exploration, large-scale production is not expected before 2017. Additionally, development of unconventional gas sources in Europe may be constrained by lack of equipments and the absence of a mature exploration service sector, though this point is disputed. In the mid-to-long term, development will be strongly dependent on the success of initial ventures. Should US-style expansion rates occur, it has been predicted that production from UK shales would peak in 2035 [25].

Shale gas extraction and fracking has received a huge amount of media interest in UK. Some of those relevant to shale gas include ‘induced seismicity’, such as the low magnitude earthquakes experienced in Lancashire in 2011. There is also the potential for groundwater and surface water contamination. This may arise from surface activities that may lead to spills associated with the storage and mixing chemicals at the drill/ fracking site or the storage/ management of fluids that return to the surface from the borehole, the so-called ‘flowback and produced waters’. Other potential pathways for contamination of groundwater include poor well-design and well construction, and the migration of contaminants along natural pathways into overlying aquifers.

4.4 Mitigation Strategies in Minimizing the Environmental Issues of Hydraulic Fracturing

Many technologies and best practices that can minimize the risks associated with shale gas development are already being used by some companies, and more are being developed. The natural gas industry should work with government agencies, environmental organizations, and local communities to develop innovative technologies and practices that can reduce the environmental risks and impacts associated with shale gas development. The mitigation strategies used in the certain United States basins are waterless fracture, environmentally friendly proppant and brine in replacing fresh water.

4.4.1 Waterless Fracture (Liquid Nitrogen Fracturing)

Environmental questions have arisen about water use and water quality in unconventional resource development, which requires millions of gallons of water per well to open pathways for oil and gas trapped in nearly impermeable rock.

The Research Partnership to Secure Energy for America (RPSEA) has one waterless project in progress to investigate if liquid nitrogen can fracture effectively and the government/industry-funded research group is seeking more projects that experiment with waterless alternatives (Stephen Rassenfoss, 2013) [21]. Waterless fracturing could remove an impediment to tapping unconventional formations in many spots around the world: limited water supplies.

BlackBrush Oil & Gas is the first company has been testing natural gas liquids (NGLs) to produce oil in a formation in South Texas. They were pumped by GasFrac Energy Services, which developed the first closed system able to pump these volatile liquids into a formation. The advantage of using waterless fracture is the average initial gas production is 77% higher per stage fractured. Another advantage is any liquid can soak into a low-permeability reservoir. When liquid nitrogen warms, it turns into a gas and flows out so there will be no formation damage, there is no productivity reduction (Yu Shu Wu, 2013) [21].

However, waterless fracturing involves high cost of oil which is magnified by wells with as many as 20 stages to fracture and major logistical challenges.

4.4.2 Environmentally Friendly Proppant (Non-Phenolic, Resin-Coating Technology)

A company namely Preferred Sands has launched a non-phenolic, resin-coating technology designed to be more environmentally friendly and efficient than conventional phenolic-based resins. The technology, developed in collaboration with Dow Chemical Company, has been introduced in five US basins, including the Permian, Bakken, Mid- Continent, Utica and Eagle Ford, and in central Alberta, Canada (Michael O'Neill, 2013) [22].

This innovative process allows for coated sand to be produced in a manufacturing process that requires less energy while minimizing environmental impact compared to current phenolic resins. This technology perform well under a range of conditions and depths, it is also cost-effective and contributes to the sustainability of the drilling process and can hold all the bond strength ability to consolidate in the fracture, resulting in greater efficiency and reduced cost.

4.4.3 Brines Reservoir to replace Fresh Water

A non-fresh water source has been proposed and tested in the laboratory and field for application as a fracturing fluid in shale gas formations, with potential to replace a very high percentage of the fresh water used in the Encana and Apache area of the Horn River Basin in British Colombia, Canada (George E. King, 2011) [23].

Brine can be supplied at high rate to the treating facility for sweetening and then to the fracture spread for pumping. This technology also minimizes the water storage needs and fresh water requirements as well as lowest environmental impact and smallest footprint possible

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

Shale gas is natural gas produced from shale formations and these shales function as both reservoir and source rock for natural gas and mainly composed of methane. Shale reservoirs are typically characterized by extremely low permeabilities and this necessitates the use of hydraulic fracturing treatments and horizontal well completions to contact larger volumes of the reservoir and to allow the gas, or oil, to flow from the rock. This project is focusing on the generic environmental implications of shale gas production from the hydraulic fracturing technique by analyzing the data from countries with technically recover shale gas resources like United States, Australia, China and United Kingdom.

In a nutshell, shale gas development in the countries with technically recoverable shale gas resources in the world is still a new development, and much can be learned from the environmental consideration and mitigations techniques that are being imposed on development. Many technologies and best practices that can minimize the risks associated with shale gas development are already being used by some companies, and more are being developed. The natural gas industry should work with government agencies, environmental organizations, and local communities to develop innovative technologies and practices that can reduce the environmental risks and impacts associated with shale gas development. Understanding the risks is a very important step in the design and approval process and very strict controls and regulations are in place to reduce the risks to an acceptable level.

Stronger, fully-enforced government regulations are needed in many states to provide sufficient protection to the environment as shale gas development increases. In addition, continued study and improved communication of the environmental risks associated with both individual wells and large scale shale gas development are essential for society to make well-informed decisions about its energy future.

This paper is a part of an ongoing work on the role of natural gas in the future energy economy, provides an overview of how the horizontal drilling and hydraulic fracturing are used to extract shale and the details of the mitigation techniques used, provides an overview of the industry best practices and government regulations that are needed if shale gas is to contribute its full potential to help build a low-carbon economy in the years ahead. Another suggested future work for continuation and expansion is the analysis of source rock found in shale formation at Sabah basin and the status of the Maliau Basin from the government’s perspective.

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APPENDIX 1

Criteria that are widely used to define a successful shale gas play.

Criteria	Range of data and definitions
Organic matter content (TOC)	Shales should be rich in organic matter, with total organic carbon (TOC) values > 2% (TNO 2009, Charpentier & Cook 2011, Gilman & Robinson 2011). >4% (Lewis et al. 2004). Jarvie (2012) uses a cut-off of just 1% present-day TOC, and quotes averages for the 10 top US systems as 0.93-5.34% TOC.
Gamma-ray values	High gamma radiation is typically an indication of high organic carbon content. Gamma log response should preferably be 'high' (Charpentier & Cook 2011); 20 API above shale baseline (Schmoker 1980); >230 API (NPC 1980); >180 API (DECC 2010a); >150 API, but lower if TOC is demonstrably high (D. Gautier, USGS, pers. comm.).
Kerogen type	Kerogen should be of Type I, II or IIS (Charpentier & Cook 2011). Ideally, II (Jarvie 2012). This indicates a planktonic, marine origin.
Original hydrogen index (HI_o)	HI_o preferably >250 mg/g (TNO, 2009, Charpentier & Cook 2011); 250-800 mg/g (Jarvie 2012). Note: it is important to have information on original, rather than present day, HI values. This conversion relies heavily on kerogen type.
Mineralogy/clay content	Clay content should be low (< 35%) to facilitate fracking and hence gas extraction. Jarvie (2012) stresses the requirement of a significant silica content (>30%) with some carbonate, and presence of non-swelling clays.
Net shale thickness	Moderate shale thicknesses are considered ideal; >50 ft (15 m) (Charpentier & Cook 2011); >20 m (TNO 2009); >150 ft (Jarvie 2012). Conventional wisdom is that the 'thicker the better', but this may not necessarily be the case (Gilman & Robinson 2011); >25 m in <200 m gross section (Bent 2012). Thick shale sequences (100s of metres) tend to be regarded as 'basin centre gas' plays rather than shale gas plays.
Shale oil precursor	A shale oil precursor should ideally be identified.

Thermally maturity	The shale should be mature for gas generation; Ro = 1.1 – 3.5% is widely accepted as the ‘gas window’. Charpentier & Cook (2011) use a cuff-off of Ro >1.1%. Smith et al. (2010) use 1.1% as it demarcates the prospective area in the Fort Worth Basin; Jarvie (2012) quotes a higher cut-off of Ro >1.4%; 1.2 – 3.5% (BGR 2012); <3.3% (TNO 2009). Conventional wisdom is 1.25 – 2%, but ‘empirical wisdom’ is 1.75 – 3% (Gilman & Robinson 2011).
Gas content/saturation	Gas should be present as free gas (in matrix and fractures) and adsorbed gas. Gas contents should be 60-200 bcf/section (Bent 2012) or >100 bcf/section (Jarvie 2012).
Depth minimum	Depth >5000 ft (>1500 m) (Charpentier & Cook 2011). Lower pressures generally encountered at shallower depths result in low flow rates.
Shale porosity	Typically 4-7%, but should be less than 15% (Jarvie 2012).
Overpressure	Slightly to highly overpressured (Charpentier & Cook 2011, Jarvie 2012). The Barnett Shale is slightly overpressured (Frantz et al. 2005).
Tectonics and burial history	Preferably in large, stable basins, without complex tectonics (Charpentier & Cook 2011). Wells should be drilled away from faults where possible.

APPENDIX 2

Composition and purposes of typical constituents of hydraulic fracturing fluid

Constituent	Composition (% by volume)	Example	Purpose
Water and sand	99.50	Sand suspension	"Proppant" sand grains hold microfractures open
Acid	0.123	Hydrochloric or muriatic acid	Dissolves minerals and initiates cracks in the rock
Friction reducer	0.088	Polyacrylamide or mineral oil	Minimizes friction between the fluid and the pipe
Surfactant	0.085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0.06	Potassium chloride	Creates a brine carrier fluid
Scale inhibitor	0.043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0.011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Iron	0.004	control Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0.002	n,n-dimethyl formamide	Prevents pipe corrosion
Biocide	0.001	Glutaraldehyde	Minimizes growth of bacteria that produce corrosive and toxic by-products
Breaker	0.01	Ammonium persulphate	Allows a delayed breakdown of gel polymer chains
Crosslinker	0.007	Borate salts	Maintains fluid viscosity as temperature increases
Gelling agent	0.056	Guar gum or hydroxyethyl cellulose	Thickens water to suspend the sand
Oxygen scavenger	-	Ammonium bisulphite	Removes oxygen from the water to prevent corrosion