

# **CASE STUDY OF SHALE OIL PRODUCTION**

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**A project report submitted in partial fulfilment of the  
requirements for the award of Bachelor of Engineering  
(Hons.) Petrochemical Engineering**

**Faculty of Engineering and Green technology  
Universiti Tunku Abdul Rahman**

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## DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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**APPROVAL FOR SUBMISSION**

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## CASE STUDY OF SHALE OIL PRODUCTION

### ABSTRACT

Shale oil or retort oil is rapidly emerging as a significant unconventional fuel in USA and successfully found a place in the world energy mix. The production of shale oil lowered the current crude oil prices proved that this type of viable energy has high potential to spread globally over the next couple of decade. The global energy markets will start to shift from petroleum/crude oil to shale oil as the impending shortage of petroleum reserves in the coming decade. This project presents an overview of the typical shale oil production and its technologies, upgrading of shale oil, environmental impacts and control technologies, shale oil future trends and future development as it is the most viable energy over the next couple of decade. Although OPEC endures its price war against upstart US shale oil and subsequently affect the marginal barrel output of shale oil, US shale industries are still possible to have a longstanding impact on global oil market due to the invention of new production techniques or technologies and more flexible financing system. The flexibility of US shale oil makes them capable to bounce back rapidly as global oil prices recoup. The establishment time between the decision of investment and operation in shale oil production is shorter as it can be measured in weeks compared to crude oil production which might take for years also one of the reasons for shale oil to adapt and respond quickly to the changes in global oil prices.

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**LIST OF SYMBOLS / ABBREVIATIONS**

ATP	Alberta Taciuk Process
CCR	conduction, convection, reflux
ICP	in-situ conversion process
SCF	supercritical fluid
BBL	barrel
Ft	feet
%	percent

## CHAPTER 1

### INTRODUCTION

#### 1.1 Background

Shale oil, also known as retort oil or light tight oil, is the unconventional oil produced from oil shale rock fragment. Shale oil contains large amount of hydrocarbon compounds such as paraffin, olefin, aromatics and heteroatoms. The extraction process of shale oil includes pyrolysis, hydrogenation and thermal dissolution of oil shale. Raw shale oil extracted from oil shale can be used as fuel oil directly. However, most of the application of shale oil requires it to be re-processed as hydrocarbon fuel or transport fuel.

The origin of shale oil, which is known as oil shale, is a large reservoir of untapped hydrocarbon resource. Oil shale contains cruel oil content. It is a sedimentary rock containing large quantities of solid and insoluble naturally occurring organic matter like kerogen, where the shale oil can be extracted. In shale oil refining, there are two basic methods to extract kerogen from oil shale. First method is a cracking process named as surface retorting used to break down the kerogen by heating it in absence of oxygen to release hydrocarbons and produce low molecular weight products such as nitrogen, oxygen and sulphur. Retorting can be applied at factory site after the oil shale is mined. Second method is in-situ method, where oil shale is heated underground and the liquefied kerogen is pumped to the surface (Speight James, 2011).

The use of oil shale has been known for thousands of years. In 1830, oil shale has been used as a commercial resource in France. It was mined and cooked in small quantities to produce oil to light oil lamps (Western Resources Advocates, 2013). Oil shale production had reached one million metric tons per year during the 1800s and by 1881. The production of oil shale in Scotland was between 1 and 4 million metric tons per year from 1881 to 1955 (Western Resources Advocates, 2013). Production began to cease due to technological insufficiency, unprofitability, unsolvable environmental side effects and also the cheaper supplies of petroleum crude oil in 1966. Commercialize oil shale in USA beginning in the mid-1970s but ending in 1991 due to poor technological reliability (Speight James, 2011).

Nowadays, oil shale deposit is widely distributed around the world like Estonia, Russia, China, Brazil and USA. Several main purposes of oil shale include direct combustion to obtain heat as well as to generate electricity, to produce shale oil used as transport fuel and also as a source of other valuable chemicals. The resources of oil shale around the world are approximately 4 trillion barrels which exceed the world's petroleum reserves that has approximately 2 trillion barrels. The largest shale oil resource is in USA, which possesses roughly 70% of global oil shale resource (European Academics Science Advisory Council, 2007). In addition, global markets are currently seeing increased investment in shale oil production especially in Estonia, China, Brazil, New Zealand, Australia and Japan. The adequate resources of oil shale exceeded the world's petroleum reserve is able to support growth and it is rapidly emerging as a viable energy in future (PWC, 2013).

The shale oil as the alternative source of energy and the major shale oil extraction activities in the USA accounts as a main reason for the low crude oil price in current global oil market led by OPEC. This is due to the major technological advancements and the flexibility of the shale oil production that able to quickly adjust to the changing price. The shale oil production can be turned on when demand is high and turned off when demand is low easily and more cost effective than the current conventional oilfield (Matt Egan, 2015). Production of shale oil are believed have high potential to replace world oil and gas production that has begun to decline in order to support current energy needs for the new generations.

## 1.2 Problem Statement

As the current public discussion over shale oil's future prospects grows louder, many pertinent facts about shale oil have fallen by the wayside. Therefore, an overview of the typical shale oil production process and its facilities has been studied. The process of extracting shale oil from oil shale which is a sedimentary rock represents perhaps the most difficult and high production cost than the conventional crude oil.

The shale oil is first being mined and then be retorted and upgraded. The current process which known as in-situ retorting involves heating the oil shale while it is still underground followed by pumping the resulting liquid to the surface for further process as a source of oil. The collected shale oil need to be upgraded to produce a high quality feedstock especially for the production of transportation fuel as a substitution of conventional crude oil.

The global energy market is changing due to the large amount of shale oil reservoir around the world especially in USA and the potential of shale oil to replace conventional crude oil in world energy sector. This can be seen by the falling of global crude oil price recently. However, the mining of oil shale brings some environment impacts such as groundwater and surface water pollution. Furthermore, OPEC also initiated an economic oil war against U.S. shale oil in order to drive some U.S. shale oil producers bankrupt and stem the flow of North America shale oil onto the global market. Hence, the technology of mining oil shale must be improved to reduce the pollution and make the production more cost effective since shale oil will definitely change the picture of global economics.

### **1.3 Aims and Objective**

The main purposes of this project are:

- i. To simplify an overview of the typical shale oil production methodologies.
- ii. To compare with the current crude oil production from the Middle East and to know how shale oil production lowered the current oil price its impact to the global oil energy sector, economy and its future trends and development.

### **1.4 Scope of Study**

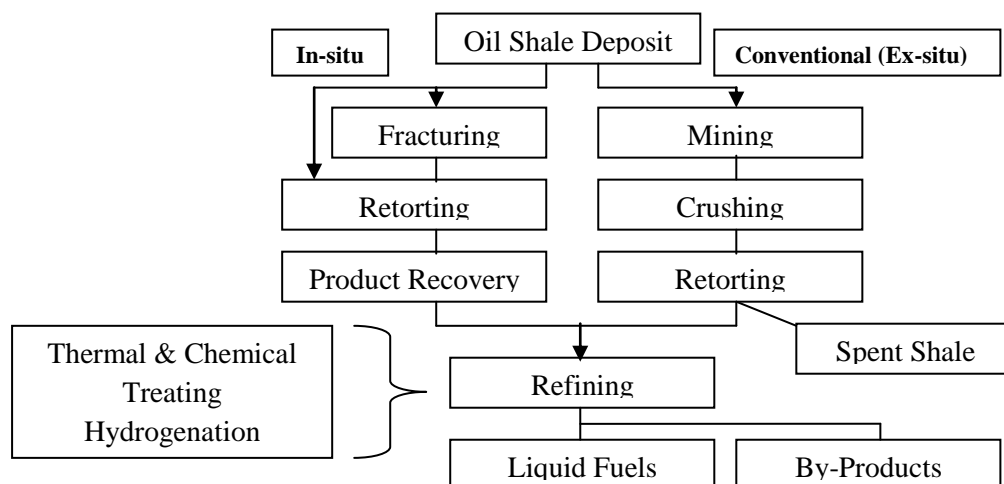
Oil shale must be mined before converted into shale oil. Depending on the target oil shale reservoir, either surface mining or underground mining methods may be used. There are 2 oil shale retorting technique for the production of shale oil which are mining followed by retorting at the surface and in-situ retorting which heating while it is still underground followed by pumping the resulting liquid to the surface for further process as a source of oil. In this project, attempts were focused on the production process of shale oil and its facilities, and also environmental impact and control technologies. In addition, how shale oil production lowered the current oil price was examined so as to determine the long term impact of shale oil on the future global energy sector and the economy. Thus, the general understanding of the technology processing shale oil and future development is presented in this study.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Shale Oil Extraction/Process Methods

There are two basic techniques to extract kerogen from oil shale for further processing into shale oil and others marketable products. First method is the surface processing which includes mining of oil shale, retorting at the surface and processing of shale oil. Second method is by in-situ retorting technique in which heating or pyrolysis is conducted while it is still underground and then pumping the resulting liquid to the surface for further process and upgrade as a fuel chemical. Commercial oil shale retorting technologies can be classified in two types which are gaseous heat carrier by using retort gas or solid heat carrier by using semi coke. The overview of shale oil extraction methods can be seen from Figure 2.1.



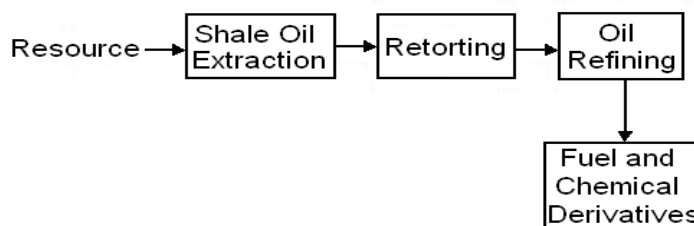
**Figure 2.1: Overview of Shale Oil Extraction Methods (Bartis et al, 2005)**



### 2.1.1 Surface Processing

For surface processing, oil shale is mined by surface-mining, which is open-pit method or underground mining technique followed by crushing into smaller pieces to increase surface area for better extraction. The selection of the mining method is depending on the depth of oil shale and characteristic of the target oil shale deposits. For oil shale resources where the thickness of the overburden less than 150 ft and the ratio of deposits thickness to overburden thickness is less than 1:1, open-pit mining is preferred method. Underground mining method is used when the depth of the oil shale is large. Few drilling methods are required to extract kerogen (the main component of shale oil) such as vertical drilling and horizontal drilling. In order to prevent oil shale collapsing, normally a strong roof formation and ventilation are provided (Ginley et al., 2012).

The steps of surface processing are shown in Figure 2.2. The mined oil shale will undergo surface retorting or pyrolysis process after excavation. Usually 1 ton or more of mined oil shale is exposed to extreme heated gases in the absence of oxygen to produce 1 barrel of oil (Bartis et al., 2005). The kerogen will begin to decompose and liquefy at about 500 °C or 932 °F. The non-condensed oil shale gas and oil vapour produced will then sent to separator and condensed. The condensed shale oil is then collected and further upgrading into fuel and chemical product, while non-condensable gas is recycled as retorting gases (Clark, 2013).

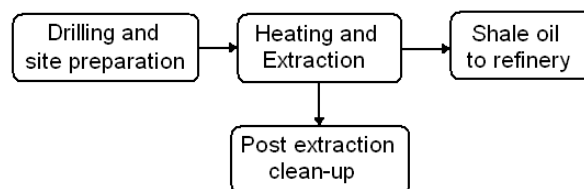


**Figure 2.2: Surface Processing Steps (Bartis et al, 2005)**

Note that this mining method brings impacts to the environment such as large land impact due to large amount of waste shale being disposed after oil shale mining (American Shale Oil Corp, 2015). Mining activities required large amount of water as large amount of ground water need to be pumped out in order to prevent mine flooding. The water discharge from oil shale may increase salinity and direct influence on the quality of ground water (Clark, 2013). In addition, large scale development of oil shale industry will left over large quantities of spent oil shale, which is economical viable to be used in road works and also brick or cement manufacture (Clark, 2013).

### 2.1.2 In-situ Processing

In-situ processes which heating or pyrolysis is conducted while oil shale is still underground. For in-situ processes, the target area is fractured in order to create permeability of the oil shale rock followed by injection of air and heating the deposits (Speight James, 2011). Oil shale can be heated by the injection of hot fluid into the rock formation. Other than that, heating sources such as thermal conduction and convection can be applied to distribute heat through the target deposits (United States Department of Energy & Office of Naval Petroleum and Oil Shale Reserves, 2014). The shale oil produced will then move through the fracture gap of the rock to the surface for further processing and re-processing. Figure 2.3 shows the in-situ processing steps in shale oil production.

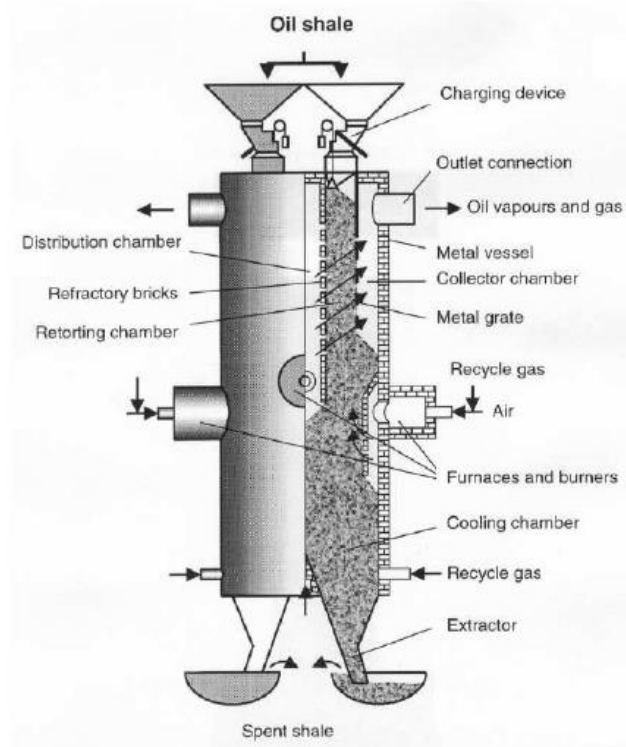


**Figure 2.3: In-situ Processing Steps (Bartis et al, 2005)**

## **2.2 Surface Processing Technologies**

### **2.2.1 Kiviter Process**

Kiviter Process retorting technology as shown in Figure 2.4 used retort gas as a heat carrier. Oil shale feed into charging device on top and spent shale is discharge from the chute at the bottom. The extractor is located on the top and at the bottom of the lined metal retort vessel. Heat carrier devices which are furnaces and burners are installed on the metal retort vessel. Thermal processing of oil shale undergoes by introducing heat carrier which are recycled air/gas into two retorting chambers covered by filled metal retort vessel, into one side of the refractory brick hot wall where nozzles are arranged and into metal grate made of vertical tubes. The mixture of oil, water vapor and heat carrier will move into collector chambers. Shale residual, semi coke which incomplete retorted organic matter solid residue will then moves into cooling chambers while gas and oil vapors moves into condensation system. The advantage of the technology is the compactness of the vertical retorting equipment and the production quantity of the retort oil shale is estimate 900-1000 tons per day. However, Kiviter process required lumpy oil shale which will increases the production costs and will produce large quantity of semi coke, which is also hazardous for the environment (Soone & Doilov, 2003).



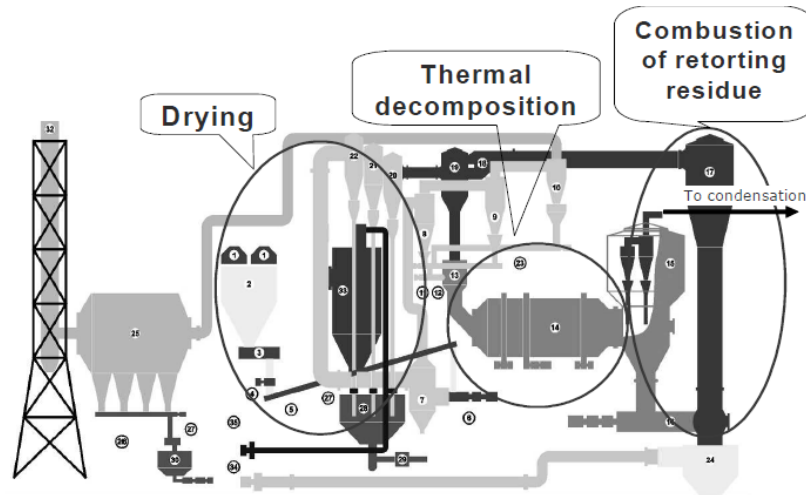
**Figure 2.4: Kiviter Retorting Process (Soone & Doilov, 2003)**

### 2.2.2 Galoter Process

Galoter Process retorting technology as it is shown in Figure 2.5 used solid as a heat carrier for thermal processing of fine-grained oil shale which the size up to 25mm. The organic matter solid residual of spent oil shale are use as the heat carrier for retorting. Spent oil shale undergoes combustion in a separated aero fountain unit which produces hot ash as the sold heat carrier.

Fine-grained oil shale is first dried in a fluidized bed dryer in the presence of gaseous heat carrier which produced by the combustion of retorting residue. Dry oil shale will then mix with hot ash and introduce into a horizontal rotating retort to undergo thermal processing oil cracking process. The products from the thermal treatment are semi coke, lighter oil fractions and gas. Semi coke which is the residual will be separated from the gas phase in dust chamber and then sent to the fountain furnace unit for burning (Golubev, 2003).

The main advantages of the Galoter process are the high technological chemical efficiency up to 78% and also high thermal efficiency. It also has high oil recovery ratio where the yield of oil up to 90%. This process able to produce high quality oil by creates less pollution. This is due to less water is needed. However, it will produced small amount of air pollutants such as carbon dioxide, calcium sulphide and carbon disulphide (Roger Ellis & Melanie Silver, 2015).



**Figure 2.5: Galoter Retorting Process (Golubev, 2003)**

### 2.2.3 Chinese Fushun Process

This internal combustion retorting technology is similar to Kiviter process. Vertical retorting equipment is used. The outside steel plate of this vertical retorting equipment is lined with inner hot bricks. The oil shale is dried and heated by the gaseous heat carrier after introduced into the pyrolysis section on the top of the retort. The pyrolysis takes place at temperature around 500 °C. This type of retort is suitable for small scale oil shale retorting plants when production of shale oil is around 100 to 200 tons per day (Qian & Wang, 2006).

The advantages of this process are it is relatively cheap and has high thermal efficiency. On the other hand, the disadvantages of this process is the pyrolysis gas/retorting gas has been diluted due to the addition of air into the retort. The

excess oxygen presences in the retort will also burns out some of the shale oil produced (Roger Ellis & Melanie Silver, 2015). Another disadvantage of this technology are large water consumption about 6-7 barrels per barrel of shale oil produced and high amount of waste shale being produced (Qian & Wang, 2006).

#### **2.2.4 Petrosix Process**

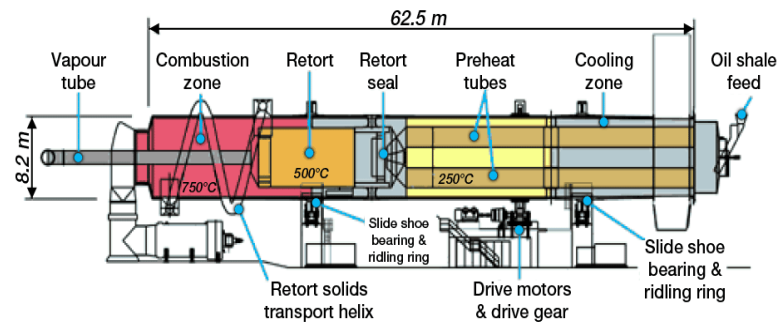
This Petrosix retort was introduced by Petrobras Company in Brazil for the processing of lumpy oil shale by vertical retorting equipment, which is similar to Kiviter process. Two Petrosix retorts have been built in Brazil with the daily production of 1,600 tons and 6,200 tons respectively. This type of retort process is suitable for middle and large scale shale oil plant. However, the main problem of this retort is the thermal efficiency. The retorting may be affected due to the unutilized of potential heat of fixed carbon in the shale coke (Qian & Wang, 2006).

#### **2.2.5 The Alberta Taciuk Process (ATP)**

The Alberta Taciuk process is a type of retorting process occurred in a single rotating multi-chamber horizontal vessel with the used of solid heat carrier. Australian Southern Pacific Petroleum Company had utilized this technology since 1999 with the production of 6,000 tons oil shale per day at Stuart, Australia (Qian & Wang, 2006). The properties of this new rotary-kiln technology for shale oil extraction and processing are energy self-sufficiency, simple and robust design, able to handle fine particles and higher yield of oil recovery factors. Solids Mechanical transferred also being allowed through the ATP machine with no moving parts and solid-to-solid heat transfer also able to achieve improved process efficiencies (Roger Ellis & Melanie Silver, 2015).

The advantage of this technology is that the oil shale gas in this process is not diluted with combustion exhaust gas because the recycle solids are heated in a

separate furnace. The process also allows all the crushed feed to be used as there is no limit for the retort to process on the smallest particles. The drawback is that large amount of water is required to handle the finer shale ash (Burnham et al, 2006). ATP retort as shown in Figure 2.6 is suitable for medium and large scale shale oil plant (Qian & Wang, 2006).

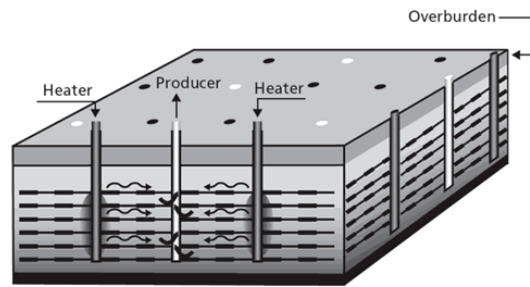


**Figure 2.6: Alberta Taciuk Processor Retort (Burnham, 2006)**

## 2.3 In-situ Processing Technologies

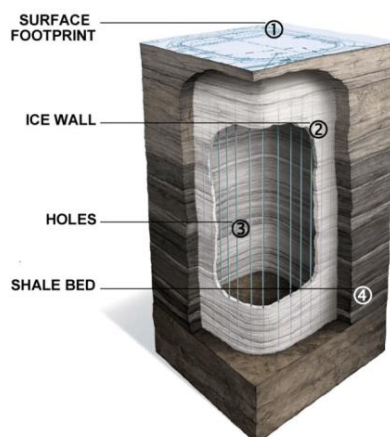
### 2.3.1 Royal Dutch Shell In-situ Conversion Process

The latest in-situ cracking technology called In-Situ conversion process (ICP) was introduced by Royal Dutch Shell Oil Company as shown in Figure 2.7. In ICP, holes are drilled into an oil shale deposits without excavating from the site and heating are conducting underground using electric heaters. The process is slow as the oil shale is heated using electrical heater over a period of two to three years, until the temperature reaches 650 °F. The oil will then be extracted and the product will be collected in the extraction site and pumped to the surface for further processing into marketable products (Argonne National Laboratory, 2012).



**Figure 2.7: Royal Dutch Shell Oil Company In-situ Conversion Process  
(Bartis et al, 2005)**

In-situ Conversion process further reduce costs for shale oil production as it avoids the mining of oil shale by supplying heat underground and able to extract more shale oil from a given target deposits area than surface processing due to the wells can reach greater depths than surface mine. The spent shale disposal problems also can be eliminated because spent shale can be remained underground. However, the uncollected liquids in the spent shale and vapour produced during retorting may leach into groundwater (Karanikas et al, 2005). Owing to this concerned, Shell's In-Situ Conversion process design includes a freeze wall which act as an underground barrier around the oil shale site as shown in Figure 2.8. The purpose of freeze wall is to prevent any groundwater from entering the oil shale site and prevents uncollected harmful liquids like hydrocarbons and vapour produced by the in-situ retorting from leaching out the site (Argonne National Laboratory, 2012).



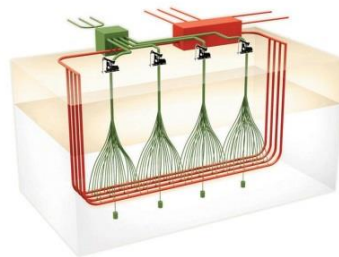
**Figure 2.8: Shell's Freeze Wall for In-situ Conversion Process  
(Bartis et al, 2005)**



### 2.3.2 American Shale Oil CCR Process

As it is shown in Figure 2.9, this process is a wall conduction in-situ technology where the heating elements are placed within oil shale resource. The heat transfer medium which is superheated steam is circulated through a series of heating pipes placed under the oil shale layer to extract the oil. The converted shale oil and others produced hydrocarbons can be extracted once superheated steam passed through horizontal wells and heat transfer flow through vertical wells (United States Department of Energy & Office of Naval Petroleum and Oil Shale Reserves, 2014).

The primary advantage of CCR process is where it applied thermo mechanical fracturing surrounding the retort. Refluxing oil will create permeability for heat distribution. Thick layers of impermeable nahcolitic oil shale which contain high amount of baking soda were used in this process in order to separate the extraction site from the aquifers. Thus, it prevents the contamination of aquifer (American Shale Oil Corp, 2015).



**Figure 2.9: American Shale Oil CCR Process (United States Department of Energy, 2007)**

### 2.3.3 Chevron Crush Process

This process known as externally generated hot gas in-situ technology was invented by Chevron Corporation and Los Alamos National Laboratory (LANL). Hot gases are heated above ground and injected into oil shale formation through drilled well. The hot gases used in this technology are heated carbon dioxide. The heated gases

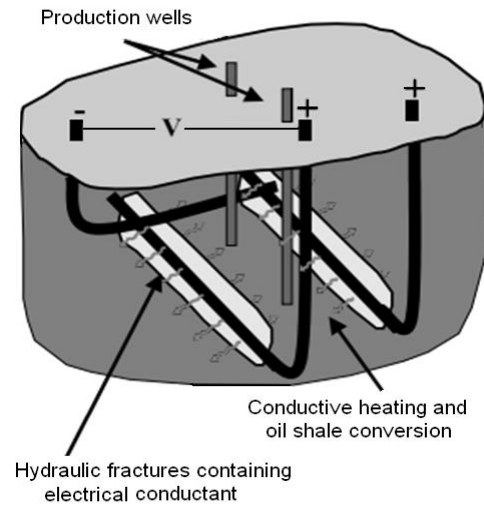
are circulated thus the oil shale formation able to be heated through a series of horizontal fractures (Chevron USA, 2006).

Chevron Crush Process able to enhance the hydrocarbons recovery in oil shale. This technology is an in-situ slow flowing oil formations process which enables to avoid the emission of greenhouse gas by capture and reuse the combustion gases. Another advantage of this process is conventional drilling which are more cost effective, less environmental impact and less consumption of water were used (Chevron USA, 2006).

#### **2.3.4 ExxonMobil Electrofrac Process**

The in-situ technology of Exxon Mobil is shown in Figure 2.10. It uses electrical heating with elements combining of volumetric heating method and also wall conduction. Electrically conductive material is injected into the hydraulic fractures of oil shale formation. It will then form a heating element in the fractures. The electrically conductive material used can be calcined petroleum coke. The electrical charges from the heating wells can be transferred to another horizontal well when both wells are placed in parallel row and intersecting to each other.

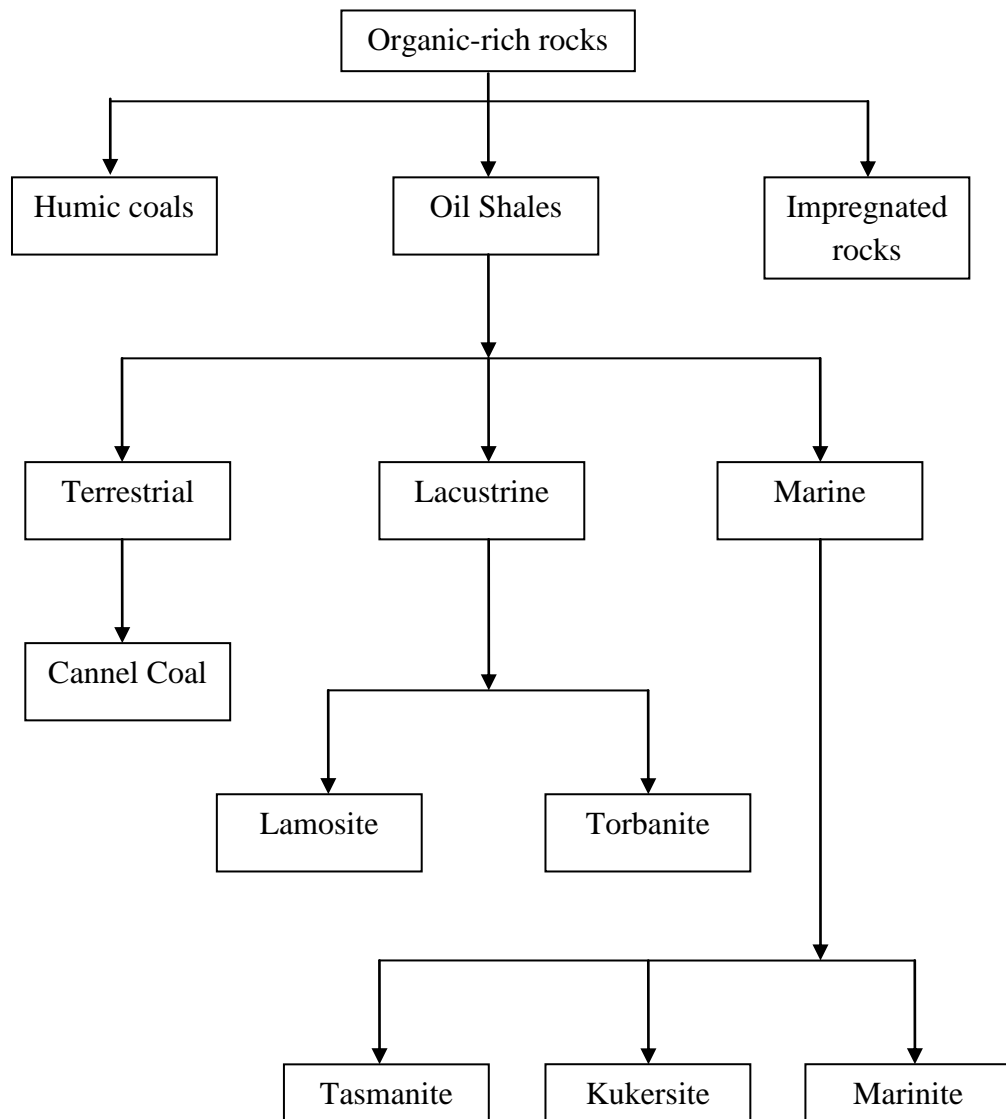
This energy efficient in-situ oil shale conversion process has ability to recover oil and gas from thick and deep oil shale by applying electrofrac. Those electrofrac can be heated for several months at low temperature without generating any hot spots which will damage the connections (Symington et al, 2008).



**Figure 2.10: ExxonMobil Electrofrac In-situ Process (Symington et al, 2008)**

## 2.4 Classification of Oil Shale

The deposition of oil shale around the world are widely distributed under sedimentary environments such as lakes, terrestrial swamps, pools, transition zone between land and sea to deep marine basins. The classification of oil shale deposition is developed by Hutton (1987) by determined the differences in the organic matter composition and the hydrocarbons that can be obtained from the oil shale as shown in Figure 2.11.



**Figure 2.11: Hutton Classification Schema for Oil Shale (Hutton, 1987)**

Cannel coals or terrestrial oil shale deposition are small in size but the grade can be very high. This type of oil shale is usually being found in stagnant and oxygen-depleted waters on land. The primary oil-generating organic matters obtained in terrestrial oil shale are derived from pollen, plant waxes, plant resins and the corky tissues of vascular plants.

Lacustrine oil shale depositions are organic rich but small size. They are usually being found in saline lakes and freshwater. The oil generating organic matters that can be obtained from lacustrine oil shale deposition is mainly derived from algae or bacteria.

Marine oil shale deposition have larger reservoir compared to terrestrial oil shale and lacustrine oil shale. They are mainly deposited in any marine area such as transition zone between land and sea, epicontinental sea and poor ventilation deep oceanic basins. The concentration of the organic matter in this oil shale type are the combination of good preservation conditions at the marine environment with high influx of organic matter and also the rate of sediment accumulation. The oil generating lipid organic compounds that can be obtained from this oil shale are algae, dinoflagellates and unicellular planktonic organisms. The only disadvantage is the grade of the deposits of marine oil shale is low to moderate (Hutton, 1987).

## **2.5 Upgrading Shale Oil**

The purpose of upgrading shale oil is to produce a high quality feedstock especially for refining into transportation fuel as a substitution of crude oil. The unique characteristic of shale oil brings difficulties for conventional refineries because typical shale oil contains about 2 % of nitrogen which is higher than the conventional crude oil that is only 0.2 %. The present of high percentage of nitrogen may poison the catalysts in conventional refineries. Thus, shale oil needs to be upgrade by reducing nitrogen content in order to produce a premium quality feedstock for conventional refineries. However, large amount of ammonia is produced during shale oil upgrading and act as a valuable by-product or a feedstock for others chemical processes.

The removal of nitrogen from shale oil may involve several types of ways such as using acid solution as a solvent to wash the shale oil and also the uses of catalyst. The process of removing nitrogen will be more efficient in the present of catalysts such as cobalt molybdenum on alumina, nickel-tungsten on alumina, nickel-molybdenum on alumina and halides of zinc under optimum pressure and temperature. The percentage of nitrogen in shale oil may reduce to less than 0.3 %.

Shale oil may undergo hydrotreating process in the presence of catalyst to remove nitrogen and other contaminants like arsenic. The metal contaminants will

attach on the catalyst while hydrogen may combine with sulfur to produce hydrogen sulfide which is an unwanted pollutant. The removal of hydrogen sulfide may need to undergo several processing. However, the sulfur content in shale oil is much lower if compared to conventional crude oil. Thus, hydrotreating process is suitable for the removal of high concentrations nitrogen in shale oil in order to produce a valuable and good quality feedstock for refineries.

In addition, 600-650 SCF/BBL of hydrogen are required to remove 1% of nitrogen for hydrogenation of shale oil and the total consumption of nitrogen may up to 1300 SCF/BBL. Therefore, ultrasound as a new hydrotreating applications are now been used to lower the cost of hydrotreating of shale oil (Savage, 2012).

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 Accumulation of Data**

Accumulation of data is known as the front-end work of the whole project and it is the initial approach in accomplishing this project. In order to complete this dissertation, this step was conducted upon obtaining in-depth understanding towards the concerns and requirements of the project by its title.

During this stage, information and data which is useful and related to the research was collected. First of all, the relevant information was sourced from electronic media which is inclusive of the international network (internet), electronic journals (e-journals) and electronic books (e-books). Besides, the mass media also been utilised such as professional handbooks, academic textbooks, industrial-oriented magazines, newspapers, journals and academic publications.

#### **3.2 Comprehensive Study of Data**

Comprehensive study was conducted after the completion of the initial approach which is accumulation of data. All data collected was comprehensively studied and simultaneously related to the requirements of this research.

During this stage, the data accumulated previously was fully studied in order for the realization of a clearer and more intelligent understanding from it. Next, the data accumulated was compared by referring to the aims and objectives of this project. This was indeed of most importance step to ensure that the data accumulated was of a sensibly high degree of applicability and would be useful for the completion of the project.

### **3.3 Organization of Data**

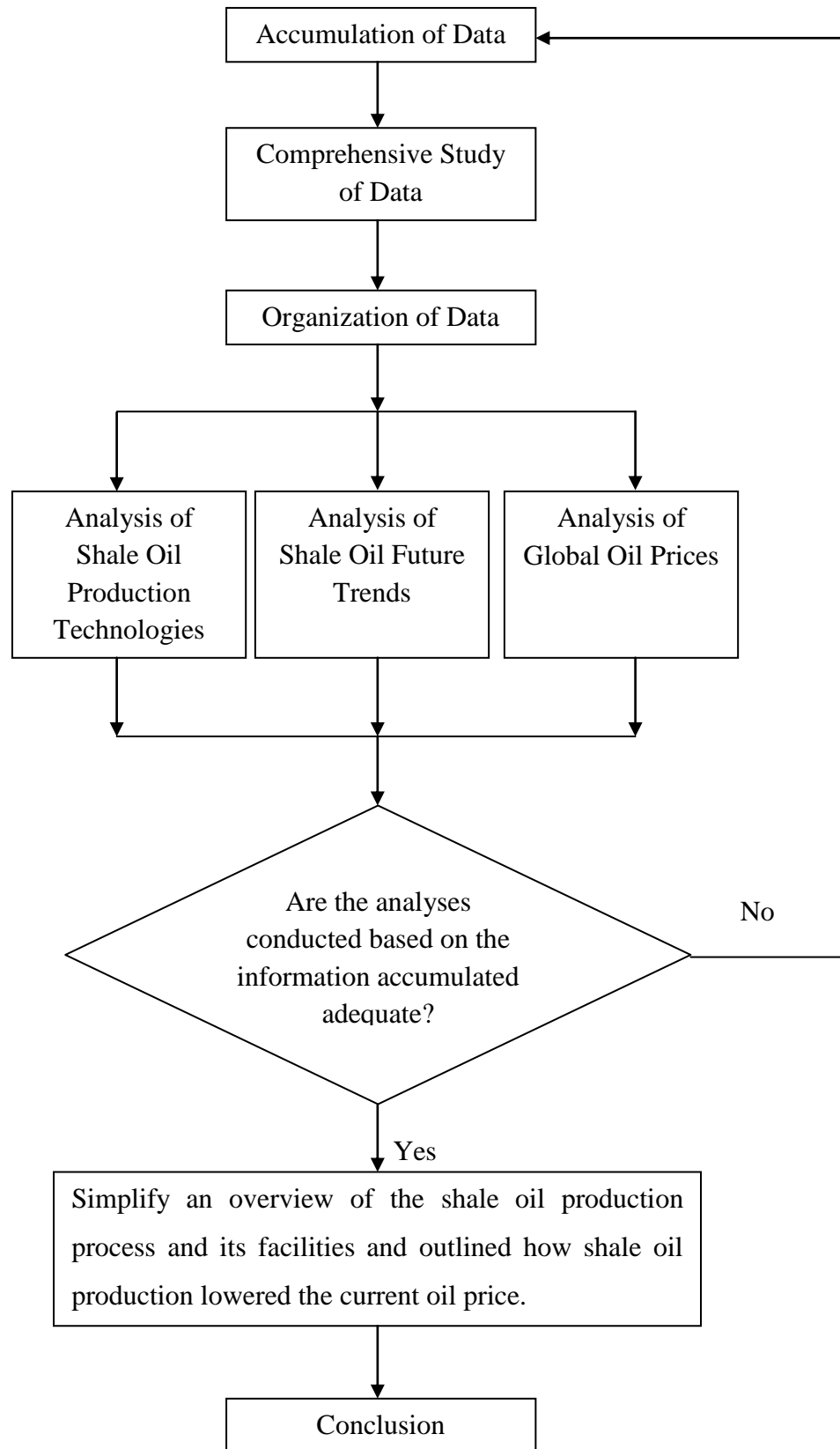
The data was then organized and sorted out properly after obtaining a deep understanding of the data collected through the comprehensive studies. This step was apparently very vital as it allowed useful and relevant data to be easily illustrated. At the same time, it also allowed unrelated data to be discarded.

### **3.4 Analyses of Data**

Two analytical methods which used to analyse the information and data gained are Politics, Economy, Social and Technology (PEST) Analysis and Strength, Weaknesses, Opportunities and Threats (SWOT) Analysis. These two analytical methods were applied regarding the main inputs researched on – shale oil production technologies offered by various licensors, shale oil market and global oil prices. Next, analyses made were then correlated, compared and contrasted with information published via accessible present-day mass media sources, electronic media sources and also past researches conducted to have their validity and relevancy before they were brought to readers.



### 3.5 Research Flowchart



**Figure 3.1: Flowchart of Research**

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 Environmental Impacts and Control Technologies**

The emerging of the shale oil industry may cause environmental pollution and this becomes main concern in the development of global shale oil industry. Environment impacts of shale oil production include the air pollution, wastewater discharge, land disruption after surface mining and also disposal of shale ash. Over several decades, many companies have developed a number of pollution control technologies. This is to ensure the shale oil production meet the regulations of pollution control and also waste disposal limitations. Nowadays, some of the wastes are collected and converted to valuable products. For example, shale ash is used in making cement and phenols can be extracted from wastewater (J.Q.Wan, 1998).

##### **4.1.1 Water Pollution and Control Technologies**

Wastewater leached from a retorting plant mainly contains suspended solid, oil, oxygen, nitrogen and sulphur compounds. The moisture content of oil shale feed, retorting condensation and recovery technology will affect the amount of wastewater discharged from retorting process of oil shale. This can be seen from the shale oil retorting process in Fushun and Maoming, China where large quantity of added water are used as a direct water scrubbing method to cool and condense the retorting hot vapour gas mixtures. Part of the added water needs to discharge as wastewater.

For example, 9 tons of fresh water is needed to produce 1 ton of shale oil and 5 tons of wastewater need to be discharged. The composition of the wastewater contains large amount of oils, dusts, phenols, sulphides and pyridines (J.Q.Wan, 1998).

In order to meet the pollution control regulations, China Maoming Oil Shale Company has invented a waste water treatment technology for treating high impurities contents wastewater. Firstly, static sedimentation, oil interception, flocculation and air floatation are used to treat the retorting water before undergoing biological treatment. By using this technology, the biological oxygen demand (BOD), chemical oxygen demand (COD), hydrocarbon and volatile phenols contents in waste water are greatly reduced. Another advantage of this waste water treatment technology is the operation cost is lower than conventional crude oil refinery.

A two stage biological treatment technology to treat the wastewater was developed by Kiviter Oil Shale Chemicals Company in Estonia to meet the pollution control regulations set by Estonian Government. The wastewater are pre-treated in the treatment plant containing commutating devices, vortex grit removals systems and primary solids sedimentation before entering aerated equalization basins for two stages activated sludge sedimentation. About 28000 to 30000 tons per day of oil shale waste water are treated by using this technology and it could be increased to 55000 tons per day (J.Q.Wan, 1998).

#### **4.1.2 Air Pollution and Control Technologies**

The mining and processing of shale oil production will also lead to air pollution. The main atmospheric emissions pollutants including sulphur dioxide, carbon monoxide, ozone, particulate, nitrogen oxides, ammonia, carbon dioxide and trace elements.

The potential emission of air pollutants such as carbon monoxide, nitrogen oxides, hydrocarbon, sulphur dioxides and particulate are during storage, transport and crushing of oil shale. The potential air pollutants that may be emitted during in-

situ processing are carbon monoxide, hydrocarbon and nitrogen oxides due to incomplete combustion of the fuel oil during blasting. The amount of air pollutants produced from surface processing are higher than in-situ processing due to large amounts of solids need to be handled on the surface and produce large quantities of dust.

Next, the quantity of sulphur dioxide emitted mainly depends on the sulphur contents of the fuels used for retorting. The amount of hydrogen sulphide, carbon disulphide and carbonyl sulphide in the off gas streams are highly dependent on type of retorting technology used. The emission of trace elements may due to the operations or retorting process. Nevertheless, the pollutants such as hydrocarbon, ammonia, hydrogen sulphide, sulphur dioxide, carbon disulphide and carbonyl sulphide may be produced during shale oil upgrading, gas cleaning and power generation.

One of the air pollution control technologies is Electrostatic Precipitator's technology which induced electrical charge on the surface of dust particle and the dust particle is trapped on the screen which is opposite charge. Recently, wet precipitators and charged droplet scrubbers are developed and widely used by Brazil Petrobras Company in their Petrosix plant due to high removal efficiency up to 99.9%, low energy requirement, able to handle high flow rates and required only little maintenance.

Next, Shell Claus off gas treating technology is used by heating the off gas with hydrogen gas and the mixture will then passed through a bed containing cobalt-molybdenum catalyst. The sulphur compound is converted to hydrogen sulphide. The gas mixtures are sent to an absorber to dissolve and concentrate the hydrogen sulphide. The hydrogen sulphide will be liberated from the absorber by heating.

Double alkali technology is a conventional wet stack gas scrubbing process which consists of two alkaline solutions, sodium hydroxide and sodium sulphite. These two alkaline solutions are used to convert sodium dioxide produced from shale oil production to sodium bisulfide. Lime or limestone is used to regenerate the spent scrubber solution by converting bisulfide to sodium hydroxide. This

technology is well established and able to remove 99% of sulphur dioxide (United States Congress Office of Technology Assessment, 1980).

#### **4.2 Impacts to World Economy and Global Oil Prices**

Shale oil is rapidly emerging as a viable energy in the future as the reserves of petroleum oil is declining in the coming decades. The future productions of shale oil are mainly depending on few aspects such as economical aspect, geographical aspect and political aspect.

In the early 1900s, the shale oil industry was started in Green River, United States. However, the development of shale oil industry is unsuccessful due to the lack of improve extraction technology, the high costs of mining oil shale and also the environment problem made in disposal of spent oil shale. However, recent developed new technology is able to improve the economics of oil recovery. All oil shale technologies required large quantity of high quality heat energy supplied to reach retorting temperature in order to extract one barrel of oil from more than one ton of shale. Thus, in order to make shale oil industry more viable, the recovery of sensible heat from the hot rock is very important in new technology to optimize the process economics (Speight, 2011).

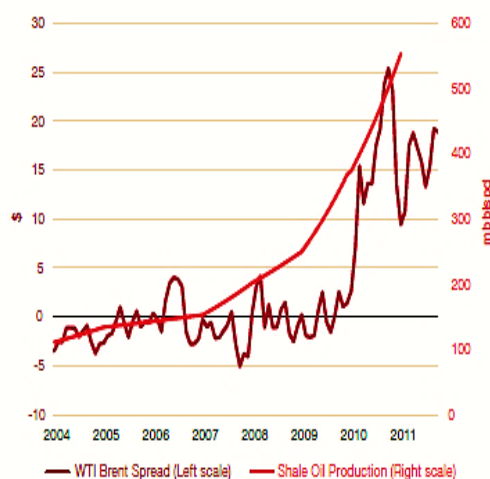
Nevertheless, the oil shale technology and resource assets in earlier oil shale projects are still holding by the particular company. This provides the fundamental for ongoing advances in shale oil production technology. This can be proven by the invention of Shell's In-Situ Conversion Process design with a freeze wall where successfully increase the shale oil production and subsequently reduce the environment problem.

The major capital investment of oil shale project in United States and the increase of shale oil market demand which reduce the current global oil prices shows that the invention of different type of new oil shale technology successfully

support the growing worldwide interest in the expansion and development of shale oil activity in future date (Speight, 2011).

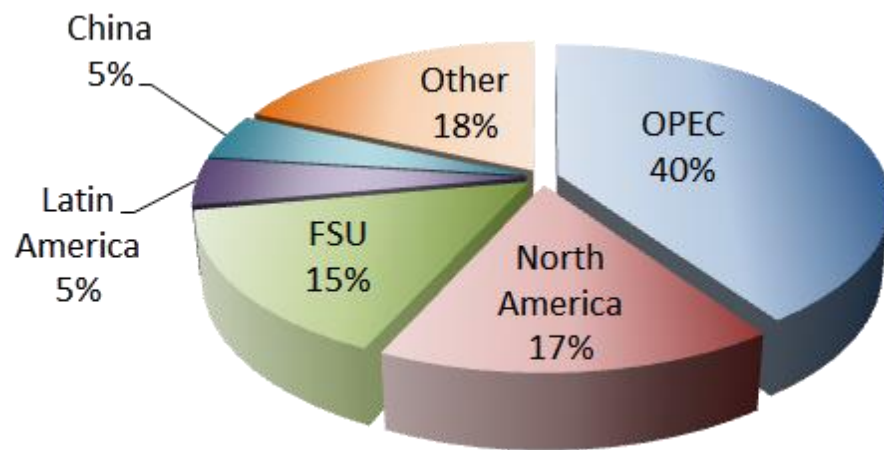
Conventional sources of energy, such as crude oil, have been dominating the global energy market for centuries. The demand for oil is substantially high. As a result, countries that extract crude oil and process it into usable fuels such as Saudi Arabia and Venezuela have been widely benefitted. Unfortunately enough, the glory of monopolizing the energy sector become a shattered dream for OPEC. This is due to the discovery of Shale Oil.

The shale oil production in United States is growing rapidly from 111,000 barrels per day in 2004 to 553,000 barrels per day in 2011 as shown in Figure 4.1. The production may strike 1.2 million per day by the date as forecast by United States Energy Information Administration (EIA). In 2010, the total shale oil resources in United States are estimated 33 billion barrels (U.S. Energy Information Administration, 2012). Around 35-40% of waterborne crude oil imports to United States are predicted to be replaced by shale oil and shale oil could make the largest single contribution to total United States oil production growth by 2020 (Price Waterhouse Coopers (PWC), 2013). The United States domestic oil prices are reduced significantly due to the rapidly growth of shale oil production.

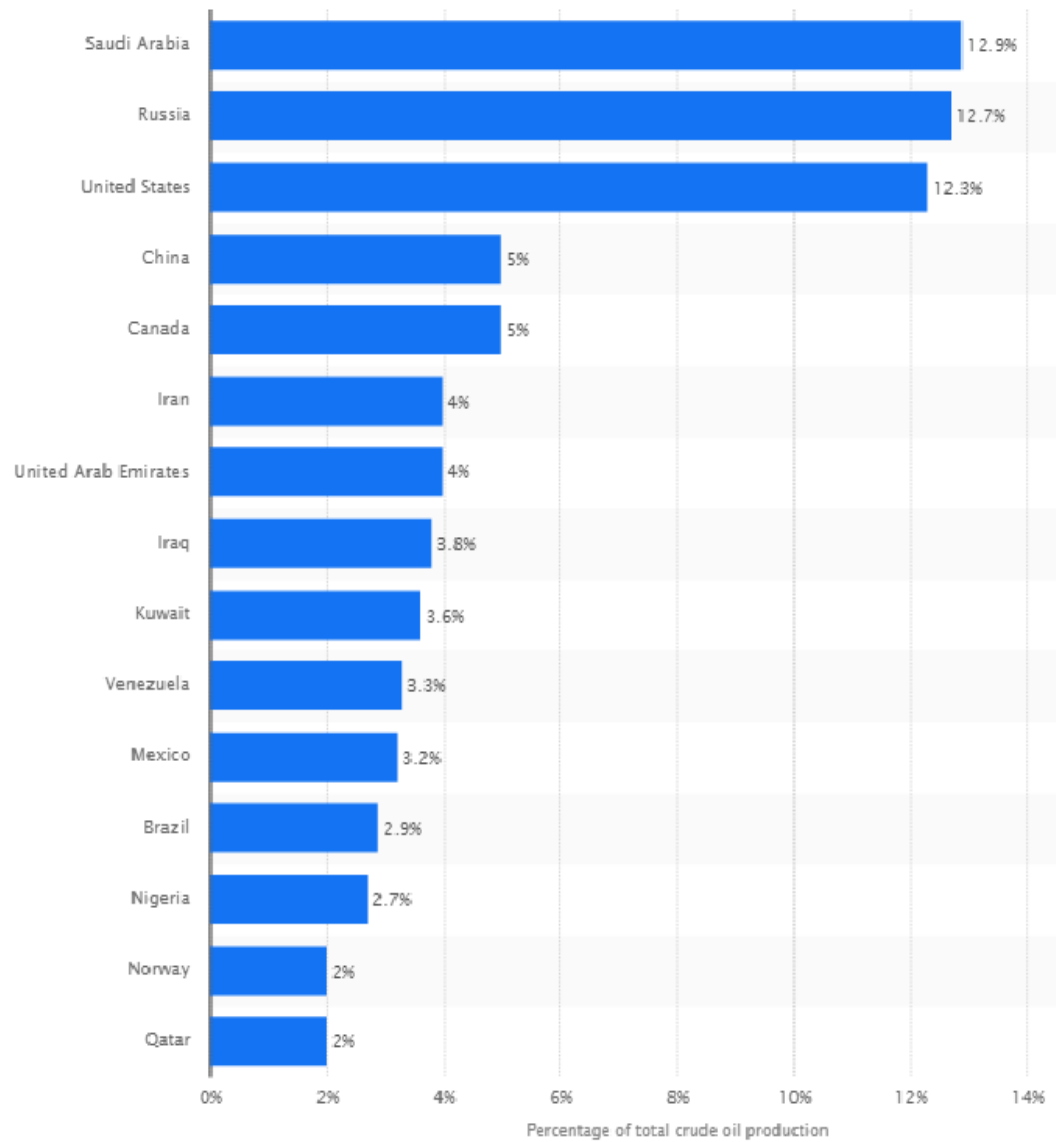


**Figure 4.1: WTI and Brent Oil Price Spread with Shale Oil Production from 2004 to 2012 (United State Energy Information Administration, 2012)**

The United States has shot up to rank as one of the “big three” oil producers in global market share since 2014, along with Russia and Saudi Arabia as shown in Figure 4.2 and Figure 4.3. In 2014 alone, shale oil was the primary reason United States oil production increased by 1.2 million annually, and oil prices have dropped from over \$100 per barrel to current prices. United States shale production successfully changed the global oil landscape.



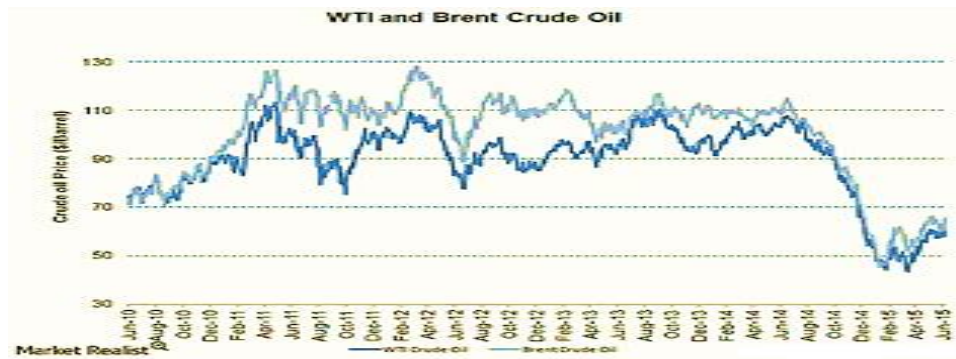
**Figure 4.2: Global Oil Market Share in 2014 (Taosif Khan, 2014)**



**Figure 4.3: Total Global Oil Production in 2014 (Statista, 2015)**

The WTI and Brent Crude Oil Price are in reducing trend from June 2010 to June 2015 due to the weak demand, increased supply and the growth in USA shale oil production that can be seen from Figure 4.4.

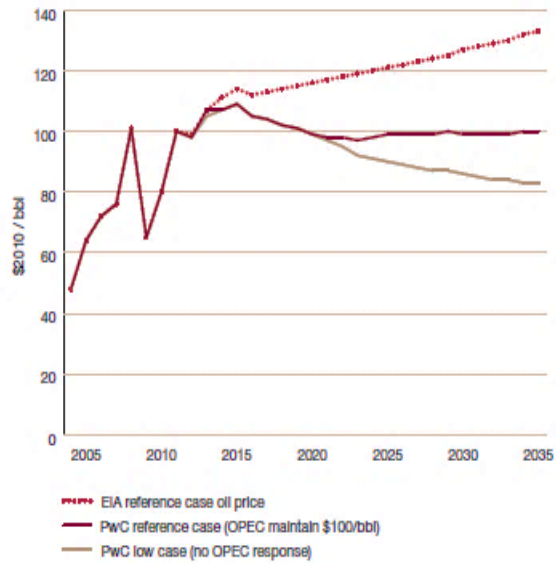




**Figure 4.4: WTI and Brent Crude Oil Price from June 2010 to June 2015  
(Market Realist, 2015)**

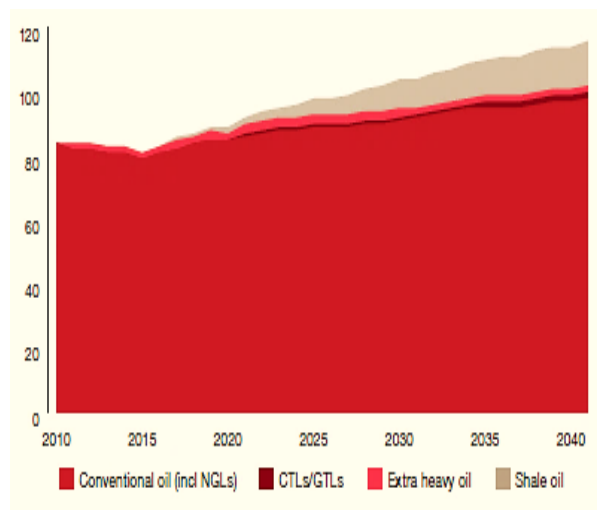
The development of shale oil production industry beyond the United States is still at an early stage but many extraction technologies are invented globally as the global shale oil resources are estimated around 330 billion to 1465 billion barrels (McGlade, 2011). The investment in shale oil exploration and production are already underway in Argentina, China, Russia, New Zealand, Australia, Mexico and Japan since the beginning of 2012.

Recently, United States Energy Information Administration (EIA) and International Energy Agency (IEA) suggest that each forecast on global shale oil production will achieve 28 % and 19 % increases by 2035. EIA estimate the oil price will increase steadily to reach \$133 per barrel by 2035 while IEA predicting the oil price will have a sharp short term increase to \$127. According to the forecast made by EIA and IEA in Figure 4.5, both agencies assume that modest growth in shale oil as a proportion of total global oil production. This forecast is arguably conservatives as the shale oil resources are likely to be revised increase significantly over time as the development and investment is already underway in United States and globally (U.S. Energy Information Administration, 2012).



**Figure 4.5: Forecast of Oil Price Incorporating Impact of Shale Oil Production vs. EIA Forecast (United States Energy Information Administration, 2012 & PWC Analysis, 2013)**

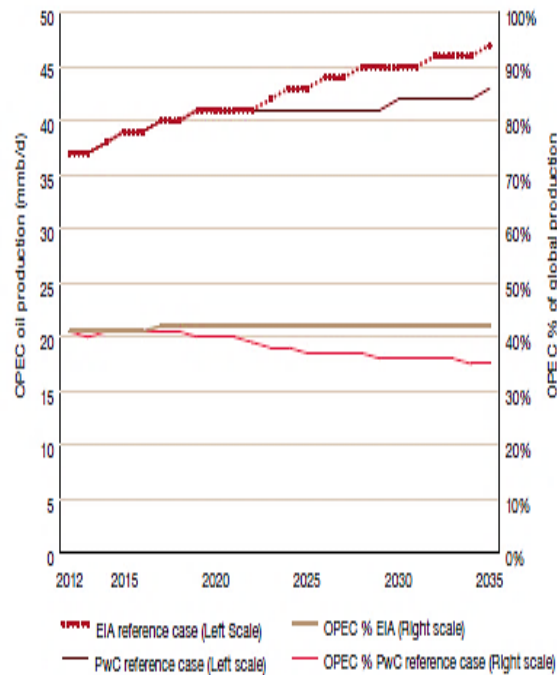
The global shale oil productions have highly potential to increase to up to 14 million barrels per day which is about 12% of total global oil supply as shown in Figure 4.6.



**Figure 4.6: Global Oil Production by Resources (United State Energy Information Administration, 2012 & PWC Analysis, 2013)**

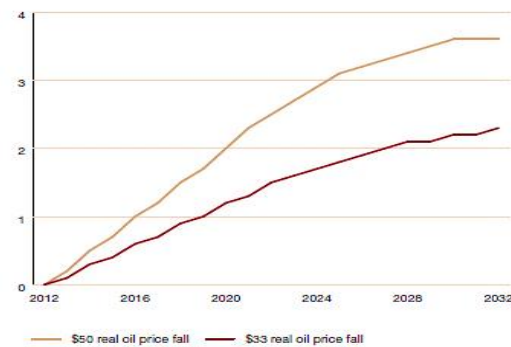
In addition, according to the PWC Analysis in Figure 4.7, two core long term oil price scenarios based on the shale oil production outlook have been developed. In first scenario which is the PWC reference case, the increases in shale oil production will subsequently lower oil prices as OPEC will limit its oil production in order to maintain the average oil price of around \$100. This shows that OPEC losing some global oil market shares although OPEC members continue to increase total production in order to meet rising demand. The second scenario which does not include an OPEC response shows that the oil prices may fall to around \$83 per barrel by 2035 due to the increased of overall oil supply (PWC, 2013).

Thus, by referring to both scenarios, the production of shale oil will bring the impact to lower the global real oil price to around \$33-\$50 per barrel by 2035 which is 25% lower than the forecast made by EIA.



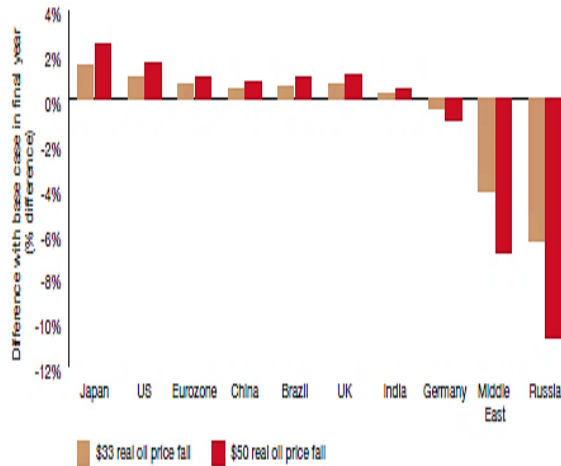
**Figure 4.7: Forecast of OPEC production in PWC reference case vs. EIA reference case (United State Energy Information Administration, 2012 & PWC Analysis, 2013)**

Another long term macroeconomic impact of lower global oil prices due to the production of shale oil is higher global GDP. The level of global GDP is estimated to increase between 2.3% to 3.7% as the decrease to \$33-\$50 in real global oil prices. This global economy is said to be increase around \$1.7-2.7 trillion per year as shown in Figure 4.8 (PWC, 2013).



**Figure 4.8: % of Global GDP Benefits from a Lower Oil Price (PWC Analysis, 2013)**

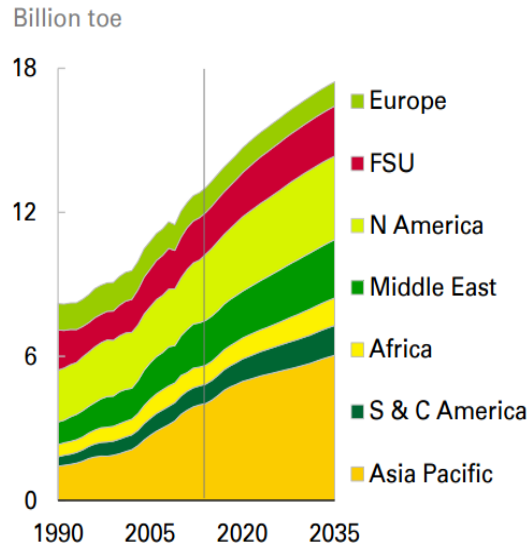
The PWC Analysis shown in Figure 4.9 forecasts that the shale oil revolution may bring benefit to large net oil importers such as Japan and India by boosting their GDP by around 4% to 7% by 2035 while China, United States, United Kingdom and the Eurozone may get 2% to 5% increase of GDP. On the other hand, major oil exporting countries such as the Middle East and Russia may have a significant reducing of their trade balances by roughly 4% to 10% in long run if they unable to develop their own shale oil resources. The shale oil bloom may reduce the influence of OPEC in global oil and gas industry.



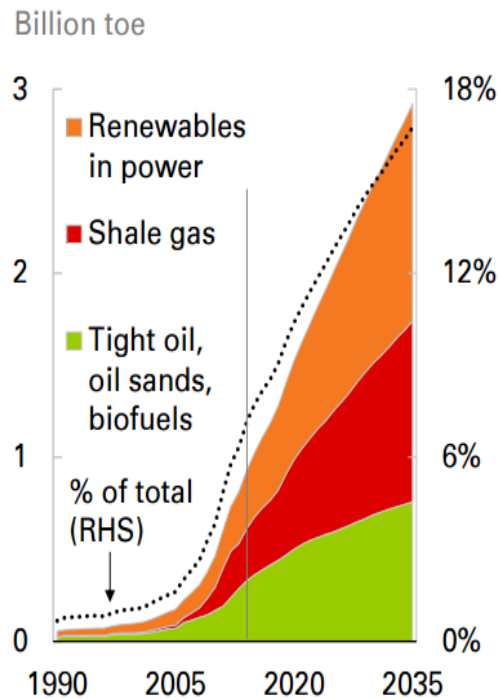
**Figure 4.9: Change in % of Global GDP in Alternative Oil Price Scenarios (PWC Analysis, 2013)**

### 4.3 Future Energy Outlook and Requirements

Unconventional oil and gas such as shale oil and shale gas will boost the world energy supply and demand in future as shown in Figure 4.10. The estimated average production of world primary energy will increase for 1.4% per year from 2013 to 2035. Asia Pacific shows the largest increment of around 45% while Central and South America have the fastest growth rate of around 2.1%. North America is the second largest regional energy producer due to large shale oil resource. Shale oil and others new sources of energy able to achieve aggregate grow of 6% per annual which contribute 45% of the increment in energy production to 2035 as shown in Figure 4.11.



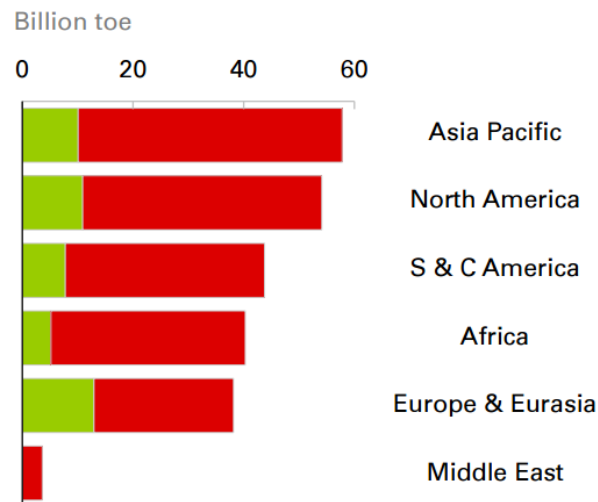
**Figure 4.10: Forecast of Global Primary Energy Production Growth (BP p.l.c, 2015)**



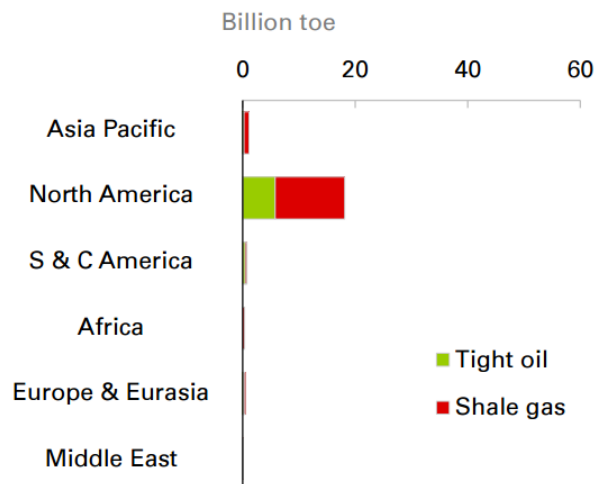
**Figure 4.11: Forecast of Global New Sources Energy Growth (BP p.l.c, 2015)**

The high global oil price previously is the main factor lead to significant increase of North America shale oil production. This shale oil boom has potential to alter global energy balances as the technically recoverable of unconventional oil are estimated around 240 billion barrels globally as shown in Figure 4.12. The shale oil

production is remains concentrated in North America although the resources are spread around the world as shown in Figure 4.13, the cumulative of shale oil production in North America is about 50% of technically recoverable resources. However, the factors which lead to dramatic growth of production in North America are unlikely to be achieved outside North America.



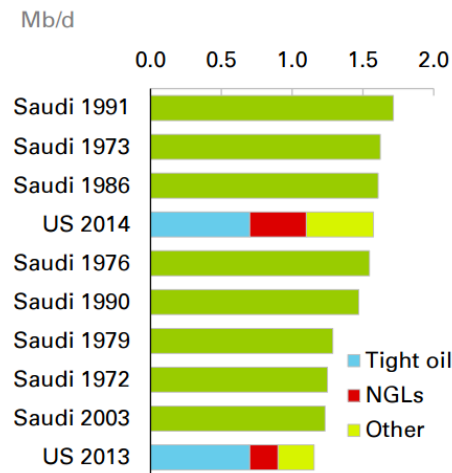
**Figure 4.12: Remaining Technically Recoverable Resources (BP p.l.c, 2015)**



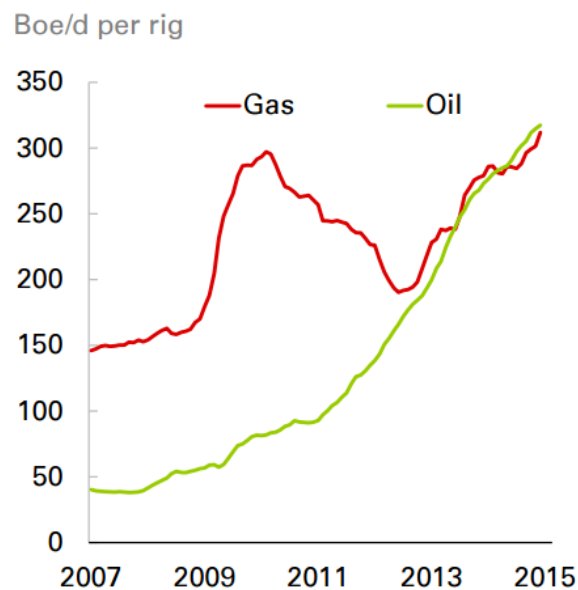
**Figure 4.13: Cumulative Production of Unconventional Resources from 2013-2035 (BP p.l.c, 2015)**

The development of unconventional resources industry helps North America to strike highest oil production growth in 2014 in the history as shown in Figure 4.14. The innovation of new technology and increasing investment support the growth of

unconventional resources by increasing the new-well production per rig by 34% per year for shale oil from 2007 to 2015 as shown in Figure 4.15.



**Figure 4.14: Largest Growth of Oil Production (BP p.l.c, 2015)**

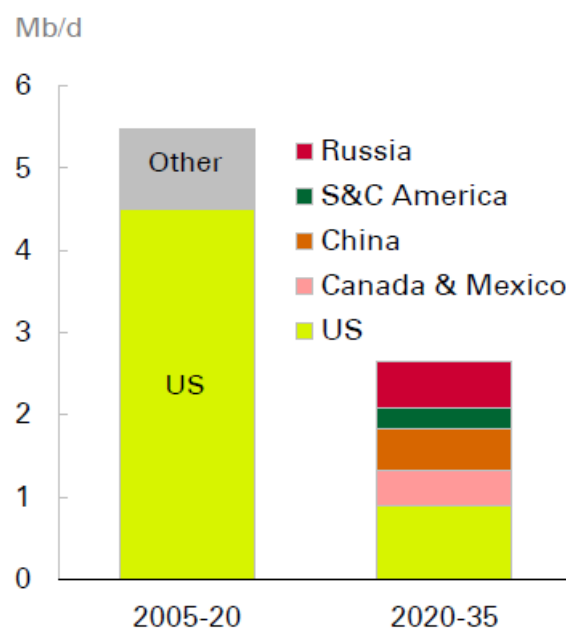


**Figure 4.15: North America New-well Production per Rig (BP p.l.c, 2015)**

Furthermore, due to the production of shale oil, North America which originally a net importer of energy switches to a net exporter in 2015. Although Middle East still remains as the largest net energy exporter, but as a long term impact, its share is estimated to fall from 40% in 2014 to 30% in 2035 due to the low global oil prices and large unconventional energy resources. Asia also consider



as a highly potential energy consumption market. This is because the estimated amount of energy import may achieve around 70% of inter-regional net imports by 2035. The Asia's oil imports in 2035 are believed as large as OPEC's current entire oil production. In recent year, the low market requirement for OPEC crude is due to the strength of shale oil. In near term, shale oil is believed to remains as a disruptive force to the global energy requirement. The shale oil production at North America will obtain an estimated growth by around 3Mb per day from 2013-2035. It is about two thirds of the global shale oil production in 2035 as can be seen in Figure 4.16.



**Figure 4.16: Growth of Shale Oil Supply (BP p.l.c, 2015)**

#### **4.4 Impacts of Low Oil Prices toward Shale Oil Production**

Recently, both WTI and Brent global crude oil prices descended to a 12 year low to below \$40 per barrel which breaking through a threshold on January 2016 as shown in Figure 4.17 and Figure 4.18. The main reason is due to OPEC endure its price war against upstart US shale oil and subsequently create some negatively affect to the marginal barrel output of shale oil. OPEC expects that the amount of typical oil wells in shale will decline 60% annually as high cost of drilling subsides and a

relatively low global oil price. Thus, a drop in shale oil production can be expected (Jessica Menton, 2015).

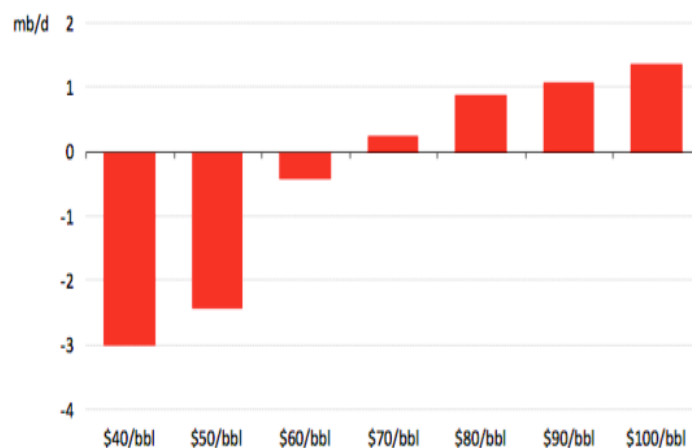


**Figure 4.17: WTI Global Crude Oil Prices (Nasdaq, 2016)**



**Figure 4.18: Brent Global Crude Oil Prices (Nasdaq, 2016)**

The U.S. shale oil productions reduce from 9.6 million barrel per day peak in April 2015 to about 9.1 million barrels per day in October 2015 according to the US Energy Information Administration (EIA). The US production may drop to 8.8 million barrels per day in 2016 and of which about 4 million would be shale oil as predicted by EIA. As for the base case prediction from International Energy Agency (IEA), the global crude oil price will climb to a more beneficial \$80 per barrel by the end of the decade. However, if shale oil producer capable to sustain its production and confront the forecast from EIA while OPEC maintain its barred output without limitation, the global oil prices would still stay at about \$30 to \$50 per barrel at the end of the decade. At the end, U.S. shale production yet would get negatively affect drop down by a projected 2.2 million barrels a day as shown in Figure 4.19 (Steve LeVine, 2015).



**Figure 4.19: Changes in Production of US Shale Oil for a range of 2020 Oil Prices (Steve LeVine, 2015)**

In response to lower oil prices, exploration and production companies have slashed capital budgets by over 40% on a year-over-year basis, and the oil rig count fell by 58% from its 2014 peak. Over 1,000 drill rigs in America, a third of all rigs that were active, have been disassembled in the first half of year 2015. The rig count fell at a pace of 57 rigs per week in the first quarter, faster than the 49 rigs per week decline in 2009 when the financial world was collapsing. This is just what OPEC was hoping for in their oil war with the United States, but it does not seem to be

accomplishing what they expected. The low prices led to a global glut that led to the falling rig count, but without so many rigs, the supply cannot rebound quickly and prices increased again, bringing more rigs back. The cycle will repeat itself and the U.S. oil industry gets more efficient and smarter. The big global oil companies could weather this war, but the small ones, some of which led the fracking revolution may not. What this war has engendered, instead of halting U.S. shale oil production, is a rapid consolidation and merging of companies that has increased efficiencies and lowered production costs so that the marginal cost of shale oil can go lower and lower and still allow shale oil to compete on the global market.

Today, crude oil spare capacity is less than 2 million barrels per day compared to the 1980's oil glut when spare capacity was over 15 million barrels per day. This means that small changes in supply or demand can cause large changes in the price of oil. This leads to significant price volatility, which should only increase in the coming years. The cost of production of a barrel of oil is the most important component of determining the marginal cost. One reason Saudi Arabia has dominated the world oil market is that they have more oil that is easier to produce than anyone else. The nominal cost of oil production for various countries is:

1. Saudi Arabia – \$21/bbl
2. Middle East – \$24/bbl
3. Russia – \$26/bbl
4. Mexico – \$42/bbl
5. South America/Europe/Eurasia/Africa – \$56/bbl
6. North America – \$60/bbl
7. Gulf Deep Water – \$70/bbl
8. Canada tar sands – \$82/bbl
9. other unconventional – \$100/bbl

However, while Saudi Arabia and other OPEC nations produce 10 million barrels of oil per day, more than any other country, it has little-to-no extra capacity to adjust to sudden increase in demand. So OPEC can no longer control the price and supply as well as they used to - too much outside supply and too much growing volatility in demand. OPEC need over \$100 per barrel to significantly grow their capacity to produce. Oil had remained above \$100 per barrel for the longest time in

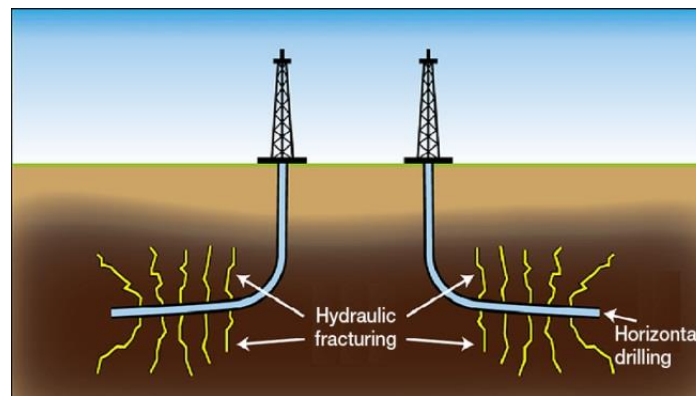
history, which allowed OPEC governments to dramatically increase their spending on social programs. At some point, OPEC countries will begin to bleed too much as it has been showed up in social disruptions, but they are content to fight the oil share war for now. So, the Saudis pressed the OPEC nations to drop prices by increasing production in the hope of driving U.S. oil companies out of business (James Conca, 2015).

#### **4.5 Lasting Impacts of Shale Oil Production on Global Oil Market Dynamics**

Although the low global oil prices may bring negative impact to shale industry, US shale industries are still possible to have a longstanding impact on global oil market due to the different production techniques or technologies used and more flexible financing system. First of all, the flexibility of US shale oil makes them capable to bounce back rapidly as global oil prices recoup. One of the reasons is shale oil able to adapt and respond quickly to the changes in global oil prices due to the short establishment time between the decision of investment and operation as it can be measured in weeks compared to crude oil production which might take for years. Other than that, the shale well life cycles are much shorter than conventional well too. In first year, shale oil production commonly falls by essentially 70-80 per cent. Thus, investment and drilling activity will deterioration speedily follow by production once global oil prices fall. This greater responsiveness of supply impairs the volatility of global oil prices (Spencer Dale, 2015).

Furthermore, the US shale producers start to apply a forefront technology recently which is the combination of advanced hydraulic fracturing and horizontal drilling method for the shale production as shown in Figure 4.20. Hydraulic fracturing which is also known as fracking involves harmfully tapping oil shale formations by drilling a mile or more below into the ground to extract oil from shale rock that lays thousands of feet below the surface. A new horizontal drilling technology will then be used and continuing several thousand feet more to explore more shale. This technical and intensive technology is very efficiency and less time consuming as a single surface site can accommodate a number of wells. Thus, the

production of shale oil and gas can be increase in shorter time and up to 95% of shale oil and gas wells drilled in the next decade will be using this technology. Once the well is drilled and formation is reached, gallons of water with approximately 90%, sand with approximately 9.5% and additives with approximately 0.5% is injected into the well under high pressure to create micro-fractures in the shale rock that are held open by the grains of sand. The purpose of adding additives are to prevent pipe corrosion, to reduce friction in order to reduce the amount of pumping pressure and also reduces air emissions. This leading edge technology allows US shale industry to response far more quickly to the changes of global oil prices than the conventional oil industry and generates strong productivity profit once the oil prices bounce back (Energy from Shale. org, 2015).



**Figure 4.20: Hydraulic Fracturing and Horizontal Drilling (Morikawa Tetsuo, 2011)**

As an indication of this oil evolution, \$11 billion of new equity was issued from the major oil companies in 2015. This was more equity issued than in all of previous year, and means the capital markets are available and ready and see a strong shale oil future. As all this has been occurring within the United States, the rest of the world has been changing too. Dropping oil prices from \$100/bbl to below \$40/bbl has imperilled the finances of many OPEC nations and authoritarian governments' overly-dependent on oil revenue. This, in turn, has produced social unrest, since many of these governments are already at risk of violence from their populations. Even worse for OPEC, the rate of change in oil production has recently begun to slow, and the oil price has recovered from the low \$30's per barrel to the

mid \$40's. Moreover, five-year deferred oil futures contracts have increased to \$66 per barrel. This level can easily sustain the newly-consolidated U.S. shale oil industry, effectively ending this oil war (James Conca, 2015).

## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

Shale oil act as a viable energy are a direct source of fuel. The significant reserve of shale oil around the world proves that shale oil has the ability to reshape the global energy market and improve the energy security.

The two typical techniques to extract kerogen from oil shale for further processing into shale oil and others marketable products are surface processing and in-situ retorting processing. Surface processing includes mining of oil shale, retorting at the surface and processing of shale oil while in-situ retorting technique undergoing heating or pyrolysis underground and then pumping the resulting liquid to the surface for further process and upgrade as a fuel chemical. The commercial oil shale retorting technologies can be classified in two types which are gaseous heat carrier by using retort gas or solid heat carrier by using semi coke.

The global crude oil prices are limited by the impact of increased shale oil production. The future expansion and development of shale oil industry will be governed by the economic, efficient technology and the broader environmental concerned at global level. Since the energy sources have moved from wood to coal to oil and gas, shale oil are highly potential to become a substitution for the impending shortage of crude oil in the next decades. Although OPEC endure its price war against upstart US shale oil which leads to the drop of the global crude oil prices to below \$40 per barrel recently bring negatively affect to the production output of



shale oil, the flexibility in investment, production and also the applied of high efficiency forefront fracking technology ensure that the shale oil to response rapidly from the fluctuating global oil price and have a long-lasting impact on global oil market and change the global oil picture in the future.

## **5.2 Recommendation**

Due to the shale oil boom phenomena in recent year which successfully lower the global crude oil price, the public awareness about the lasting impact of shale oil production is in increasing trends. A lot of nations and shale oil industry have realized that key technologies in shale oil development, the importance of key equipment or facilities and process management are the most important key point for the success of shale oil exploitation and production.

The U.S. shale oil industry may have an impressive impact on the global hydrocarbon sector by gradually applying hydraulic fracturing and horizontal drilling which able to lower the production cost, recover more oil from conventional, unconventional, mature, and declining oilfields worldwide. Thus, more study or research on the process line or process parameters regarding this forefront technology can be carry out more in depth since this leading edge technology allows shale industry to response far more quickly to the changes of global oil prices than the conventional oil industry.

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