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Research Article

A Review of Shale Oil Production Methodologies and Its Impact to Global Energy and Economy

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Abstract: The aim of this study is to review the extraction and process methodologies of shale oil and its impact to environment, global energy and economy in near future. The production of shale oil has lowered the current crude oil price recently. The global energy market will start to shift from petroleum/crude oil to shale oil as the impeding shortage of petroleum reserve in the coming decades. The study shows that the impact to environment due to extract and process of shale oil can be contained. Shale oil will have great impact to global energy and economy. It would contribute about 6% of total energy demand by 2035 benefiting the large net oil importers with forecasted GDP growth of 2 to 7%. On the other hand, major current oil exporters would have a reduction of their trade balances by roughly 4 to 10% by 2035.

Keywords: Kerogen, pyrolysis, shale oil, unconventional fuel

INTRODUCTION

Shale oil, also known as retort oil or light tight oil, is unconventional fuel produced from oil shale rock fragment. Shale oil contains large amount of hydrocarbon compounds such as paraffin, olefin, aromatics and heteroatom. 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 by direct burning.

Shale oil, which is also known as oil shale, is a large reservoir of untapped hydrocarbon resource. Oil shale contains cruel oil content. The sedimentary rock contains large quantities of solid and insoluble naturally occurring organic matter like kerogen, where the shale oil can be extracted. There are two basic methods to extract kerogen from oil shale. First method is a cracking process named as 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 situ method, where oil shale is heated underground and the liquefied kerogen is pumped to the surface (Speight, 2011).

As shown in Fig. 1, oil shale reserves are widely distributed around the world in countries such as Estonia, Russia, China, Brazil and USA. There are several main reasons of using oil shale. They include direct combustion to obtain heat as well as to generate electricity, used as transport fuel and as a source of other valuable chemicals. The reserve of oil shale around the world is approximately 4 trillion barrels, which exceeded the world's petroleum reserve of approximately 2 trillion barrels. The largest reserve and market of shale oil are in USA in which it has roughly 70% of global oil shale reserve (European Academics Science Advisory Council, 2007). In addition, global markets are currently seeing an increase in investment for shale oil production especially countries like Estonia, China, Brazil, New Zealand, Australia and Japan. Since the oil shale reserve has exceeded the world's petroleum reserve, it is able to support growth and it will rapidly emerge as a viable energy in future (PWC (Price Waterhouse Coopers), 2013).

The shale oil as the alternative source of energy and because of the major shale oil extraction activity is in the USA, this is the main reason for low crude oil price in current global oil market. This is also due to the major technological advancement and the flexibility of

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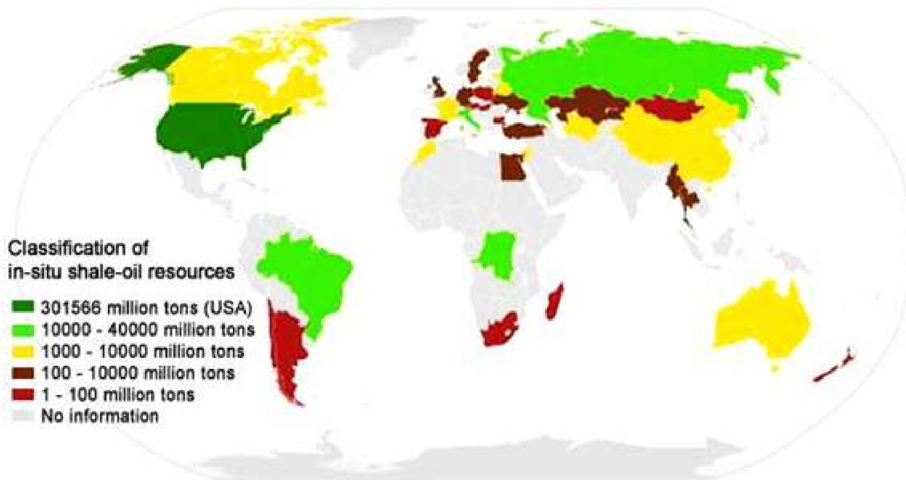

Fig. 1:Estimated world oil shale reserves (Dyni, 2006; World Energy Council, 2010)

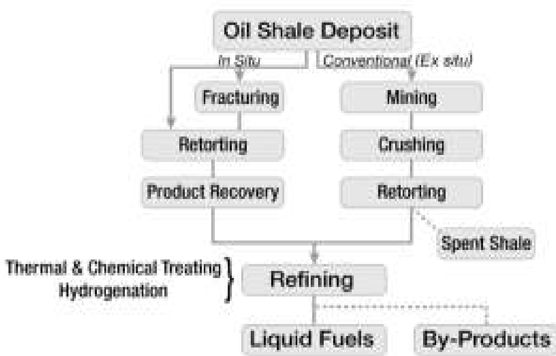

Fig. 2: Overview of shale oil extraction methods (Bartis *et al*., 2005)

the shale oil production that able to quickly adjust to the changing price. The shale oil production can be increased when demand is high and decreased when demand is low easily and it is more cost effective than the current conventional oil field (Matt Egan, 2015). Production of shale oil is believed to have high potential to replace world oil and gas production that has begun to decline and support current energy needs for the new generations.

The main objective of this study is to review the extraction and process methodologies of shale oil. In addition, the study also aims to discuss how shale oil production would affect the global crude oil price and to determine its long term impact on the global energy sector and the economy growth in near future.

LITERATURE REVIEW

The review of the methodologies to extract and process shale oil is discussed here. There are two basic techniques to extract kerogen from oil shale for further processing into shale oil and other 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 liquid shale oil to the surface for further process into fuel and 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 basic techniques for shale oil extraction is shown in Fig. 2.

Surface processing: For surface processing, oil shale is mined by open-pit method or underground-mining technique followed by crushing into smaller pieces to increase surface extraction area. The selection of the mining method is depending on the depth of oil shale and characteristic of the oil shale deposits. For oil shale deposit where the thickness of the overburden less than 150ft and the ratio of deposit thickness to thickness of overburden is less than 1:1, open-pit mining is the preferred method. Underground mining method is used when the depth of the oil shale is deep and large.

The steps of surface processing are shown in Fig. 3. The mined oil shale needs to undergo surface retorting or pyrolysis process after excavation. Usually one ton or more of mined oil shale is treated with extreme heated gases in the absence of oxygen to produce one barrel of oil (Bartis *et al*., 2005). The shale oil will begin to decompose and liquefy at temperature about 500°C. The oil vapour and non-condensed oil shale gas produced will then send to separator to be condensed. The condensed shale oil is then collected and further process into fuel and chemical product, while non-condensable gas is recycled as retorting gas (Clark, 2013).

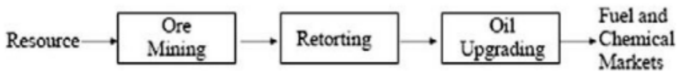

Fig. 3: Surface processing steps (Bartis *et al*., 2005)

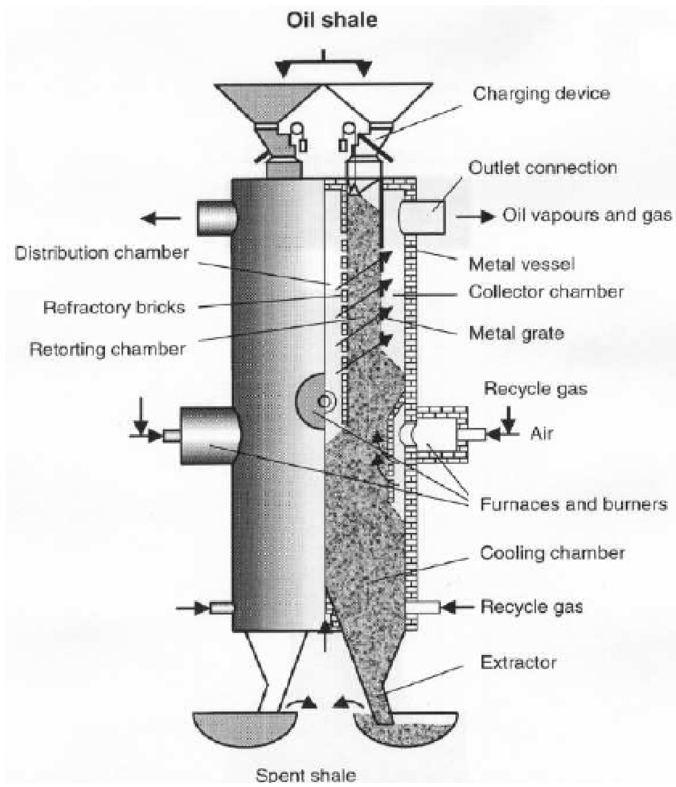

Fig. 4: Kiviter process flow diagram (Soone and Doilov, 2003)

However, this mining method brings impact to the environment. Mining activity requires pumping out large amount of groundwater to prevent mine flooding. The water discharged from oil shale may increase salinity and direct influence on the quality of groundwater (Clark, 2013). Large quantity of spent oil shale would be produced, which is economical viable to be used in road works and make into brick or cement.

Kiviter process: Kiviter process retorting technology as shown in Fig. 4 used retort gas as a heat carrier. Oil shale feeds into charging device on top and spent shale is discharged from the chute at the bottom. The extractor is located on the top and at the bottom of the lined metal retort vessel. Furnaces and burners are installed on the metal retort vessel. Thermal processing of oil shale is undergone by introducing heat carrier, which is recycled air/gas, into two retorting chambers covered by filled metal retort vessel. The mixture of oil, water vapor and heat carrier will move into collector chambers. Shale residue which is semi coke, an incomplete retorted organic matter solid will then move into cooling chamber while gas and oil vapor move 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 estimated to be 900-1,000 tons per day. However, Kiviter process required lumpy oil shale which will increase the production cost and will produce large quantity of semi coke, which is also hazardous to environment (Soone and Doilov, 2003).

Galoter process: Galoter process retorting technology, where it process flow is shown in Fig. 5, uses solid as a heat carrier for thermal processing of fine-grained oil shale which has size up to 25mm. The organic matter solid residue of spent oil shale is used as the heat carrier for retorting. Spent shale will be undergone combustion in a separated aero fountain unit to produce hot ash as heat carrier.

Fine-grained oil shale is first dried in a fluidized bed dryer in the presence of gaseous heat carrier. Gaseous heat carrier is produced by the combustion of retorting residue. Dry oil shale will then mix with hot ash, a solid heat carrier 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.

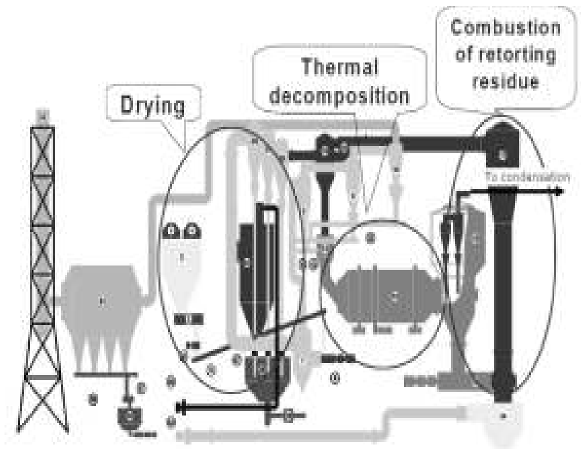

Fig. 5: Galoter process flow (Golubev, 2003)

Semi coke which is the residue will be separated from the gas phase in dust chamber and then sent into the fountain furnace unit for burning (Golubev, 2003).

Chinese Fushun process: The internal combustion of this 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 brick. The oil shale is dried and heated by the gaseous heat carrier after introducing 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 plant when production of shale oil is around 100-200 tons per day. The disadvantages of this technology are large water consumption, which is about 6-7 barrels per barrel of shale oil produced and high amount of waste shale being produced (Qian and Wang, 2006).

Petrosix process: 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. It is a proven externally generated hot gas technology. 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. Retorting may be affected due to un-utilized potential heat of fixed carbon in the shale coke (Qian and Wang, 2006).

Alberta taciuk process: Alberta Taciuk process is a retorting process occurred in a single rotating multi-chamber horizontal vessel with the use of solid heat carrier. Australian Southern Pacific Petroleum Company has utilized this technology since 1999 with the production of 6,000 tons shale oil per day (Qian and Wang, 2006). The advantages of this technology are the oil shale gas in this process is not diluted with combustion exhaust gas because of the recycle solid is 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 the small particles. The drawback is that large amount of water is required to handle the finer shale ash (Burnham and McConaghy, 2006). Alberta Taciuk process retort as shown in Fig. 6 is suitable for medium and large scale shale oil plant (Qian and Wang, 2006).

In-situ processing: In-situ process is conducted underground with heating or pyrolysis. For in-situ process, the targeted area is fractured in order to create permeability of the oil shale rock followed by injection of air and heating the deposit (Speight, 2011). Oil shale can be heated by injecting hot fluid into the rock formation or by using heating source such as thermal

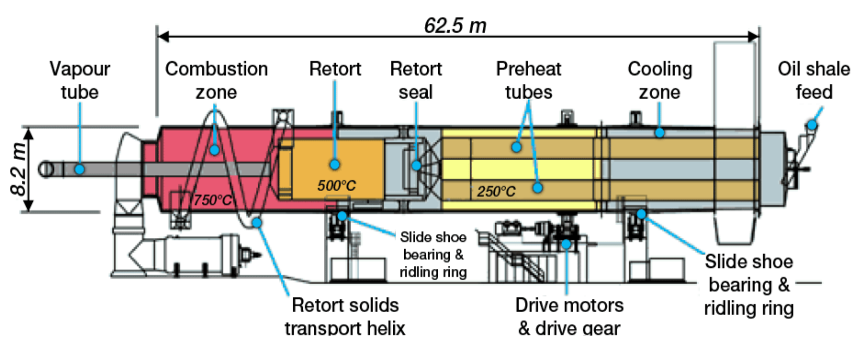

Fig. 6: Alberta Taciuk processing retort (Burnham and McConaghy, 2006)

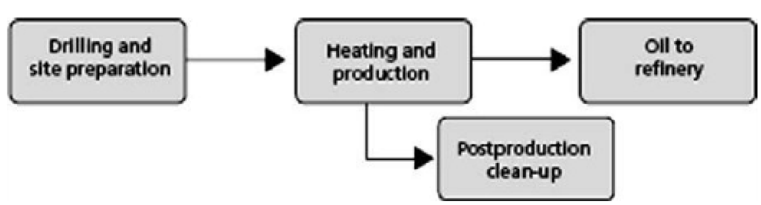

Fig. 7: In-situ processing steps (Bartis *et al*., 2005)

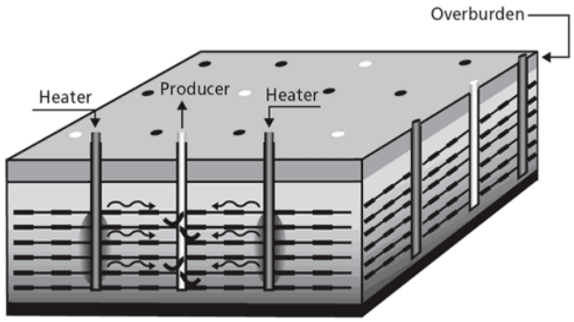

Fig. 8: Royal Dutch Shell oil company in-situ conversion process (Bartis *et al*., 2005)

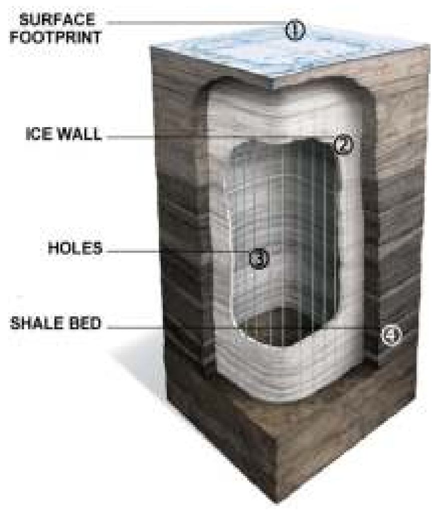

Fig. 9: Shell's freeze wall in-situ conversion process (Bartis *et al*., 2005)

Fig. 10: American shale oil CCR process (United States Department of Energy & Office of Naval Petroleum and Oil Shale Reserves, 2014)

Conduction and convection to distribute heat through the target deposit (United States Department of Energy & Office of Naval Petroleum and Oil Shale Reserves, 2014). The shale oil produced will then flow through the fracture gap of the rock to the surface for further processing. Figure 7 shows the in-situ processing steps in shale oil production.

Royal Dutch shell oil company 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 Fig. 8. In ICP, holes are drilled into an oil shale deposit without excavating from the site and heat is introduced underground using electric heater. The process is slow. It usually takes two to three years for the oil shale to be heated to temperature of 343°C. The hot shale oil will be pumped to the surface for further processing into marketable products (Argonne National Laboratory, 2012).

In-situ conversion process can further reduce the cost of shale oil production because it is able to extract more shale oil from a targeted deposits area than surface processing because the well can reach greater depth than surface mine. The issue of disposing spent shale can be eliminated because it can be remained underground. However, the uncollected liquid in the spent shale and vapour produced during retorting may leach into groundwater (Karanikas *et al*., 2005). Owing to this concern, Shell's In-Situ conversion process design includes a freeze wall which acts as an underground barrier around the oil shale site as shown in Fig. 9. The freeze wall prevents 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 from the site (Argonne National Laboratory, 2012).

American shale oil CCR process: As it is shown in Fig. 10, this process is a wall conduction in-situ technology where the heating elements are placed within oil shale deposit. 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 other product like hydrocarbon can be extracted once superheated steam passed through horizontal well and heat transfer flows through vertical well.

Chevron crush process: This process known as externally generated hot gas in-situ technology was invented by Chevron Corporation as shown in Fig. 11. Gas is heated above ground and injected into oil shale formation through drilled well. The hot gas used in this technology is heated carbon dioxide. The heated gas is circulated through horizontal rock fracture to reach oil shale (Chevron USA Inc., 2006).

ExxonMobil electrofrac process: This in-situ process technology of ExxonMobil is shown in Fig. 12. It uses electrical heating elements combining the volumetric heating method and wall conduction. Electrically conductive material is injected into the hydraulic fracture of oil shale. It will then form a heating element in the fracture. The electrically conductive material used can be calcined petroleum coke. The electrical voltage from the heating well can be connected to

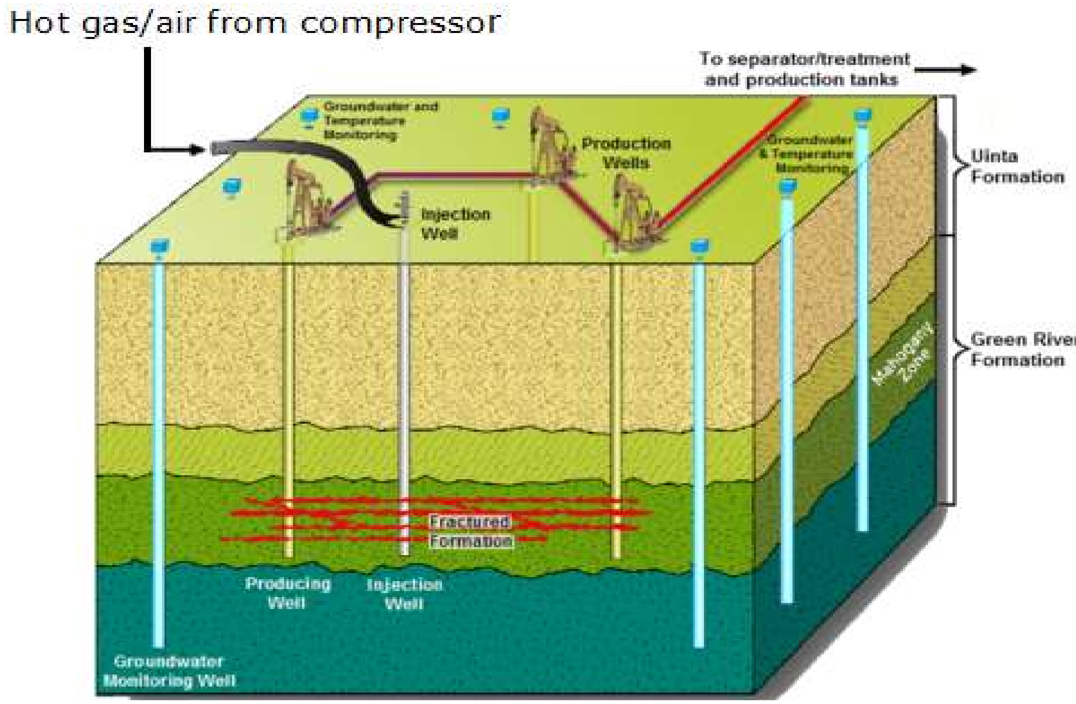

Fig. 11: Chevron crush process (Chevron USA Inc., 2006)

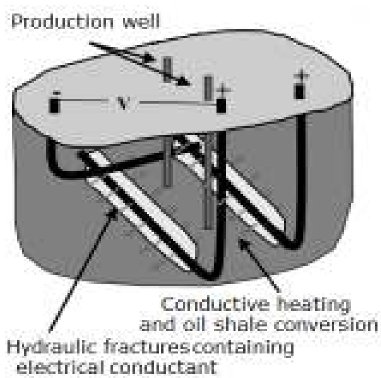

Fig. 12: ExxonMobil electrofrac process (Symington *et al*., 2008)

another horizontal well when both wells are placed in parallel row and intersecting to each other (Symington *et al*.,2008).

RESULTS AND DISCUSSION

This section provides results and discussion pertaining to the advantages and disadvantages on the various methods of shale oil extraction/process and its impacts to environment, economy of the world and future outlook and requirements.

Advantages and disadvantages of shale oil extraction/process methods: Surface processing which normally known as surface retorting is the traditional and commonly shale oil extraction method. The process is mainly divided into three steps: oil shale mining, retorting above ground and shale oil processing to obtain valuable products. Surface processing has many disadvantages such as the shale oil mining brings large impact to land due to large amount of waste shale being disposed after shale oil mining. Large amount of the groundwater needs to pump out in order to avoid the mine from being flooded.

For in-situ processing method, the shale oil processing occurs underground. Thus, in-situ processing has more advantages than surface processing. The problem of handling and disposing of large amounts of residual material can be avoided and the deep oil shale deposit can be reached from in-situ processing. In-situ processing is able to produce high quality shale oil as it utilizes slow heating and retorting underground method. Nevertheless, in-situ processing can be employed for a small scale operation by using different underground heating method (American Shale Oil Corp., 2015).

Alberta Taciuk Process (ATP): This process requires large quantity of water and it produces large volume of oily waste water. However, with the advantage of new rotary-kiln technology for shale oil extraction and processing, less amount of water is needed for processing. It is able to handle fine particle and having higher yield.

Chinese Fushun process: This process uses a vertical rotary kiln for shale oil extraction. The advantages of this process are; relatively cheap and has high thermal efficiency. During the process, pyrolysis gas or retorting gas is diluted due to the addition of air into the retort. The excess oxygen in the retort will burn out some the shale oil. It consumes large amount of water and left behind large quantities of spent shale. The process is not capable to handle ore with fine particle of less than 5% oil content.

Galoter process: This surface processing technology requires hot oil shale ash for pyrolysis process of raw shale. The main advantages of the Galoter process are the high technological chemical efficiency up to 78% and high thermal efficiency. It also has high oil recovery ratio where 90% yield can be achieved. This process is able to produce high quality oil with less pollution. This is because less water is needed. However, it will still produce small amount of air pollutant such as carbon dioxide, calcium sulphide and carbon disulphide.

Kiviter process: This surface processing using vertical retort technology uses recycled gas steam and air to heat the raw oil shale. The recycled gas is generated by burning the spent residue with the produced oil shale gas inside the retort. This process requires large amount of water, which will produce large amount of polluted water. The solid waste would leach into the surrounding environment.

Petrosix process: It is the world's largest surface processing retort. Externally generated hot gas is used for retorting. The only disadvantage of this process is that it does not utilize the potential heat of fixed carbon contained in the shale coke.

Royal dutch shell oil company in-situ conversion process: This innovative technology applies a series of underground electrical heating elements which are drilled into an oil shale deposit. This process is currently unproven on a commercial scale because it needs take few years to extract the shale oil. However, it is a very promising technology as stated by US Department of Energy. Shell has also invented a freeze wall to prevent the groundwater to enter the oil shale site (Roger and Melanie, 2015).

American shale oil CCR process: The primary advantage of CCR^{TM} process is where it applies thermal heat at mechanical fracturing surrounding the retort. Refluxing oil will create permeability for heat distribution. Thick layer of impermeable nahcolitic oil shale which contains high amount of baking soda is used in this process for separating the extraction site from the aquifer. Thus, it prevents the contamination of aquifer (American Shale Oil Corp., 2015).

Chevron crush process: This technology was invented by Chevron Corporation and Los Alamos National Laboratory (LANL) for enhancing hydrocarbons recovery in oil shale. This technology is an in-situ slow flowing oil formations process which is able to capture and reuse the combustion gas to avoid causing greenhouse effect. Another advantage of this process is the use of conventional drilling which is more cost effective, less environmental impact and less consumption of water (Chevron USA Inc., 2006).

ExxonMobil electrofrac process: This energy efficient in-situ oil shale conversion process has the potential to recover oil and gas from thick and deep oil shale by applying electrofrac. Electrofrac is produced by introducing calcined coke and cement slurry at sufficient pressure to break the oil shale rock. Electrofrac can be applied for several months at low temperature without generating any hot spot which will damage the electrical conductant (Symington *et al*., 2008).

Environmental impacts and control technologies: The emerging of the shale oil industry may cause environmental issue. This becomes the main concern in the development of global shale oil industry. Environment impacts of shale oil production include air pollution, waste water discharge, land disruption after surface mining. Over several decades, many companies have developed a number of pollution control technologies aiming to meet the regulations of pollution control and waste disposal. Today, some of the wastes are collected and converted to valuable products. For example, shale ash is used to make cement and phenol can be extracted from waste water (Wan, 1998).

Water pollution and control technologies: Waste water leaches from a retorting plant mainly contains suspended solid, oil, oxygen, nitrogen and sulphur compound. The moisture content of oil shale feed, retorting condensation and recovery methodology will determine the amount of waste water discharged from retorting process. It is distinguishable seen from the shale oil retorting process in Fushun and Maoming, where large quantity of water is used as a direct water scrubbing method to cold and condense the retorting hot vapor gas mixture and part of the added water needs to discharge as waste water. For example, 9 tons of fresh water is needed to produce 1 ton of shale oil and 5 tons of waste water would be discharged. The composition of the waste water contains large amount of oil, dust, phenol, sulphide and pyridine (Wan, 1998).

In order to meet the pollution control regulations, China Maoming Oil Shale Company has invented a waste water treatment technology. Firstly, static sedimentation, oil interception, flocculation and air floatation are used to treat the retorting water before

Table 1: The waste water treatment data (Wan, 1998)

Waste components/ Biological contents	COD (mg/L)	BOD (mg/L)	Oil (mg/L)	Phenol (mg/L)	Suspension (mg/L)
Wastewater	27,000	-	2,660	230	2,300
Setting (200 h)	24,700	-	960	210	720
Interception and flocculation	22,000	-	630	130	470
Air floatation	10,300	-	170	60	260
Water dilution	19,000	580	60	20	-
Biological treatment	900	52	20	1	-

Table 2: Two stage biological waste water treatment data (Wan, 1998)

Biological contents/Stage	Waste water in	First stage	Second stage
BOD (Tot., mg/L, 7 days)	114-292	96-255	19-62
BOD after setting (mg/L, 7days)	-	34-173	10-20
Volatile phenols (mg/L)	42500	0.3-5.0	0.05-0.25
Phenols (Total mg/L)	16-34	6.6-23	2.3-7.6

undergoing biological treatment. By using this technology, the Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), hydrocarbon and volatile phenol content in waste water are greatly reduced. The waste water treatment data are shown in Table 1. 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 of waste water was developed by Kiviter Oil Shale Chemicals Company in Estonia to meet the pollution control regulations. The waste water is pre-treated in the treatment plant containing commuting device, vortex grit removal system and primary solid sedimentation before entering the aerated equalization basin for two stage activated sludge sedimentation. About 28,000 to 30,000 tons per day of oil shale waste water are treated using this technology and it can be increased to 55,000 tons per day. The two stage biological waste water treatment data are shown in Table 2.

Air pollution and control technologies: The mining and processing of shale oil will emit pollutant including sulphur dioxide, carbon monoxide, ozone, particulate, nitrogen oxides, ammonia, carbon dioxide and trace elements into atmosphere.

Air pollutant such as carbon monoxide, nitrogen oxide, hydrocarbon, sulphur dioxide and fine particle are emitted during storage, transport and crushing of oil shale, while pollutant like carbon monoxide, hydrocarbon and nitrogen oxide would be emitted during in-situ processing due to incomplete combustion of the fuel oil during blasting. The amount of air pollutant produced from surface processing is higher than in-situ processing due to large amount of solid rock needed to be handled on the surface and it produces large amount of dust.

Large amount of atmospheric emission may be produced during retorting process. The quantity of sulphur dioxide emitted mainly depends on the sulphur content of the fuel used for retorting. The amount of hydrogen sulphide, carbon disulphide and carbonyl sulphide in the off gas stream is highly dependent on type of retorting technology used. The emission of trace element may due to the operation or retorting process. Nevertheless, the pollutant such as hydrocarbon, ammonia, hydrogen sulphide, sulphur dioxide, carbon disulphide and carbonyl sulphide may be produced during shale oil re-processing, 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 has opposite charge. Recently, wet precipitator and charged droplet scrubber are developed and widely used by Brazil Petrobras Company. It has advantages of high removal efficiency up to 99.9%, low energy requirement, able to handle high flow rates and required only little maintenance.

Shell Claus off-gas treating technology is used by heating the off gas with hydrogen gas and the mixture will then pass through a bed containing cobalt-molybdenum catalyst. The sulphur compound will be converted into hydrogen sulphide. The gas mixture is then sent to an absorber to extract concentrated hydrogen sulphide. The hydrogen sulphide will liberate 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 sulfide. The 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 the bisulfide to sodium hydroxide. This technology is well established and is able to remove 99% of sulphur dioxide (United States Congress Office of Technology Assessment, 1980).

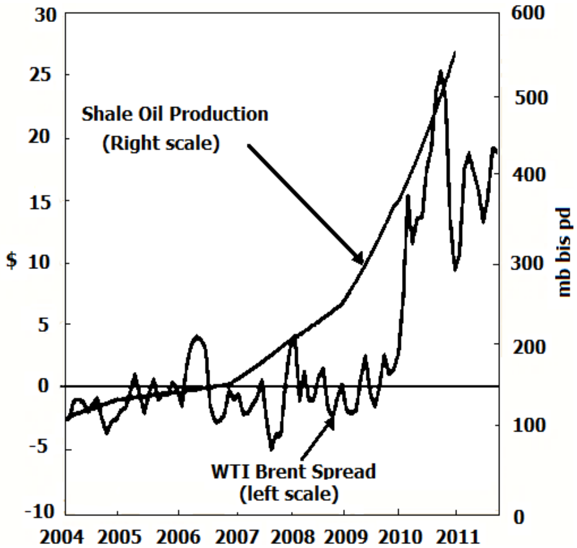

Fig. 13: WTI and Brent oil prices spread with shale oil production from 2004 to 2012 (U.S. Energy Information Administration, 2012)

Impacts to world economy and oil prices: Shale oil is rapidly emerging as a viable energy in the future as the reserve of petroleum oil is declining in the coming decades. The future production of shale oil is 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, the United States. However, the developing of shale oil industry was unsuccessful due to the lack of improve extraction technology, the high cost of mining and the environment problem in disposal of spent shale.

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 advancement 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 the United States and the increase of shale oil market demand which reduce the current global oil prices show that the invention of different types of new oil shale technology have successfully supported the growing worldwide interest in the development and expansion of oil shale activity in future (Speight, 2011).

Figure 13, the shale oil production in the United States is growing rapidly from 111,000 barrels per day in 2004 to 553,000 barrels per day in 2011 The production may strike 1.2 million per day by the date as forecast by U.S Energy Information Administration (EIA). In 2010, the total shale oil reserve in the United States is estimated to be 33 billion barrels (U.S. Energy Information Administration, 2012). Around 35-40% of crude oil imports to the United States is 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 (PWC (Price Waterhouse Coopers), 2013). Currently, the United States domestic oil price has been reduced significantly due to the rapidly growth of shale oil production.

The WTI and Brent crude oil prices are in reducing trend from June 2010 to June 2015 due to the weak demand, increase supply caused by the growth of shale oil production in the United States as shown in Fig. 14.

The development of shale oil production industry beyond the United States is still at an early stage but

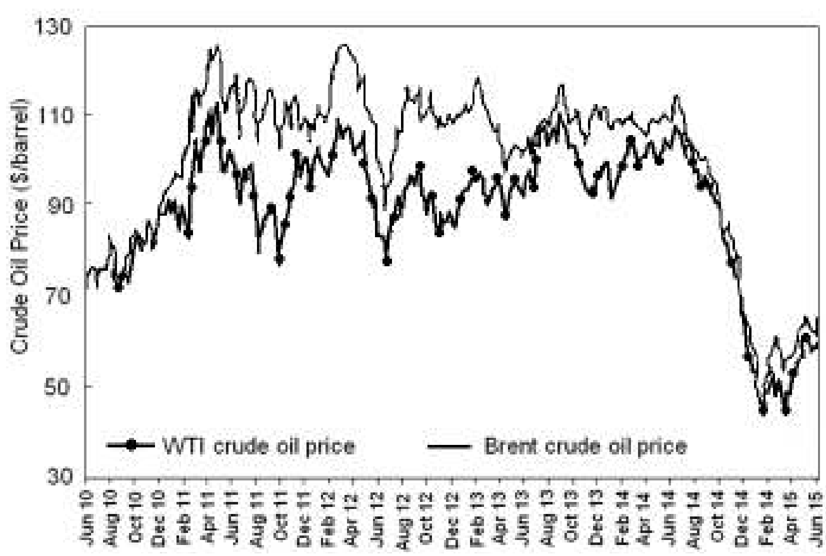

Fig. 14: WTI and Brent crude oil prices from June 2010 to June 2015 (Kristopher, 2015)

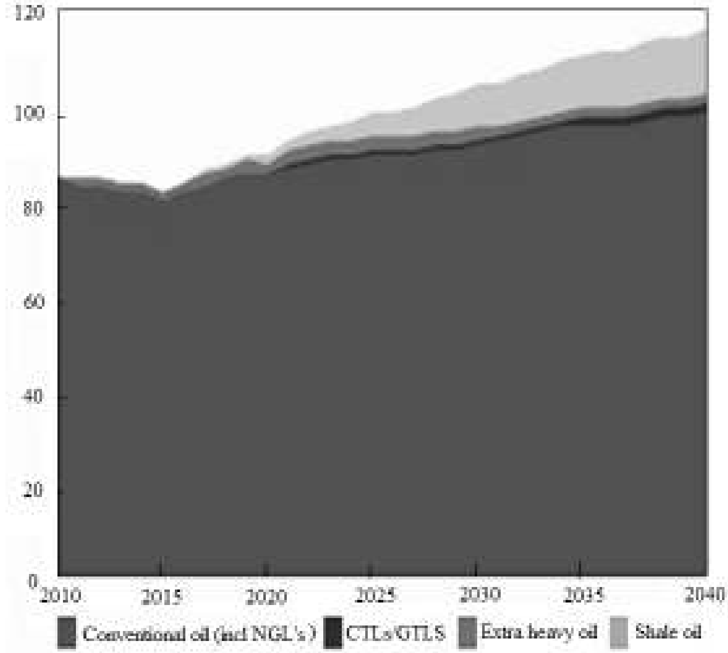

Fig. 15: Global oil production by resources (U.S. Energy Information Administration, 2012; PWC (Price Waterhouse Coopers), 2013)

many extraction technologies are developed globally as the global shale oil reserve is estimated around 330 billion to 1,465 billion barrels (McGlade, 2011). The investment in shale oil exploration and production has already underway in Argentina, China, Russia, New Zealand, Australia, Mexico and Japan since the beginning of 2012.

Recently, U.S. Energy Information Administration (EIA) and International Energy Agency (IEA) have separately forecasted the global shale oil production would achieve 28% and 19% respectively by 2035. EIA estimates that 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, both agencies assume that modest growth in shale oil production. This forecast is arguably conservative as the shale oil production is likely to be increased significantly over time as the development and investment are already underway in the United States and other counties globally (U.S. Energy Information Administration, 2012).

The global shale oil production has highly potential to increase to up to 14 million barrels per day which is about 12% of total oil supply as shown in Fig. 15.

In addition, according to U.S. Energy Information Administration (PWC) analysis shown in Fig. 16, 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 increase in shale oil production will subsequently lower oil price

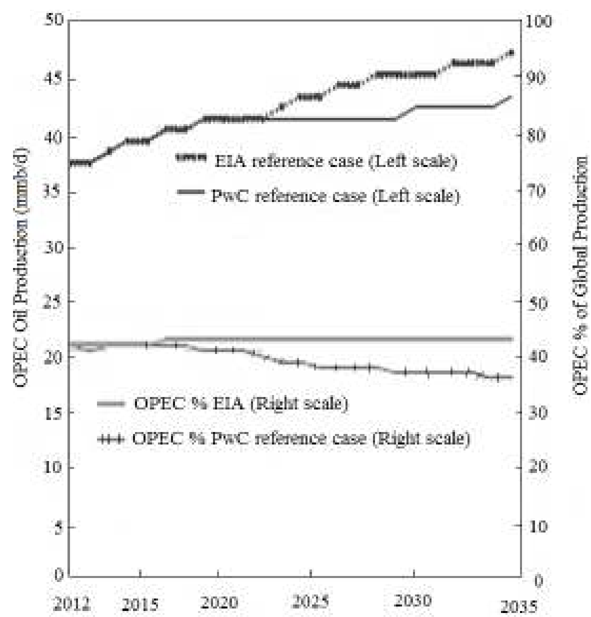

Fig. 16: Forecast of OPEC production in PWC reference case versus EIA reference case (U.S. Energy Information Administration, 2012; PWC (Price Waterhouse Coopers), 2013)

as OPEC is allowed to limit its oil production in order to maintain the average oil price of around $100. This shows that OPEC is losing some global oil market share 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 price may fall to around $83 per

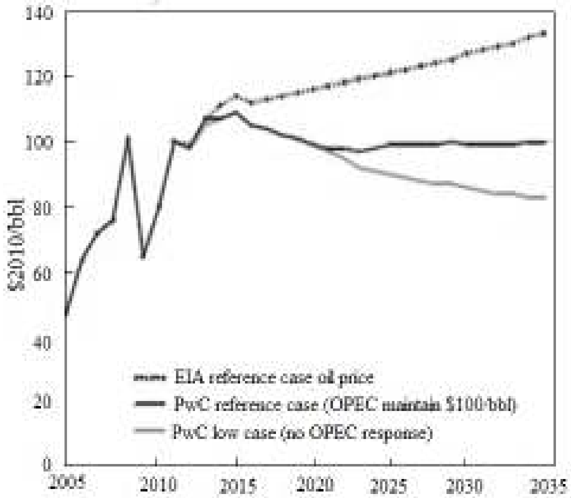

Fig. 17: Forecast of oil price incorporating Impact of shale oil production vs. EIA Forecast (U.S. Energy Information Administration, 2012; PWC (Price Waterhouse Coopers), 2013)

barrel by 2035 due to the increase of overall oil supply (PWC (Price Waterhouse Coopers), 2013).

Thus, by referring to both scenarios, the production of shale oil will bring the impact lowering the global real oil price to around $33-$50 per barrel by 2035 which is 25% lower than the forecast made by EIA as shown in Fig. 17.

Another long term macroeconomic impact of lower global oil price due to the production of shale oil is higher global GDP. The level of global GDP is estimated to increase between 2.3 and 3.7% as the decrease of $33-$50 in real global oil price. The global economy is said to be increased to around $1.7-2.7 trillion per year as shown in Fig. 18 (PWC (Price Waterhouse Coopers), 2013).

The PWC analysis shown in Fig. 19 forecasts that the shale oil revolution may bring benefit to large net oil importers such as Japan and India boosting their GDP by around 4 to 7% by 2035, while China, the United States, United Kingdom and the Euro zone may get 2 to 5% increase of GDP. On the other hand, major oil exporters such as the Middle East countries and Russia may have a significant reducing of their trade balances by roughly 4 to 10% in long run if they are unable to develop their own shale oil reserves. The shale oil bloom may reduce the influence of OPEC in global oil and gas industry and also the government worldwide as it increases energy dependence for many countries.

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 Fig. 20, the estimated average production of world primary energy will increase 1.4% per year from 2013 to 2035. Asia Pacific region shows the largest increase of around 45%, while Central and South America have a growth rate of around 2.1%. North America is the second largest regional energy producer due to large shale oil reserve. Shale oil and other new sources of energy able to achieve aggregate growth of 6% per annual which will contribute 45% increase in energy production by 2035 as shown in Fig. 21.

The high global oil price two years ago was the main factor lead to significant increase of North America shale oil production. This shale oil boom has the potential to alter global energy balance as the technically recoverable of unconventional oil is estimated around 340 billion barrels globally as shown

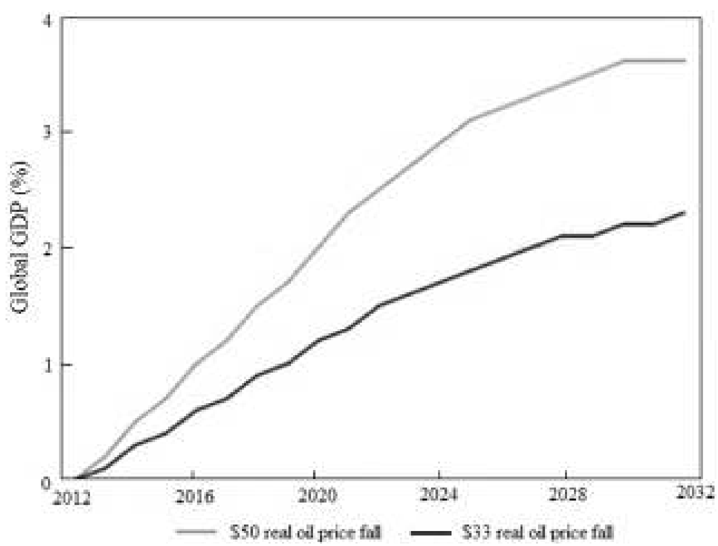

Fig. 18: Percentage of Global GDP benefits from a lower oil price (PWC (Price Waterhouse Coopers), 2013)

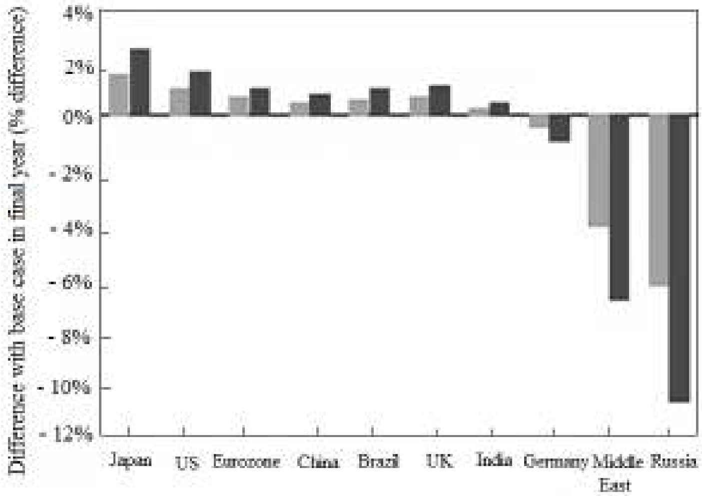

Fig. 19: Change in % of global GDP in alternative oil price scenarios (PWC (Price Waterhouse Coopers), 2013)

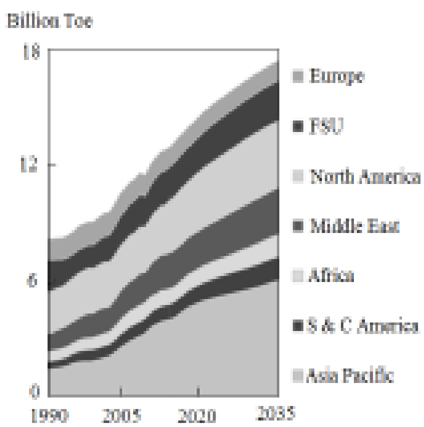

Fig. 20: Forecast of global primary energy production growth (BP p.l.c., 2015)

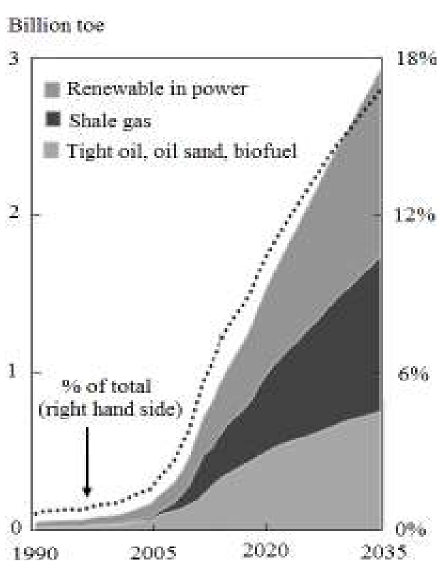

Fig. 21: Forecast of global new sources energy growth (BP p.l.c., 2015)

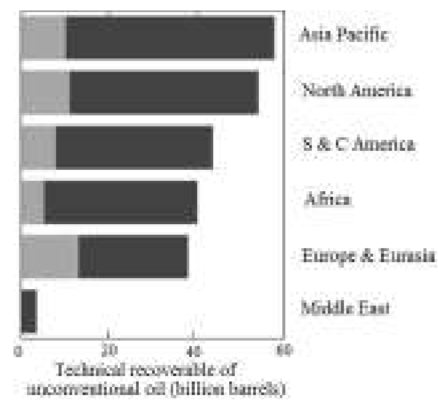

Fig. 22: Technically recoverable of unconventional oil (BP p.l.c., 2015)

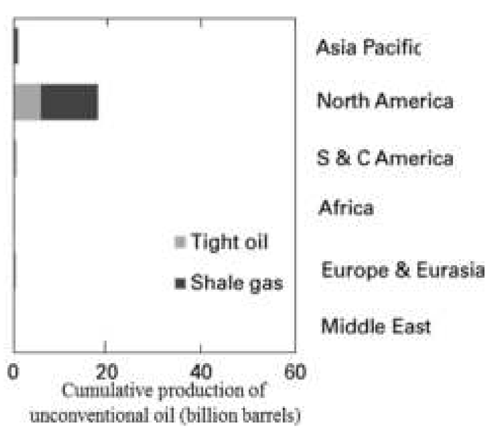

Fig. 23: Cumulative production of unconventional resources from 2013-2035 (BP p.l.c., 2015)

in Fig. 22. The shale oil production is remaining concentrated in North America although the reserves are spread around other part of the world. As it can be seen in Fig. 23, the cumulative of shale oil production in North America is about 50% of technically

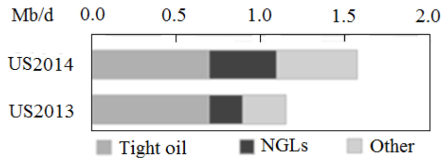

Fig. 24: North America oil production (BP p.l.c., 2015)

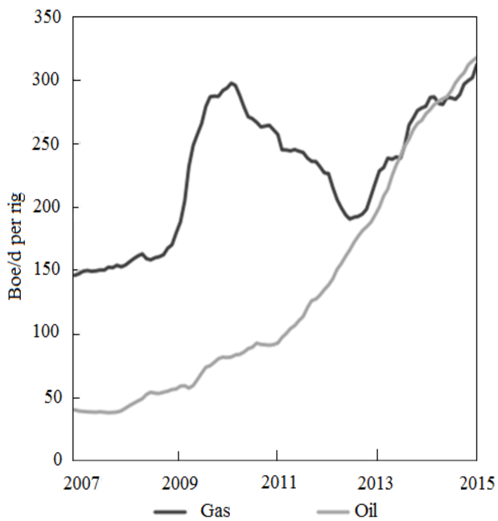

Fig. 25: North America new-well production per rig (BP p.l.c., 2015)

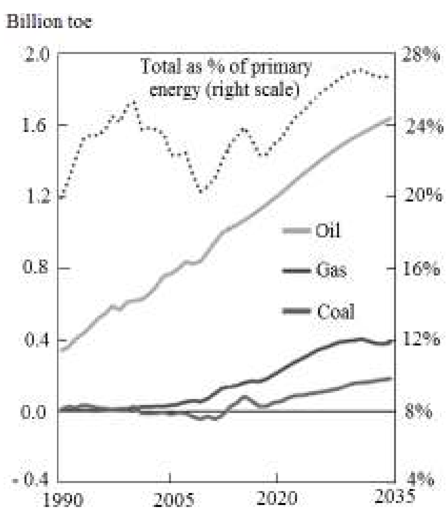

Fig. 26: Asia's net import of energy (BP p.l.c., 2015)

recoverable resource. However, the factor which leads to dramatic growth of production in North America is unlikely to be achieved outside North America.

The development of unconventional resource industry helps North America particularly the United States to strike a highest oil production growth in 2014 as it is shown in Fig. 24. The innovation of new technology and increasing investment support the growth of unconventional resources with the new well production has increased per rig by 34% per year for shale oil from 2007 to 2014 as shown in Fig. 25.

Owing to the production of shale oil, North America, which is originally a net importer of energy, becomes a net exporter soon after 2015. Although Middle East countries still remain as the largest net energy exporters but as a long term impact, their share in oil business are estimated to fall from 46% in 2013 to 36% in 2035 due to the low global oil price and large unconventional energy resources. As shown in Fig. 26, Asia is considered as a highly potential energy consumption market. This is because the estimated amount of energy import may achieve around 70% of inter-regional net import by 2035. The Asia's oil import in 2035 is believed to be as large as OPEC's current entire oil production (BP p.l.c., 2015).

CONCLUSION

The study has reviewed several extraction and processing methods of shale oil. The impact to environment due to extract and process of shale oil can be contained as many producing companies have their own methods to tackle environmental issue. Shale oil will have great impact to global energy and economy. It would contribute about 6% of total energy demand by year 2035 benefiting the large net oil importers with forecasted GDP growth of 2 to 7%. On the other hand, major current oil exporters would have a reduction of their trade balance by roughly 4% to 10% by year 2035.

REFERENCES

American Shale Oil Corp., 2015. Oil Shale Extraction Method. AMSO American Shale Oil Corp.

Argonne National Laboratory, 2012. About Oil Shale. 2012 Oil Shake and Tar Sands Programmatic EIS.

Bartis, J.T., T. LaTourrette, L. Dixon, D.J. Peterson and G. Cecchine, 2005. Oil Shale Development in the United States: Prospect and Policy Issues. National Energy Technology Laboratory of the U.S. Department of Energy by the Rand Corporation, Santa Monica, California.

BP p.l.c., 2015. BP Energy Outlook 2035. United Kingdom, London.

Burnham, A.K. and J.R. McConaghy, 2006. Comparison of the acceptability of various oil shale processes. Proceeding of the 26th Oil Shale Symposium. Lawrence Livermore National Laboratory. Golden, Colorado.

Chevron USA Inc., 2006. Oil Shale Research, Development & Demonstration Project Plan of Operations. Chevron USA Inc. Retrieved from: http://www.blm.gov/style/medialib/blm/co/field_offices/white_river_field/oil_shale.Par.37256.File.dat/OILSHALEPLANOFOPERATIONS.pdf.

Clark, J., 2013. What's Oil Shale. How Stuff Works Science, pp: 1-3.

Dyni, J.R., 2006. Geology and resources of some world oil-shale deposits. USGS Scientific Investigations Report 2005-5294.

European Academics Science Advisory Council, 2007. A study on the EU oil shale industry-viewed in the light of the Estonian experience. A Report by EASAC to the Committee on Industry, research and Energy of the European Parliament, pp: 47-50.

Golubev, N., 2003. Solid oil shale heat carrier technology for oil shale retorting. Oil Shale, 20(3): 324-332.

Karanikas, J.M., E.P. de Rouffgnac, H.J. Vinegar and S.L. Wellington, 2005. In Situ Thermal Processing of an Oil Shale Formation while Inhibiting Coking. Patent: US 6877555 B2.

Kristopher, G., 2015. U.S. Crude Oil and Brent Crude Oil Spread Widens. Market Realist.

Matt Egan, 2015. Why OPEC can't kill the U.S. oil boom. CNN Money International.

McGlade, C.E., 2011. A Review of Uncertainties in Estimates of Global Oil Resources. UCL Energy Institute.

PWC (Price Waterhouse Coopers), 2013. Shale Oil: The Next Energy Revolution. United Kingdom. Retrieved from: https://www.pwc.com/gx/en/oil-gas-energy/publications/pdfs/pwc-shale-oil.pdf.

Qian, J. and J. Wang, 2006. World oil shale retorting technologies. Proceeding of International Conference on Oil Shale: Recent Trends in Oil Shale. Amman, Jordan.

Roger, E. and S. Melanie, 2015. Oil Shale: A Fuel Lifeline. Oil Shale Information Centre. United Kingdom, London.

Soone, J. and S. Doilov, 2003. Sustainable utilization of oil shale resources and comparison of contemporary technologies used for oil shale processing. Oil Shale, 20(3): 311-323.

Speight, J., 2011. Handbook of Industrial Hydrocarbon Processes. Elsevier Inc., pp: 203-238.

Symington, W.A., D.L. Olgaard, G.A. Otten, T.C. Phillips, M.M. Thomas and J.D. Yeakel, 2008. ExxonMobil's electrofrac process for *in situ* oil shale conversion. Proceeding of AAAPG Annual Convention. American Association of Petroleum Geologists, San Antonio.

United States Congress Office of Technology Assessment, 1980. An Assessment of Oil Shale Technologies. Congress of the United States, Office of Technology Assessment, Washington, D.C.

United States Department of Energy & Office of Naval Petroleum and Oil Shale Reserves, 2014. Secure Fuels from Domestic Resources: The Continuing Evolution of America's Oil Shale and Tar Sands Industries (PDF). 5th Edn., NTEK, Inc., Report.

U.S. Energy Information Administration, 2012. Annual Energy Outlook 2012. Washington DC, June 2012.

Wan, J.Q., 1998. Environmental Impacts of Oil Shale and Pollution Control Technologies. Coal, Oil Shale, Natural Bitumen, Heavy Oil and Peat-Vol. II.

World Energy Council, 2010. 2010 Survey of Energy Resources. SER Committee Membership.