Shale Oil: Its Present Role in the World Energy Mix

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Abstract: When oil shale rocks are heated (pyrolysed) in absence of oxygen it produces shale oil. The shale oil available technologies and production capacities in million bbl/year are the Enefit280, (1.7) VKG Petroter, (0.63), (while total Estonian companies production is 1.6) Brazilian Petrosix, (1.0) Fushun retorts processes, (0.9) and the newly installed ATP process in China in testing stage. The shale oil produced by these technologies is used as heavy fuel oil for heating purposes or ships fuels due to its physical properties and contaminants. The contribution of shale oil in the energy mix is increasing but up to now is insignificant.

Keyword: Shale oil, energy mix, oil shale, heavy fuel.

1. INTRODUCTION

Extracting shale oil from oil shale is more potentially costly than the production of conventional crude oil both financially and in terms of its environmental impact [1]. Deposits of oil shale occur around the world, including major deposits in the United States of America. Estimates of global deposits range from 2.8 to 3.3 trillion barrels [2].

Shale oils obtained by different retorting technologies are characterized by wide boiling point range and by large concentrations of hetero-elements and also by high content of oxygen, nitrogen, and sulfur containing compounds [3].

Mining oil shale involves a number of environmental impacts, more pronounced in surface mining. They include acid drainage induced by the sudden rapid exposure and subsequent oxidation of formerly buried materials, the introduction of metals including mercury into surface water and groundwater, increased erosion, and sulfur-gas emissions [4]. The recent rebound in US oil and gas production, driven by upstream technologies that are unlocking light tight oil and shale gas resources, is spurring economic activity with less expensive gas and electricity prices giving industry a competitive edge [5]. By year 2020, the United States is projected to become the largest global oil producer (overtaking Saudi Arabia until the mid-2020s) and starts to see the impact of new fuel-efficiency measures in transport [5].

Shale oil extraction is also very energy-intensive [6]. Researchers have found that a gallon of shale oil can emit as much as 50 percent more carbon dioxide [7] than a gallon of conventional oil would over its given lifecycle from extraction to tailpipe.

Crude shale oils are viscous, waxy liquids made up of hydrocarbons (alkanes, alkenes and aromatic compounds) and polar components (organic nitrogen, oxygen and sulfur compounds [8]). Crude shale oils are very complex mixtures, and only few of the compounds have been identified [9]. The gaseous product is a mixture of carbon monoxide, carbon dioxide, hydrogen, nitrogen, hydrogen sulfide, methane, and other hydrocarbons gases (C_4^-), i.e. methane, ethane, and propane.

Oil-shale industries are operating in Europe (Estonia), South America (Brazil) and Asia (China). The largest operations are in Estonia, where approximately 12 million tonnes of oil shale is mined annually [10] (underground and open-pit mining). About 85% of this material is burned as fuel in electric power-plants in north-eastern Estonia; the remainder is retorted for shale oil and used to manufacture fuels and petrochemicals. In Brazil [11], oil shale is mined in open pits and is retorted for shale oil, liquefied petroleum gas, sulfur and fuel gas.

Estonia is unique in its reliance on oil shale for energy. It sits on large deposits and is almost independent in energy an important consideration for a young nation bordering oil-rich Russia. Estonia uses 85 per cent of the shale it mines to generate electricity [12], with most of the rest producing oil.

Now Eesti Energeia (Enefit outside Estonia) is taking the first steps towards exporting the technology

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E-ISSN: 2409-5818/18

it has refined for decades. It expects to build a 540MW power station in Jordan [13]. Several multibillion projects to generate oil from oil shale and build oil shale-fueled electricity plants are underway in Jordan. Jordan has signed several agreements and memoranda of understanding with key international companies with experience in oil shale in order to utilize its reserves of oil shale. According to the Jordan government [14], between 2 and 6 million barrels of oil are expected to be produced from oil shale per day by the year 2035. Production is expected to start initially in small quantities, rising gradually every year to reach significant quantities.

In 2011 Eesti Energeia bought a large oil shale deposit in the US state of Utah, which the company believes contains 2.6bn barrels of recoverable oil [15]. The US has 80 per cent of the world's oil shale. The IEA estimates [16] that an oil price of at least $60 per barrel is required to make commercial exploitation of kerogen shale for oil production profitable.

Other processes include the Kiviter (Prtroter) and Galoter (UTT 3000), Enefit280 retorts in Estonia, the Alberta Taciuk Processor considered for use by OSEC in Utah, Shell's In-Situ Conversion Process (ICP) under consideration in Colorado and Jordan, Petrobras' Petrosix Gas Combustion Retort (and variations) in use in Brazil, the Raytheon/CF radio-frequency with critical fluids technology just licensed by Schlumberger, and the EcoShale process under development in Utah [17].

2. SHALE OIL

Although, shale oil is not considered renewable energy, the share of renewables in the energy mix will continue to grow [18] in Europe from 21% in 2020 to 27%in 2030 and 31% in 2050.

Retorting oil shale industrial processes [19] are operating in Estonia (Enefit140, Enefit280, Petroter, and Galoter), Brazil (Petrosix, Prix) and China (Fushun retort, recently ATP). Table **1** list the oil shale retorting technologies and related specifications.

The hydrocarbon bearing material in oil shale is termed kerogen which constitute up to 20% of the oil shale material. It is necessary to heat the oil shale to 450 – 520^{o}C (low temperature pyrolysis) to thermally break up kerogen into shale oil (65-70%), gas (10-15%), coke (15-20%) and retorted water (2-7%) [18].

As a result of retorting, a lot of unsaturated hydrocarbons are also formed. Phenols and alkenes, are typical compounds in shale oils. For example, alkanes, cycloalkanes and alkenes constitute 10% of shale oil whereas, aromatics slightly higher than 27% and heteroatomic compounds makes 60% of the liquid shale [17] as indicated in Table **2**. The average H/C

Table 1: Overview of the World's Commercial Oil Shale Retorting Technologies [20]

Country	China	Estonia			Brazil	Alberta Taciuk
Retort	Fushun Type	Kiviter Petroter	Galoter UTT 3000	Enefit140 Enefit280	Petrosix (Prix)	ATP (China)
Retort Configuration	Vertical	Vertical	Horizontal	Horizontal	Vertical	Horizontal
Heat carrier	Gas	Gas	Ash	Ash	Gas	Ash
Particle size, mm	10 – 75	0 –25	0 – 25	0 – 25	6 – 75	0 – 25
Shale oil, 10^3ton/year	600[20]	100[24]	2.8*	248[22]	210[21]	testing
Gas, MM^3/year (Ton)	N.A.	30[23]	N.A.	75	29207 T	testing

Table 2: Average Chemical Composition of Shale Oils [28]

Chemical Group	Composition, wt.%
Alkanes, cycloalkanes and alkenes	9.0 – 10.5
Aromatics	25.0 – 30.0
Phenols	10.0 – 30.0
Ketones	15.0 – 30.0
Sulfurous compounds, (thiophens, mercatpens)	5.0 – 40.0
Nitrogenous compounds, (Pyridine, Quinoline derivatives)	0.0 – 4.0

ratio of the shale oil varies between 1.1 and 1.8 depending on kerogen type, I, II and III. In crude oils, the H/C ratio varies as1.1 to 1.2 depending on the petroleum composition [25].

In general, shale oil main constituents are saturate hydrocarbons include n-alkanes, Iso-alkanes, and cycloalkanes, and the alkenes consist of n-alkenes, Iso-alkenes, and cycloalkenes, while the main components of aromatics are monocyclic, bicyclic, and tricyclic aromatics and their alkyl substituted homologues.

Oxygenated species are generally present in shale oil liquids. Molecular phenolic compounds are the main acidic oxygen-containing compounds in the light fraction of the shale oil. In addition to small amounts of carboxylic acids may also be present such as ketones, indenones, aldehydes, esters, and amides.

The basic nitrogen-containing compounds [28] of shale oils are pyridine, quinoline, acridine, amine and their alkyl substituted derivatives, the relative magnitude depend upon source of oil shale. The weakly basic nitrogenous compounds are pyrrole, indole, carbazole and their derivatives, and the nitrile and amide homologues are the non-basic constituents. Most of these compounds are useful chemicals, they also contribute to stability problems during storage of shale oil products since they induce polymerization processes, which cause an increase in the viscosity and give rise to the odor and color of the shale oil product.

The average heating value of a typical shale oil is reported to fluctuate between 7.0–40 MkJ/kg, depending on source, method of retorting and other factors. Shale oil has a wide boiling range depending on deposits and processing technology [25]. For example, more than half of the Kukersite shale oil [25] boils above 350^{o}C, whereas, more than 90% volume distilled of Sultani shale oil [26] boils at lower than 350^{o}C, this makes the Jordanian shale oil is lighter in composition. The boiling range is indicative of the constituent elements of the shale and its molecular weight distribution.

Shale oil is a synthetic petroleum oil produced by oil shale pyrolysis. In Comparison with petroleum crude, shale oil is heavy with 0.9-1.0 specific gravity due to the presence of heteroatoms such as nitrogen, sulfur and oxygen, viscous, and is rich in nitrogen and oxygen compounds [17]. High pour points are observed and small deleterious quantities of arsenic and iron are present. In general, shale oil has a particular and offensive odor, caused by the presence of nitrogen compounds; these components and sulfur bearing compounds are well-known to poison catalytic in various refining processes, such as fluid catalytic cracking, catalytic reforming, and catalytic hydro-treating. They cause stability problems in gasoline, jet and diesel fuels, and produce NO_x emissions. Finally, hydrotreating or upgrading of shale oil is difficult, increasing refining costs significantly.

Synthetic shale oils have high levels of olefins and diolefins, which are not present in petroleum crudes, requiring special care during processing due to their activity to polymerize and form gums. The presence of suspended solids (finely divided rock due to retorting) which cause process problems chiefly if a first step of processing is hydrotreating.

As indicated earlier, few countries produces shale oil industrially and commercially. The shale oil serves best to produce middle-distillates [27] such as kerosene, jet fuels and diesel fuels.

In addition to its use as a fuel, shale oil may also serve in the production of specialty carbons fibers, adsorbent carbons, carbon-black, phenols, and resins, glues, tanning agents, mastic and pharmaceutical products. Products of shale oil refining, whether waste residues or refined fractionates, are both useful. Its concentration of high-boiling point compounds is suited for the production of middle distillates, and additional cracking can create the lighter hydrocarbons used as raw fuels. The shale oil directly derived may be as useful as the products because it may contain higher concentrations of olefins, oxygen, and nitrogen than conventional crude oil.

3. WHAT IS ENERGY MIX

The Energy Mix of a country is the specific combination of different energy sources it uses to meet its energy consumption needs. Energy mix varies according to the energy resources available to a country, either as national resources or what it can import, choices over what it exploits, standard of living (the type of appliances that can be afforded by most people and the level of energy bills they can contemplate) and level of development. A nation's energy consumption is likely to come from various sources as different types of energy are more suitable for some uses.

The variety of electricity generation sources, when they are used collectively are called the energy mix. The following are known source of generating power from un-depleting sources of nature:

1. Hydropower is the renewable energy contained in flowing water. Electricity generated using hydropower is known as hydroelectricity and is generally considered to be reliable.

2. The movement of the sea can generate electricity in three ways: *via* tidal turbines, tidal barrages or wave power. Each of these technologies is in the early stages of development, and not yet deployed on a large scale.

3. A wind turbine is a device that converts the wind's kinetic energy into electrical energy. Wind turbines are manufactured in a wide range of vertical and horizontal axis types.

4. Sunlight is a renewable energy source. Solar thermal panels use sunlight to heat water for washing and heating, while solar photovoltaic (PV) panels convert sunlight into electricity.

4. SHALE OIL IN THE WORLD OF ENERGY

Renewable energy sources include solar thermal and photovoltaic energy, hydro (including tide, ocean energy and wave), wind, geothermal energy and all forms of biomass (including biological waste and liquid biofuels). The contribution of renewable energy from heat pumps was reported. The renewable energy delivered to final consumers (industry, transport, households, and services including public services, agriculture, and forestry).

The latest figures [29] available show that in 2014, the EU member states imported just over half of the energy (53.4%) they used. In the same year, the share of energy from renewable sources in the gross final consumption of energy reached 16.0%, which is a 7.5% increase since records of renewables began in 2004. So there is no doubt that steps are being made towards making the continent more sustainable while ensuring energy security.

In 2014, the share of energy from renewable sources in gross final consumption of energy reached 16.0% in the share of renewables in gross final consumption of energy is one of the headline indicators of the Europe 2020 strategy. The target to be reached by 2020 for the EU is a share of 20% energy from renewable sources in gross final consumption of energy. However, renewables will continue to play a key role in helping the EU [29] meet its energy needs beyond 2020. For this reason, Member States have already agreed on a new EU renewable energy target of at least 27% by 2030.

Share of energy from renewable sources in the European Union (in % of gross final energy consumption [30]), Figure **1** shows the rising trend of renewable energy contribution to the total European energy mix. It is expected that the contribution should reach 20% by the year 2020.

One of the major countries employing oil shale in its energy mix is Estonia. The Estonian national gross energy consumption in 2012 was 6.13 Mtoe (Million

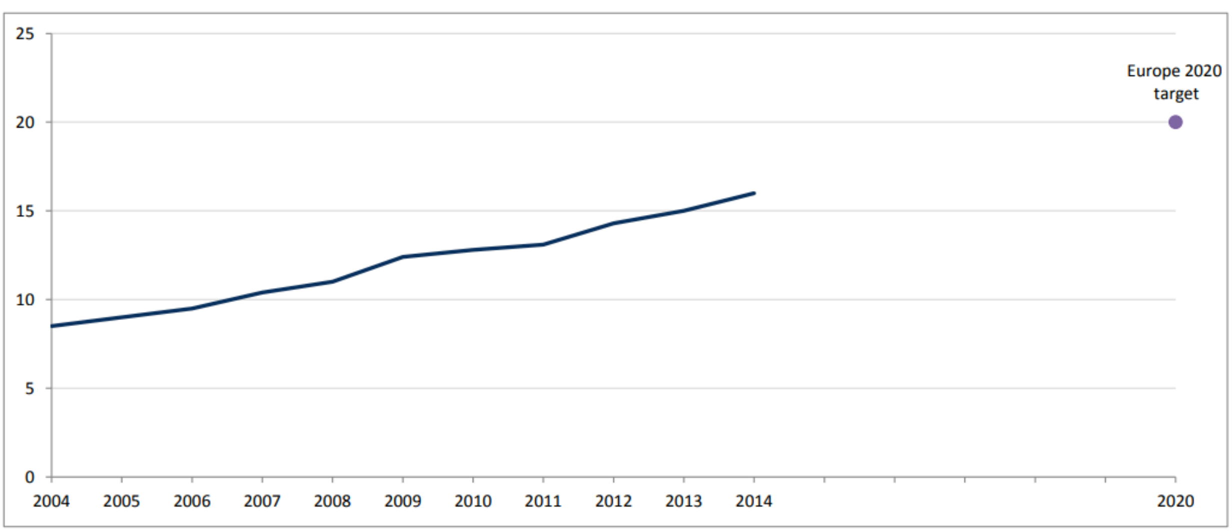

Figure 1: Renewable Energy in rising contribution in Europe [30].

Ton of Oil Equivalent). It was based largely on oil shale, less notable was crude oil, petroleum products and natural gas, while the share of renewables in gross final energy consumption in 2012 amounted to 25.2%. According to Eurostat [29], the renewables share between 2008 and 2012 grew from 19.0% to 25.2% accordingly. The Estonian renewables target for 2020 is 25%. Figure **2** below shows the energy mix of Estonia till 2012.

It can be seen from Figure **2** that the solid fuel (oil shale) contribute more than 60% of the total energy mix. The annual production of shale oil in Estonia is estimated to be more than 250,000 ton. As indicated in Figure **3** below, approximately, 1700 thousand barrels are produced yearly [31].

The main consumers [31] of products are:

- Heat producers.
- Power Plants.
- Road construction companies, farmers and various manufacturing businesses.
- Producers and sellers of bunker fuels.
- International Traders.

Simple calculations show that the contribution of the shale mix in the total energy mix in Estonia is 28% as of 2014; it is anticipated to increase after commissioning the Enefit280 process. The contribution of the liquid shale oil is limited to needs other than normal transportation. Figure **3** present the shale oil

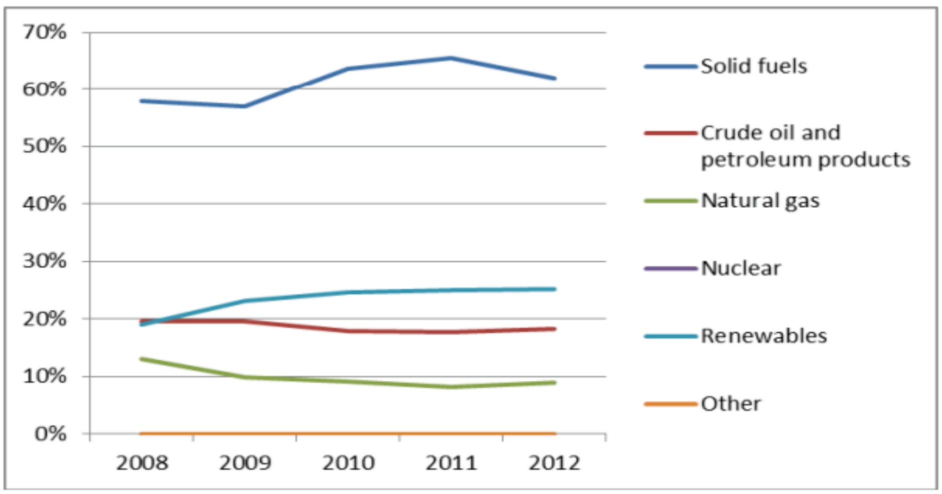

Figure 2: Estonian gross inland consumption mix 2008-2012 [29].

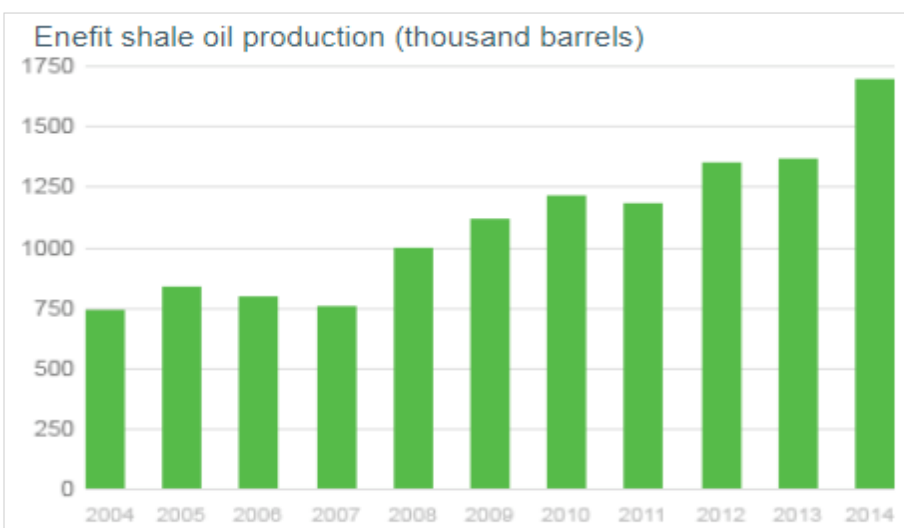

Figure 3: Shale oil production of Enefit Company in Estonia.

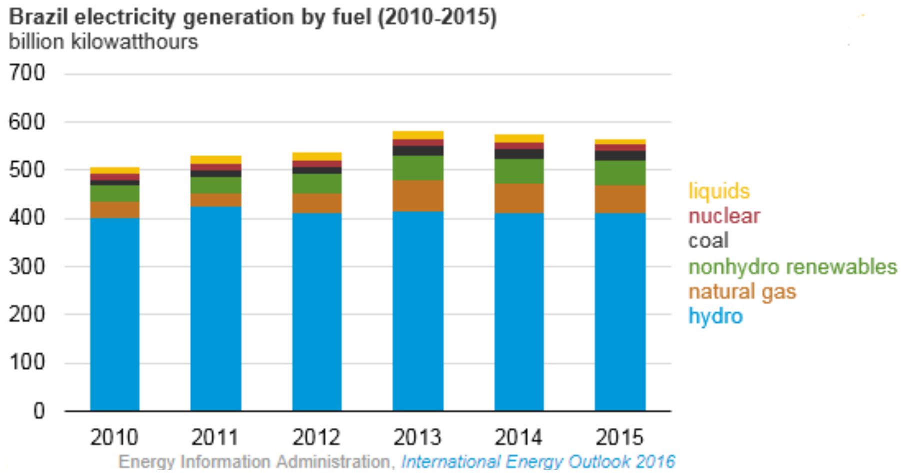

Figure 4: The electricity production in Brazil [35].

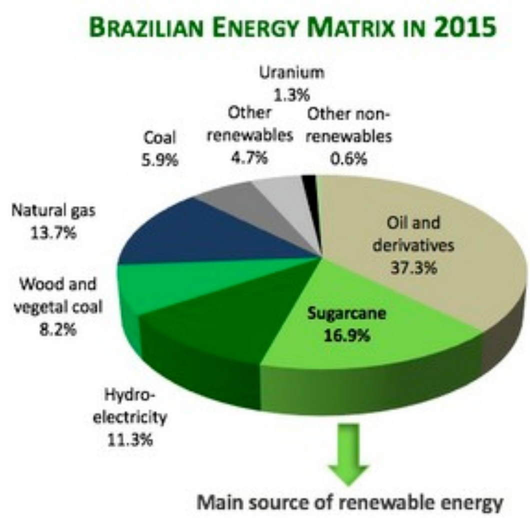

Figure 5: Distribution of energy sources in the total energy mix in Brazil [36].

production of Enefit, the leading company in shale oil. Other Estonian companies are electricity producing rather than shale oil.

The Chinese government plans to cap coal use to 62% of total primary energy consumption by 2020 in an effort to reduce heavy air pollution that has afflicted certain areas of the country in recent years. China's National Energy Agency claims that coal use dropped to 64.2% of energy consumption in 2014 [33].

The Chinese government set a target to raise non-fossil fuel energy consumption to 15% of the energy mix by 2020 and to 20% by 2030 in an effort to ease the country's dependence on coal [33]. In addition, China is currently increasing its use of natural gas to replace some coal and oil as a cleaner burning fossil fuel and plans to use natural gas for 10% of its energy consumption by 2020.

As a result of high coal consumption, China is also the world's leading energy related CO_2 emitter, releasing 8,106 million metric tons of CO_2 in 2012. Gas emits less than half the CO_2 that coal emits. China [34] produces 2.5 million bbl/year of shale oil whereas oil imports are estimated to be more than 3.3 billion bbl/year. This makes the contribution of shale oil in the total energy mix is almost negligible.

Brazil generates the third-highest amount of electricity in the Americas, behind only the United States and Canada. Hydroelectricity provides more than 70% of Brazil's generation [35].

Brazil electricity generation by fuel during the period 2010-2015, more than billions of kilowatt-hours. Production of shale oil in Brazil is only through Petrobras Company using PRIX technology based on

Petrosix process. The 3870 bbl/day (208,000 ton/year) shale production is used as heating fuels. The contribution of shale oil in the Brazilian energy mix is minimal. As indicated in Figure **5** below. The Brazilian oils and their derivatives which include shale oil contribution to total energy mix [36] is estimated as 37.7%. Figure **4** as indicate shows the huge contribution of the hydropower and other sources in the total gigawatt produced in Brazil. The total energy mix contributors are presented in Figure **5** below.

In the USA, Enefit's Utah project [37] is located within one of the richest areas of the regions of oil shale formation, containing a continuous layer of oil shale resource more than 15 m. thick. An estimated 3.5 billion barrels of in-place shale oil resource lies within Enefit's Utah location.

Enefit is planning to start with a 50,000 bbl/day project which would be located on only a portion of the Enefit South property and would be enough to feed the project for 30 years. Enefit's Utah [37] project's planned 50,000 barrels per day is enough to meet 1/3 of today's liquid fuel demand in Utah State in the USA. This project is under construction and is expected to start production in within few years from now. The USA [38] consumes 19.69 million bbl/day in which the 50,000 bbl/day are negligible contribution in the total energy mix.

CONCLUSIONS

Despite the huge reserves of oil shale available on earth crust, which is estimated to contain more than discoverable liquid petroleum reserves, the exploitation of this material is minimal. The contribution of shale oil as liquid material to present energy mix in the entire universe is poor. Estonia is the only country where oil shale plays a significant role in the energy mix and to some extent shale oil. On the other hand, Brazil and China also involved in oil shale industry but due to the huge power needs the produced quantity of shale oil in each country is worthless in the overall power consumption.

The USA and Jordan are building up units for utilization of the huge reserve of oil shale. Jordan will complete its first thermal power station based on oil shale burning then the owner company might enter the shale oil production business.

In conclusions, few countries are taking concrete steps toward oil shale utilization in the energy mix. Jordan is striving to be a leading country after Estonia to have oil shale business in the year 2035 [39].

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Received on 18-12-2017 Accepted on 24-01-2018 Published on 31-01-2018

DOI: http://dx.doi.org/10.15377/2409-5818.2018.05.2