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JORDAN OIL SHALE, AVAILABILITY, DISTRIBUTION, AND INVESTMENT OPPORTUNITY

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ABSTRACT

Jordan (as a non-producing oil country) imports 97% of its energy needs coupled with the impact of the current rising oil prices. The need for developing our indigenous energy resources (i.e. Oil shale) sets as a high priority on the national agenda of the Government of Jordan.

More than 65 Billion tons have been recorded over all Jordan of which 50 billion tons are located in central of Jordan. Jordan is ranked as 8th country among 37 countries in the world shale oil reserves.

Oil shale in central of Jordan is characterized by huge reserves relatively close to each other, good quality offering favorable mining conditions such as Shallow and suitable for surface mining, Stripping ratio is low (1:1 in general), beds are horizontal and structurally undisturbed, soft to moderate overburden rocks, located in remote or thinly populated areas and have good roads connected with asphalted highways.

During the last 28 years, Natural Resources Authority (NRA) has been carrying out extensive geological studies to determine the oil shale quantities and qualities in Jordan. Moreover, NRA in cooperation with many foreign companies, institutes and organizations from many countries in the world carried out technical and prefeasibility studies on oil shale for oil extraction and power generation.

Based on the mentioned facts, there is a very good opportunity to invest in oil shale as a source of energy whether to produce oil or to generate electricity.

1. Introduction

Jordan is one of the developing countries, whose fuel and electricity industries are mostly dependent on imported crude oil. The daily petroleum consumption is around 100,000 bbl*I* day, which becomes a significant load on the GNP and the development of Jordan's economy. So far, the only important indigenous source of energy in Jordan is oil shale.

Oil shale rocks were recognized for the first time since the early time of the Twentieth century in the Yarmouk region north of Jordan near Al-Maqqarin Village. The German Army during the First World War had used it when they installed the first project to produce oil from the Oil Shale to operate the Hijazi Railway. Exploration work started after El Lajjun deposit had been discovered by the German Geological Mission in the 1960s. Intensive exploration activities on oil shale in central of Jordan were carried out during the Eighties as part of the technical cooperation between Natural Resources Authority (NRA) and the German government represented by BGR institute and resulted in delineating other deposits such as Sultani, Hasa and Jurf Ed Darawish. NRA continued its role in exploration and discovered other deposits such as Attarat Um Ghudran, Wadi Maghar, Siwaqa, Khan El Zabib, and El Thammad.

Oil shale is defined as sedimentary rock (mostly carbonates; chalk marl and shale) whose solid immature

organic content is insoluble in organic solvents, but forms liquid oil-like hydrocarbons when exposed to destructive distillations of temperatures up to 500-600ºC.
The Jordanian Oil Shale is kerogen-rich, bituminous, argillaceous limestone that was deposited in shallow marine during the Maestrichtian-Danian periods. The origin of the kerogen is the dead plants and animals that found in the ancient seas and lakes during the Upper Cretaceous period and after the burial process, heat and the pressure which caused the change from organic matter to kerogen.

2. General geology of the Central of Jordan

Three main formations could be identified in center of Jordan in areas where oil shale deposits were found. They are (from old to young) Al Hisa Phosphorite, Muwaqqar Chalk Marl and Umm Rijam Chert Limestone Formations. The stratigraphic and lithological distribution of these formations is as in the following paragraphs.

-Al Hisa Phosphorite Formation (Campanian-Maestrichtian in age)

The formation consists of different lithologies including phosphorite, phosphoritic chert and limestone, chert, fossiliferous limestone (coquina) and marl. The most important is the phosphorite beds where phosphate is extracted as economic raw material. The upper part of this formation (5-10m) is slightly bituminized which is close to the lower surface of the oil shale bed in the upper formation (Muwaqqar Chalk Marl). The coquina beds (two beds) in this formation occur in between the phosphorite beds and are considered the source of calcium carbonate industrial raw material as fossiliferous pure limestone beds.

-Muwaqqar Chalk Marl Formation (Maestrichtian-Paleocene in age)

It consists of (from top to bottom) yellowish marl, pale marly chalk, chalk and marly limestone with some concretions. In some areas beds are recrystallized and slightly metamorphosed (marble). It is characterized by gentle topography slope, low escarpment and straight flat bottom wadis. Bituminous marl (oil shale) and marly limestone beds occur at the lower part of this formation. The lower most beds of this formation contain few bituminized phosphatic limestone and chert beds (5-10m) which indicate the beginning of the underlying Al Hisa Phosphorite formation.

-Umm Rijam Chert Limestone Formation (Eocene in age)

This formation disconformably overlies Muwaqqar Chalk Marl formation. It has been subdivided into two parts; the lower part consists of chalk and chalky limestone associated with marble, while the upper part consists of alternating beds of limestone and chert overlain by chalk dominating beds comprising chalk, chalky limestone, chert and microcrystalline limestone concretions.

-Fluviatile and Lacustrine gravels of Pleistocene age

These sediments form relatively elevated portions above the graben erosional surfaces. They are composed of pebbles and cobbles of limestone, chert and phosphatic chert and limestone. The Aluvium and Wadi sediments of Holocene to Recent in age consist of unsorted limy and siliceous gravels with sand matrix.

Structurally, the area between Siwaqa and Jurf Ed- Darawish forms part of an east Jordanian block-faulted zone. Cretaceous and Tertiary sediments dip gently towards the east and southeast to the El-Jafr basin and are cross cut by a system of faults trending north–west and north – northwest (Bender 1968). The available information from exploratory drilling of the surveyed oil shale deposits suggest that oil shale bodies consist of shall lenses and forming elongated big ones. However, the deposits are bounded by faults to varying degrees.

3. Geology of Oil Shale in Jordan

3.1 Origin and Definition

Oil shale is widely distributed in Jordan and can be identified in few outcrops and mostly in the subsurface. The most important Oil shale occurs in the lower part of the Upper Cretaceous Muwaqqar Chalk Marl Formation which outcrops across much of central northern and central southern Jordan. Although the oil shale is widespread, it varies in thickness and oil content. Studies suggest that the hydrocarbons are concentrated in down faulted (garben) elongate basins. Oil shale horizons of less apparent importance occur in the underlying AL Hisa Phosphorite formation and in the overlying Eocene rocks of the Um Rijam Chert Limestone Formation.

Oil shale is defined as sedimentary rock where solid organic content is insoluble in organic solvents, but forms liquid oil-like hydrocarbons when exposed to destructive distillations, i.e. to temperatures up to 500-600 ºC, with a minimum oil yield of around 5%. The Jordanian oil shale are naturally bituminous marls and are varying shade of brown, grey or black with typical bluish light-grey color when weathered. Another characteristic feature is their content of light fine-grained phosphatic xenocrysts.

The organic material of the oil shale consists largely of prebitumen bituminous ground-mass (Huffnagel 1980). This was formed during sedimentation or in the early diagenetic process by mainly microbial influence, from initial plant and animal materials with a lipidic composition. A special feature of Jordanian oil shale is the fact that the foraminiferal shells are filled with bitumen instead of the usual calcite (Jacob 1983). Very small humic and intertinitic (charcoallike) small particles also exist. A vitrinite reflectance of 0.32% has been measured in El-Lajjun samples, which means that the organic substance has not sufficiently matured to generate petroleum. This was also confirmed by the organic geochemical investigations conducted by Abed (1982) on hydrocarbons extractable from shale of El –Lajjun and Yarmouk areas.

The oil contents show considerable variations within the stratigraphic sequence, and between the individual deposits. Throughout the world an oil content of 5% is considered the minimum for any technical exploitation and especially for direct combustion. The oil shale calorific value shows considerable fluctuations, just like the oil content.

3.2 Mineralogy and Chemistry of oil shale

The principal mineral component of the oil shale is calcite or more rarely quartz together with kaolinite and apatite and, on occasion feldspar, muscovite, Illite, goethite and gypsum as secondary components. Dolomite occurs in some individual carbonate beds as in the Arbid limestone of El-Lajjun. The main elements of the oil shale, if organic carbon is excluded are calcium, and silicon; minor constituents are sulphur, aluminium, iron and phosphorous. The concentrations of the remaining components are generally low. The silicon is derived from two sources: clastic sediment input together with titanium, aluminium and iron; and from synsedimentary or early diagenetic silicification.

The distribution of phosphorous is of particular interest. Its amount increases from the top to the bottom of the bituminous sequence. Phosphorous content is not favorable in the utilization of the spent shale for the manufacture of cement. However, certain percentage of the oil shale and/ or the spent shale can be used in the cement manufacturing. Molybdenum, chromium and tungsten are significantly enriched in the bituminous marl in comparison to limestone. Zinc, vanadium, nickel, copper, lanthanum and cobalt are also enriched, where as barium is depleted. The contents of arsenic and lead are low to moderate and do not pose any problem for the technical processes, nor for the environment. The uranium content is relatively high but it is clearly associated with phosphorous and not with the bituminous organic matter (Hamarneh, 1998). Significant positive correlations exist between the oil content and the elements sulphur, chromium, nickel, copper, zinc and molybdenum as well as with the clastic components like silicon, aluminum, titanium, iron and probably zirconium. A pronounced positive correlation occurs between phosphorous, uranium, yttrium, and vanadium. The sulphur content ranges from 0.3 to 4.3%. Sulphur is of particular importance with regard to the use of the oil shale as energy source. About one third of the sulfur is organically bound (Huffnagel 1980).

Table-1 and Table 2 show averages of the chemical analysis, trace and heavy metals of the oil shale rocks in some deposits.

Table 1 Average chemical composition of Oil shale (Modified after Hamarneh, 1998)

Attarat Um Ghudran	El-Lajjun	Sultani	Major oxides
23	16.13	26.26	SiO_2%
0.2	0.16	0.13	TiO_2%
2.7	3.77	2.87	Al_2O_3%
0.9	1.55	1.12	Fe_2O_3%
-	0.01	-	MnO%
-	0.65	0.95	MgO%
25.6	30.43	26.3	CaO%
1.1	0.1	0.27	Na_2O%
0.3	0.00	1.37	K_2O%
2.4	3.3	3.48	P_2O_5%
4	4.83	4.38	SO_3%
-	38.13	33.0	LOI%

LOI: Loss On Ignition

Table 2 Heavy and trace elements in oil shale (Modified after Hamarneh, 1998)

El-Lajjun	Sultani	Element (ppm)
-	17	As
92	115	Cu
73	99	Mo
167	139	Ni
7	11	Pb
10	14	Rb
n.d	235	Sn
1015	707	Sr
6	10	Th
29	25	U
n.d	10	W
33	27	Y
451	649	Zn
36	46	Zr
113	45	Ba
9	15	Co
431	267	Cr
27	28	La
162	268	V

While table 3 summarizes the average analysis of some properties such as oil content, organic matter and physical properties.

Table 3 Summary of Chemical and physical properties

	Jurf Ed Darawish	Wadi Maghar	El-Lajjun	Sultani	Attarat Um El-Ghudran
Av. oil content (wt%)	5.7	6.8	10.5	7.5	8.5
Total Organic matt. (wt%)	18	20.8	22.1	21.5	23.16
Calorific value (kcal/kg)	864	780-1270	1590	1210	---
$CaCO_3$ (wt%)	69.1	48	54.3	46.96	52.2
SO_3 (wt%)	4.3	4.2	4.8	4.4	4.9
Bulk density (g/cm3)	2.1	---	1.81	1.96	-----
Moisture (wt%)	2.8	3.8	2.43	2.6	1.71

* Information is from few boreholes drilled in the area.

3.3 Uses and Industrial applications of oil shale

The main utilization and use of oil shale as energy resource is to produce: -
-Oil and gas by surface retorting methods, chemical extraction and in-situ heating process.
The oil and/or gas could be upgraded and refined to produce petroleum products or the crude oil could be burned to generate electricity.
-Power generation by the means of direct combustion techniques (i.e. directly burning the ground oil shale). As by-products, the retorted oil could be utilized in the petrochemical industry to produce plastics, rubbers, chemicals, insecticides, .etc. In case of Jordanian oil shale, a considerable percentage (8-10%) of sulphur exists in the oil and this could be recovered for uses in industry. The heavy metals are significantly enriched in oil shale and mostly returned to the spent shale and ash. These metals could be recovered (i.e. Vanadium, Molybdenum, Chromium, tungsten zinc, nickel, copper, lanthanum and cobalt).

Spent shale and ash could be used in the cement manufacturing, road construction, asphalt production, and soil conditioning.

4. Oil Shale Deposits

Jordan possesses a very large energy resource in its vast reserves of oil shale (over 50 billion tons of geological reserves) which is ranked as the **8**th country in the world for its shale oil reserves (Table 4). There are 23 known sites of shallow and deep deposits of oil shale occurrences have been reported in most of the Jordanian districts. The geological studies and exploration for water, oil, and minerals showed that oil shale is widely distributed in many parts of the country, either cropping out at the surface or encountered in the exploratory wells.

The following are the main localities of oil shale:

A. In Northern Jordan (Irbid District), for example at Yarmouk River, Buweida & Beit Ras villages, and at the Risha Rweished area in the northern east panhandle.
B. In Central Jordan (Karak District), in the area between Husseinieh in the south and Daba'a in the north along the desert highway, and also in the EI-Lajjun area and in Madaba District at Eth Thamad area.
C. Southern Jordan (Ma'an District), at the Jafr area.

From the above-mentioned 23 deposits, Eight of these deposits i.e. El- Lajjun, Sultani, Jurf Ed– Darawish, Attarat Umm Ghudran, Wadi Maghar, Siwaqa, Khan Al – Zabib & Eth–Thamad, were investigated to different degrees (Fig. 1).
Among these deposits, El-Lajjun, Sultani, Attarat Um Ghudran and Wadi Maghar deposits are of major

deposits of commercial scale interest. They represent the core for any future investment interest in central of Jordan. The following description will highlight the main deposits.

4.1 El-Lajjun deposit

El-Lajjun deposit is located approximately 110 km south of Amman and mid way along the asphaltic road between Karak and Qatrana. The oil shale deposit consists of limestone, marl, cherts, shales and phosphates of Campanian - Maestrichtian. It is situated in a north -south trending graben. The average thickness of oil shale is 30 m. The average stripping ratio is approximately 1. The proven reserve amounts to 1.2 billion tons of oil containing oil content of approximately 115 million tons. One hundred and seventy three (173) boreholes were drilled during the periods 1968/1969, 1979, and 1982-1985. The drilled thickness varies from 1.4 to 86.5 m. The BGR and Klockner-Lurgi reports confirmed the oil shale reserves both in quality and quantity. In further investigation, another 22 boreholes were drilled by Suncor Company during the time of 1998-1999. In the investigated area the main structural feature is the El-Lajjun graben, controlling a morphological depression bordered from east and west by faults striking generally north – south. The deposit is characterized by its homogeneity. This is shown by the uniformity of lithology as well as the distribution of several constituents such as moisture, oil and sulphur. The stratigraphy of the bituminous layers is based on boreholes data. On the basis of the oil content determined by Fischer Assay, the bituminous sequence has been subdivided into several sub-units, which have been recognized from bottom to top as shown in Table 5 (Huffnagel, 1980).

Table 5 The average physical and chemical characteristics of the sub–units of El-Lajjun deposit.

Thick (m)	SiO2	P2O5	Al2O3	CaCO3	Cal.Value KgJ/kg	C-org	S	Moisture	Oil%	Subunit *
7	5.6	0.5	2.5	73.9	2580	3.6	1.9	3.6	4.3	G
17	6.7	1.3	3.1	71.1	2050	5.6	1.7	2.3	3.4	F
4-23	12.4	1.73	4.8-6.7	56.0	4180	8.6	2.6	2.8	5.7	E
2-11	13.3	3.35	5.0-6.7	45.0	6850	12.8	3.3	3.4	11.1	D
5-6	11.5	3.3	4.2-4.8	53.0	4700	9.8	2.3	2.2	7.8	C
8-11	26.1	3.6	2.6-2.9	33.0	8100	14	3.2	3.1	12.3	B
1-2	22.0	3.0	20.1-6.6	60.0	4090	6.2	1.7	2.3	5.2	AL
12-18	14.6	2.7	3.4-3.5	46.0	8170	14.5	3.5	1.9	12.6	A
2-6	9.1	9.7	1.1-1.4	45.0	4200	8.3	1.9	1.8	6.1	P

* Oil shale deposit is considered from A to E sub-units and P (phosphatic unit).

Studies of the El-Lajjun deposit were started in 1968 by the Natural Resources Authority (NRA). The studies consisted of core drilling and laboratory analysis. Reports reflecting these activities were prepared by Spears, 1969; Dinneen, 1970; Hamarneh 1970, and Omary, 1979. Operations were discontinued in 1969 owing to the low prices of crude oil, but as a result of the energy crises in 1973, investigations were resumed early in 1979 by the NRA with much greater interest.

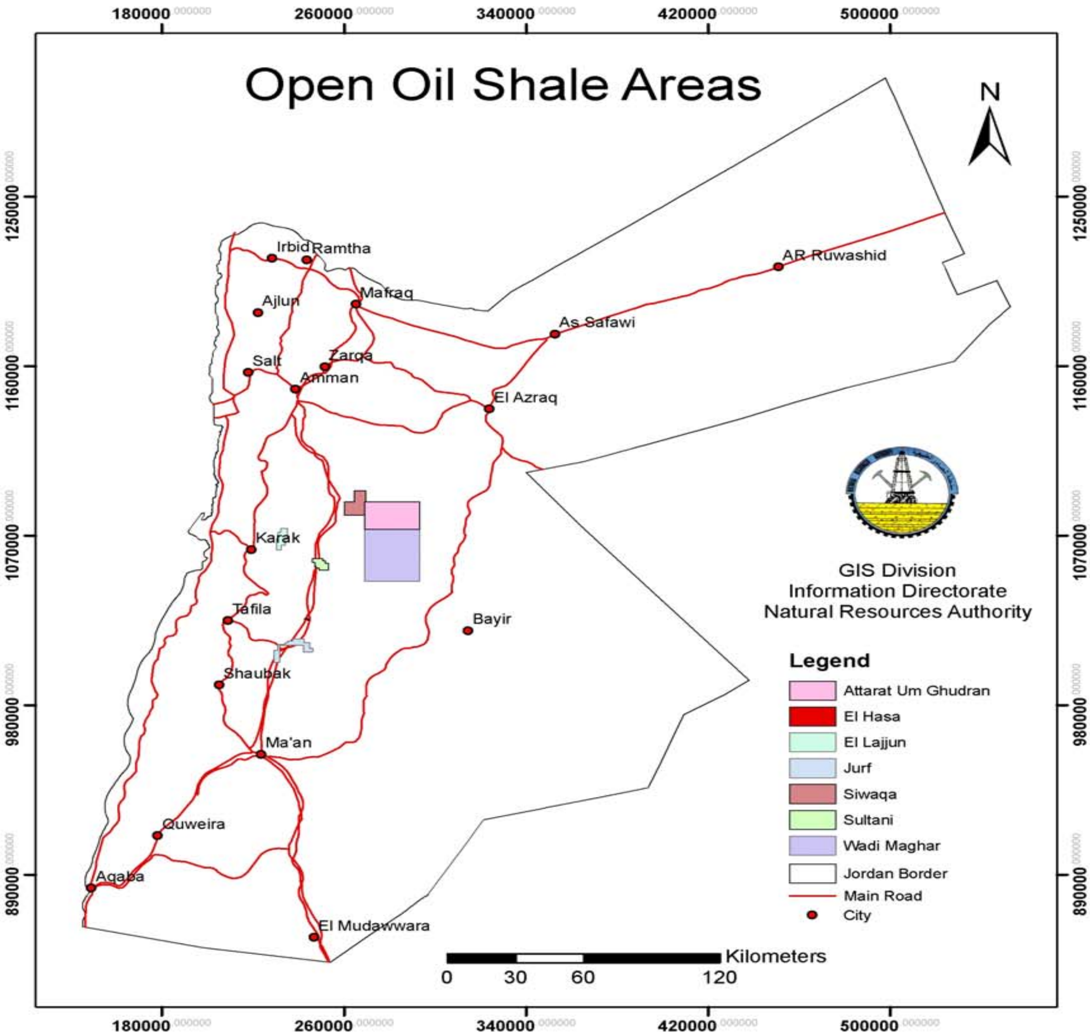

Figure 1 Location map of the major oil shale deposits.

Table 4 World Shale Oil Reserves (Qian, 2003)

Shale Oil Reserves Million Tons	Country	No
304000	USA	1
39000	Russia	2
14310	Zaire	3
12000	Brazil	4
7739	Morocco	5
6300	Canada	6
4080	Australia	7
4000	**Jordan**	**8**
2483	China	9
2457	Estonia	10
1431	Italia	11
1000	France	12
857	Thailand	13
816	Egypt	14
714	Israel	15
600	Ukraine	16
450	Sweden	17
400	Kazakhstan	18
500	England	19
286	Burma	20
286	German	21
220	Yugoslavia	22
200	Mae Sot	23
147	Turkey	24
100	Belgium	25
100	Luxemburg	26
57	Argentine	27
44	Armenia	28
42	Mongolia	29
40	Spain	30
35	New Zealand	31
19	South Africa	32
18	Bulgaria	33
8	Hungary	34
7	Poland	35
5	Madagascar	36
3	Chile	37
TOTAL 404754		

Through the technical cooperation between Jordan and Germany, a program of operation was assisted by the Federal Institute of Natural Resources and Geosciences (BGR) in 1980. The program consisted of additional boreholes in the El- Lajjun area to delineate the deposit plus laboratory analysis and semi-industrial tests. In October, 1980, the NRA commissioned the services of the German Consortium Lurgi-Klockner to conduct a mining and technical pre-feasibility study concerning the exploitation of El-Lajjun oil shale for retorting in 50.000 bbls/day plant, and also for supplying a 300 MW power plant. The study was completed in 1982 and concluded that commercial utilization is economically viable and that retorting is cheaper than the generation of electricity by direct combustion.

In 1980 the NRA commissioned a pre-feasibility study by TechnopromExport to assess the potential for direct burning of El-Lajjun oil shale in a 300 MW power plant (by a conventional combustion method). This study concluded that EI-Lajjun oil shale is also suitable as a fuel for direct combustion. In 1985, the NRA contracted China Petro-Chemical International Company (SINOPEC) to perform tests on El-Lajjun oil shale using the existing Fushun type retort. The performance test proved the viability of using the Fushun type retort for the production of shale oil.

In March, 1986 the NRA contracted the West German Consortium again to update the previous studies, with a view to assessing the technical and economic feasibility of a large scale retorting complex. This study consisted of revised geological study, performance of a retorting pilot test with CFB combustion test, and hydrogeological studies for water resources.

4.2 Sultani Oil Shale Deposit

The area was first geologically mapped at a scale of 1:25.000 by Heimbach (1962 & 1964) and was included also in the phosphate exploration project carried out by the NRA and United Nations (Sunna', 1974). Sultani deposit was also included in the NRA and BGR exploration studies of oil shale (Huffnagel 1980). In 1987, NRA carried out a further detail drilling program to delineate the deposit in the area (Project Staff, 1987). The deposit is located at about 115kms south of Amman just adjacent to the desert highway. It is situated in a NNW - SSE oriented graben structure 8 km long and 2-5 km wide bounded and transected by faults mostly of the same orientation.

The bituminous marl is overlain by the barren rock (overburden) of Cretaceous, Tertiary and Quaternary formations. The type of rocks are limestone, phosphates, chalk marl, cherts, basalts, wadi and mud flat sediments of Campanian Maestrichtian, Paleocene and Holocene ages.

The characteristics of the Sultani oil shale deposit are summarized in Table 6.

Table 6 Sultani oil shale deposit.

29.6	Area of the deposit, km2
1130	Geological reserves (Mt)
989	Indicated reserves (Mt)
2 -65	Thickness of Oil Shale (m)
31.6	Average thickness, m
34 – 86	Thickness of overburden, m
49.3	Average OB, m
1.6 (0.9-3.2)	Stripping Ratio (Average)
3.2 - 10.2	Oil content, %wt
7.5	Average oil cont., %wt.
0.964	Oil density (150C)
15	API

The calcareous bituminous marl (oil shale) of Sultani is generally gray, gray brown, and brown. It is thin bedded and laminated and has a distinct bituminous smell, phosphatic material is always present. The oil shale is calcareous marl with calcite as main component and varying amounts of quartz, clay and occasionally phosphatic material.

Table 7 Chemical Composition and trace elements of Sultani oil shale deposit (Haddadin, 1987)**.**

Max.	Min.	Average	Component.%
60.45	6.31	26.26	SiO2
0.26	0.04	0.13	TiO2
6.48	1.10	2.87	Al2O3
2.33	0.53	1.12	Fe2O3
7.54	0.09	0.95	MgO
43.34	10.81	26.3	CaO
0.93	0.04	0.27	Na2O
0.62	0.17	0.37	K2O
8.42	1.37	3.48	P2O5
6.27	2.05	4.38	SO3
42.66	15.95	33.0	LOI
34	15	17	As (ppm)
319	59	115	Cu
217	12	94	Mo
252	55	139	Ni
143	<5	11	Pb
25	8	14	Rb
27	20	22	Sn
1131	404	707	Sr
17	5	10	Th
40	14	25	U
49	5	10	W
1339	150	27	Y
94	29	46	Zr
94	29	46	Ba
32	2	15	Co
385	120	267	Cr
173	2	28	La
596	78	268	V

4.3 Attarat Umm Ghudran Oil Shale Deposit: First attempt to explore the oil shale deposit was made during the activities of the geological mapping project carried out by NRA A report about this deposit was prepared by Sunna'a (1985).A detailed report with drilling campaign was prepared to delineate the deposit by Haddadin & Abu Qudireh in 1988.

This large oil shale deposit is located 40 km east and southeast of Qatrana. An asphalted road
(27) km branching off the desert highway from a point at a distance 70km from Amman reaches the western border of the ore body. The area is located within the Upper Cretaceous chalk marl belt. The rocks forming the overburden and the deposit are: Marl chalk, limestone and chert. The thickness of oil shale varies from 10 to 60+ in and the thickness of overburden varies from 45 to 62m. The deposit features low mining costs and it is suitable for open pit/ cast mining: This shallow deposit render favorable conditions for further exploitation both for retorting and direct combustion.
The estimation of the reserves was based on the information derived from the cuttings of 43 drill boles. The depth of the drill holes varies from 85 to 110.5 meters. None of the drilled boreholes penetrated the whole chalk-marl sequence to prospect the occurrence of bituminous rocks in the underlying formation. However, current investigations carried out by NRA indicate thicker oil shale bed and reached more than 90m in one

of the boreholes (Verbal communications with project staff). The spacing between the boreholes ranges between 4-8 kms throughout the investigated area, which is of about 348 km^2. The chemical analysis was carried out on the core and cutting samples. The oil content varies between 6-13% with average oil content of about 8-8.5%. The sulfur content varies from 1.93 to 5.3% and the moisture content varies from 0.4 to 2.3%. X-Ray analysis indicates that the main components of the oil shale are; calcite and quartz and the secondary mineral apatite. The calcium carbonate content ranges from 21 to 55%. The organic carbon ranges from 9 to 19 **%.** The characteristics of the Attarat Um Ghudran oil shale deposit are summarized in table 8.

Table 8 Attarat Um Ghudran oil shale deposit

348 km^2	Area
10 – 90+m	Thickness of oil shale
45m	Average thickness of Oil shale
45 – 62+m	Thickness of overburden
53.2m	Average thickness of overburden
1.2	Stripping Ratio (Average)
-	Geological reserves
21000(Mt)	Indicated reserves
1185(Mt)	Oil content of indicated reserves
53 + (22*)	Number of drilled boreholes
8.5%	Average oil yield
1.7%	Moisture content,
53.2%	Ash content
18.9%	CO_2
2.6%	Sulfur

* Current drilling campaign.

4.4 Wadi Maghar Oil Shale Deposit:

The deposit is located approximately 35 km south east of Qatrana town. This deposit is the extension of Attarat Umm Ghudran to the south. This deposit shows even larger reserves of oil shale, but rather of lower quality than Attarat Umm Ghudran.

The area is located within the Upper Cretaceous Chalk Marl Formation. This oil shale was explored during the geological mapping activities (Sunna' 1985). NRA made further and detailed investigations of the deposit (Haddadin & El Khatieb, 1986). The thickness of the oil shale varies from 10 - 61 m. The thickness of overburden ranges from 32.5 to 50 m. The rocks forming the overburden and the deposit are: Marl, chalk, limestone and chert. The estimation of the reserves was based on the information derived from cuttings of boreholes covering a huge area. The characteristics of the Wadi Maghar oil shale deposit are summarized in table 9.

Table 9 Wadi Maghar oil shale deposit

660 km^2	Area of the deposit,
31600	Oil shale Geol. Reserve (Mt)
2000	Shale oil (Mt)
21500	Oil shale Indicated Reserve(Mt)
1500	Shale oil (Mt)
10 - 61	Thickness of oil shale (m)
40	Average thickness of Oil shale (m)
32.5-50	Thickness of overburden (m)
40.5	Average thickness of overburden (m)
1	Stripping Ratio (Average)
6.8 %	Average oil yield
2.7 %	Moisture content,
57.5 %	Ash content
19.9%	CO_2
0.9-3.5	Sulfur, wt%
2.4%	Avg. Sulfur

5. Summary of Previous Technical Activities

The Natural Resources Authority (NRA) has done extensive geological studies to delineate the oil shale reserves at El-Lajjun, Sultani, Attarat Umm Ghudran, and Wadi Maghar deposits. In addition, the Government of Jordan contacted and commissioned different foreign governmental institutes and companies for technical assistance in order to study, test and exploit oil shale for power generation and crude oil production. In 1980, NRA commissioned a study by the BGR (German Federal Institute) for the evaluation of El-Lajjun, Jurf Ed-Darawish, El-Hisa and Sultani deposits in central Jordan, and a techno-economic pre-feasibility study for an oil shale retorting complex using Lurgi - Ruhrgas Process. The results of this study indicated that EL-Lajjun oil shale deposit shows continuity over an area of 18 km^2 with about 1.2 billion tons of oil shale reserves containing some 115 million tons of shale oil. The deposit was suitable for open cast mining and could support a 50,000 bbls/day oil shale retorting complex for about 25 years.

In October 1980. NRA commissioned Phase I of the two pre-feasibility studies for:

An oil shale complex using the Lurgi-Ruhrgas (LR) process for extracting 50,000 bbls/day of shale oil.

Installation of a power plant of 300 MW capacity utilizing El-Lajjun oil shale by means of Lurgi's circulating Fluidized bed combusting process (CFB). The studies were completed in 1982 and concluded that both options were technically viable. In 1985, another agreement was signed with the China Petrochemical International Company (SINOPEC) to carry out a proving test in order to determine whether a Fushun- Type retort would be technically feasible for processing El-Lajjun oil shale. The final report of the proving test was submitted in 1986 and the results emphasized that the Fushun - Type retort was quite suitable for processing E1-Lajjun oil shale and that the results were promising. SINOPEC International proposed the installation of a 100 tons/day Fushun-Type retort at a cost of US $6 million. Cooperation with SINOPEC was halted due to high operation costs.
In March 1986, NRA contracted with the German Consortium Lurgi-Klockner to revise and update the previous study. The update study consisted of a revised geological study, revised prefeasibility study, performance of retorting pilot tests, CFB combustion tests on 200 tons of ElLajjun oil shale sample in Germany, and hydrogeological studies for water resources. In addition, Lurgi-Klockner

also undertook an assessment of the possibility of burning the spent shale in the electric power generation plant of 350 MW by adopting Lurgi's CFB process.

Since 1986, the Jordan Electricity Authority (JEA) and NRA together with the assistance of USAID and CIDA (Canadian) and Brown Boveri and Company (Swiss), has been investigating the possibility of exploiting Sultani oil shale for direct combustion for power generation. That effort was to utilize the state of the art Circulating Fluidized Bed (CFB) technology. Performance tests on Sultani oil shale carried out by B.B.C, Lummus/Combustion Eng. and Bechtel Pyropower (funded by CIDA and USAID) had demonstrated that Sultani oil shale was suitable as fuel for direct combustion in CFB power plants.

Although oil shale retorting has a long history, the research conducted by the Americans and the Europeans after the 1973 oil crisis resulting high prices led to further research and development of modern oil shale retorting processes. Lurgi technology and other processes based on tar sands in USA and Canada has proven the technology on a pilot scale and the current lower level of oil prices has rendered commercial development and operation of such plants uneconomic.

As regards to CFB technology, in the Eighties of last Century more than 60 plants were operating on low calorific value fuels. However, none of these plants have been operated on oil shale. Further, the technical problems involved in the disposal and the utilization of spent ash have not been analyzed in detail. In 2004 Foster Wheeler company had constructed and installed CFB boilers at Narva plant in Estonia.

6. Mining Aspects

There are many issues that should be considered when time comes to start mining and extraction of oil shale. All data and information gathered from the geology, topography, geochemistry, mineralogy, drilling, engineering properties of the rocks, surface and underground water situation, climate, infrastructure, and the environment on the surrounding areas of the deposit should be compiled and studied in order to design, proceed and maintain a successful mining plan.

6.1 Overburden

All rocks overlying the oil shale are considered as the overburden. Most of the rocks of the overburden consist of the upper sequence of the Muwaqqar Formation in addition to a few meters of gravel and wadi sediments and some places of the remnants of Umm Rijam Chert Limestone formation. The upper Muwaqqar sequence mainly consists of chalk, chalky limestone, marl and marly limestone with some concretions of limestone. These materials are soft to moderate in hardness. At the topmost of the overburden, gravels of Pleistocene and wadi sediments consist of limestone, chert, basalt are present in thickness ranging between 2-10m at the most (see Figs. of El-Lajjun outcrop and Sultani open pit). The thickness of overburden ranges from 15–62 meters at El-Lajjoun, 34–86 meters at Sultani, 45–62 meters at Attarat Umm Ghudran, and 32.5 –50 meters at Wadi Maghar.

6.2 Ore body of the oil shale

Based on the detailed geological information gained from El- Lajjun, Sultani, Attarat Umm Ghudran and Maghar deposits, the oil shale ore bodies are in the shape of elongated big lenses. Although the upper and lower surfaces of these lenses are undulated, but lay as a horizontal bed-like.
The chalk and chalky marl rocks become hard to moderate hard due to bituminization. However, there is a proportional relationship between hardness and organic carbon content in the oil shale ore body. The average thickness of oil shale deposits vary from 30 m in the El-Lajjun area to 110m in the Attarat Um Ghudran area.

6.3 Reserves

Reserves have been delineated and estimated based on core and cutting samples from exploratory boreholes drilled in the areas. It could be stated that El-Lajjun and Sultani deposits are ranked as calculated reserves while Umm Ghudran and Wadi Maghar deposits are considered indicated and inferred reserves (Table 10).

Table 10 Estimated and calculated reserves of the oil shale deposits

Jurf Ed Darawish	Wadi Maghar	Attarat El-Ghudran	Sultani	El-Lajjun	
90.6	660	348	24	20.4	Area (km^2)
63.8	40	45	31.6	29.6	Av. thickness oil shale
					(m)
47.3	40.5	53.2	69.3	28.8	Av. thickness of OB
					(m)
-	1	1.2	1.6	1	Stripping Ratio (average)
8000	31600	26000+	1130	1196	Geological reserves (Mt)
2500	21600	(21000)*	989	1170	Calculated & Indicated reserve (Mt)

* NRA current investigation indicates substantial amount more than this.

6.4 Mining method

A geological estimate of oil shale reserves of the five deposits is **62.7** billion tons, while the calculated and indicated reserves are **47.3** billion tons (See Table 9). It is obvious that there is huge reserves exist, but most important is the mineable reserves in these deposits with favorable characteristics for large-scale economical development. The deposits are characterized by the following criteria: -

Favorable conditions for surface mining such as low stripping ratio (1:1 in general), minimal overburden, absence of significant structural disturbances, and absence or limitation of intrusive rock bodies.

Properties of oil shale, relatively high oil content and calorific value, low moisture content, and acceptable properties for processing.

Adequate reserves to justify a commercial processing plant.

Located in remote or thinly populated areas and have good roads connected with asphalted highways.

The availability of adequate amounts of deep ground water underneath the deposits for the industrial utilization.

Among the deposits in central Jordan El-Lajjun and Sultani were selected for feasibility studies.

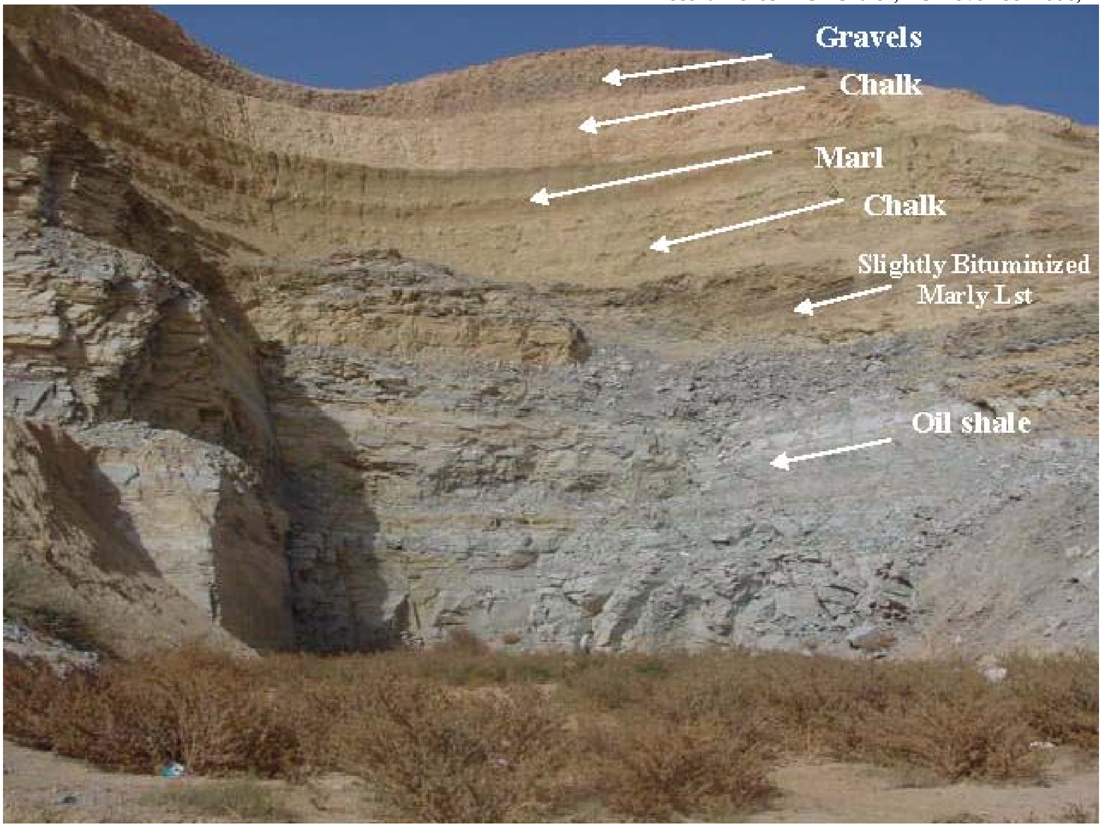

Figure 2 Oil Shale outcrop in El-Lajjun deposit

Figure 3 Open pit in Sultani deposit

Since the stripping ratio is low (1 in general, 1.6 only in Sultani deposit), beds are horizontal and structurally undisturbed, and the topography is slightly flat or little undulated, surface mining could be adapted and the cost effective mining method will be Open cast method for such deposits.

This method will require removal of the material in strips that could be designed in perpendicular to the elongated side of the deposit. The removed material of the second strip could be back filled into the one before. However, the initial stage of the overburden removal should be transferred to outside site in order to reserve room for the second strip removal. Draglines are recommended for overburden removal similar type of work in Jordan Phosphate mines (Close to Sultani and Maghar deposits). These machines are capable of removing huge quantities in short time since the overburden rock types are soft to moderate in hardness. The oil shale will be mined by drilling and blasting operations. Bulldozers and excavators could be used to extract the oil shale rocks with the help of big shovels and back trucks for transporting the oil shale material to the conveyer belts. In the initial stages, the mined oil shale should be stockpiled to maintain enough material to the processing plant. The processing plant for retorting the oil shale should not be far from the mining site. The runoff mine oil shale is transported by the conveyer belts to the oil shale stockpile site or supply directly the crushing plant and then to the processing plant.

Spent shale (shale rocks after oil extraction) should also be stockpiled in a place close to the mine area. It could be used in the cement manufacturing, road construction, asphalt production, soil conditioning and possible heavy metals extraction. The rest of the spent shale should be back filled to the excavated area and covered by the overburden material.

7. Investment Opportunities and Outlook

Oil shale in Jordan is considered to be one of the good oil shale in the world in terms of oil content and other conditions. However, oil shale in central of Jordan is characterized by Huge reserves relatively close to each other Good quality in terms of oil content and type of host rock. Offering favorable mining conditions:

Shallow and suitable for surface mining.
Low Stripping ratio (Av. 1:1 in general).
Beds are horizontal and structurally undisturbed.

- Soft to moderate overburden rocks. Located in remote or thinly populated areas. Have good roads connected with asphalted highways.

Interested companies in utilization oil shale are welcomed on the following basis: -

a. Express interest by writing to Natural Resources Authority (a governmental entity).
b. Provide solid evidence of financial and technical capabilities.
c. MOU could be signed with the company to carry out the necessary investigations to determine the vitality of the project.
d. Apply for a mining concession under the "Mineral Agreement" provided the successful technical and feasibility studies of the project.
e. Approval of the NRA's Board of Directors.
f. The Board of Ministers approves the final concession agreement.
g. Approval of the House of Parliament.

Currently, the government has started to implement a comprehensive strategy for oil shale development. This is due to many facts such as the dramatic rise of the global oil prices which has directly affected the government's budget and Jordan's GNP and the willingness of interested investors and companies whom approached NRA to exploit oil shale for producing crude oil and power generation. The main features of this strategy are in the following: -

Crude oil production: -

A specialized technical team has been set up in NRA to gather, collect, prepare and digitize all the technical studies and data of all oil shale occurrences in Jordan. The aim is to facilitate and to provide technical support for investors and interested companies in oil shale.

The Board of Ministers assigned a Special Tender Committee in order to call for proposals from interested companies in the oil shale utilization, negotiate, and sign memorandum of understanding (MOU) and commercial agreements.

A comprehensive feasibility study on all types of oil shale technologies has been started by a well known American consultant company and commissioned by the government through a technical grant from the United State Development Agency (USTDA).

Starting negotiation and signing MOU with Shell Company that leads to granting a concession through a commercial agreement using in-situ process to utilize oil shale for crude oil production. The concession will be on deep oil shale occurrences in Jordan excluding the shallow occurrences in central of Jordan, which is allocated for surface mining and retorting techniques (Fig. 4). The Shell process is called In-situ Conversion Process (ICP), which basically is based on heating the rocks in place (underneath the ground) in order to convert the Kerogen into gas and oil that could be pumped through production wells.

Call for proposals were sent to 14 interested companies whom actually approached NRA for oil shale. Negotiation has started with qualified companies in order to sign MOU on specific areas in central of Jordan and using surface retorting for crude oil production.

Direct combustion: -

MOU was signed with Jordan Cement Factories Company to burn oil shale as a source of energy and at the same time using the ash in the cement manufacturing process.

Although priority has been set for oil production in Jordan, oil shale could be utilized for power generation using CFB direct combustion technique is open for investment since this technology has been commercially approved in countries like Estonia.

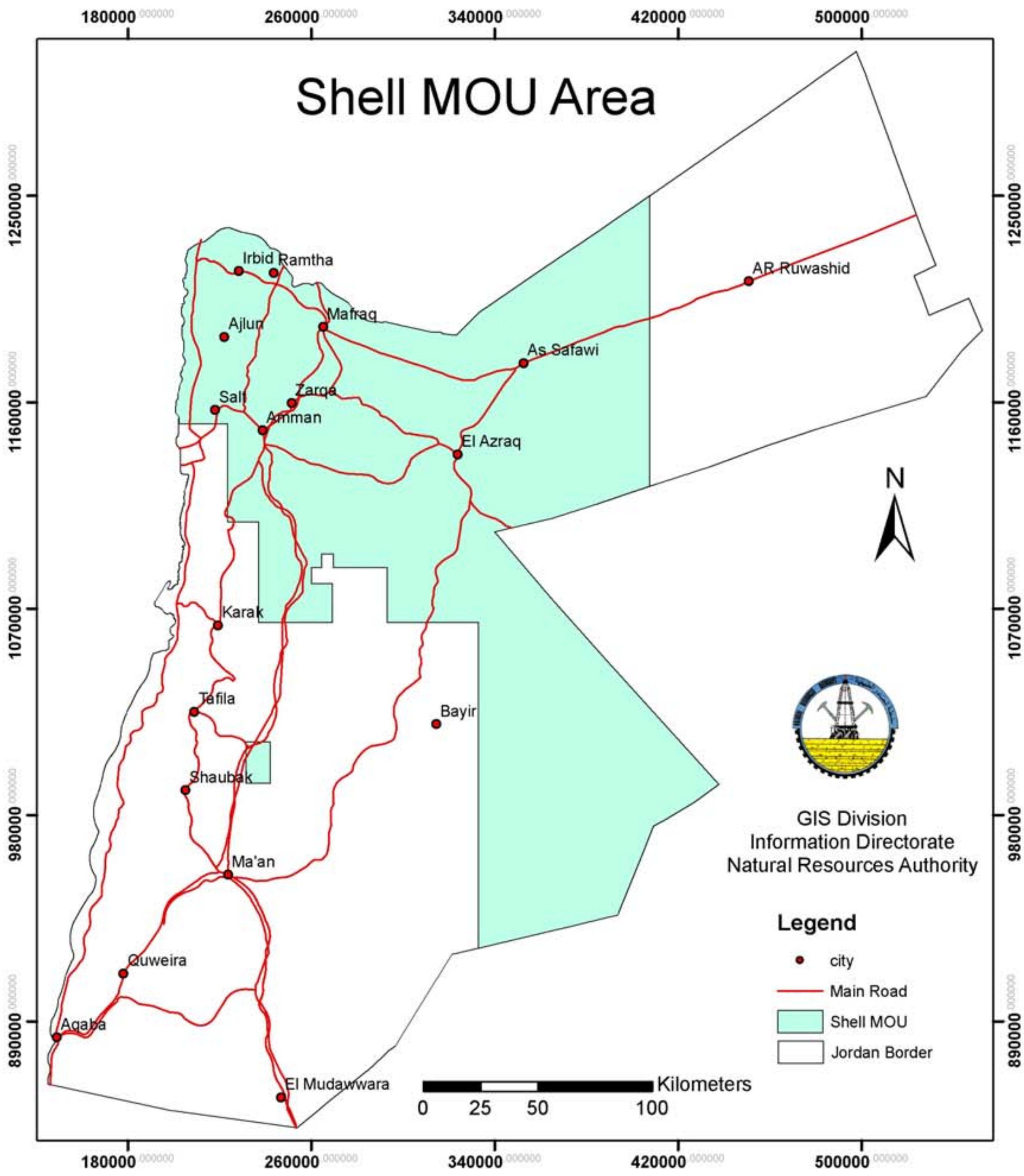

Figure 4 Location map of the MOU of Shell Company.

8. Recommended further studies

-Further studies should be carried out on other interest areas with huge reserves such as Attarat Um Ghudran and Wadi Maghar. Studies could include detailed geological, mineralogical and physical properties of the oil shale in addition to the organic and hydrocarbon characteristics.

-Details studies on the uses of the spent shale after retorting and the residual ash after combustion of the oil shale since huge quantities of these materials are expected. -Detailed geological studies of the overburden and the possibilities of industrial uses which could be derived from it. -Detailed studies of the rare earths and heavy metals in the spent shale after retorting since many heavy metals were found at different concentrations in the oil shale.

-Environmental impact assessment (EIA) and the hazardous mitigation of the following: air pollution, surface and ground water pollution, soil and agricultural pollution, hazardous chemical wastes, noise, disposal of the mining extraction and reclamation and rehabilitation of disturbed land.

-In the direct combustion side, it could be stated that the Circulating Fluidized Bed technology (CFB) is the latest technology for burning oil shale to produce electricity so far.

-Most of the technologies for exploiting oil shale, particularly power generation will require water for the process. Therefore, water studies should be considered carefully.

-In the type of oil extracting technologies, a survey study could be carried out on the conventional retorting, chemical extraction, and/or gasification in order to understand the best technology suitable for the Jordanian oil shale. There are many types of technologies being used or tested in the world. The following table shows countries, types and oil quantities produced in year 2002.

Retorting type	Oil (tpa)	Country
Fushun	103000	China
Galoter, kiviter, Generator	300000	Estonia
Generator	202000	Russia
Petrosix	160000	Brazil
Taciuk (ATP)	200000	Australia

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