

Jordan's Experience in Oil Shale Studies Employing Different Technologies

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Abstract

This paper introduces and discusses the Jordan's experience in dealing with oil shale as a source of energy. Since 1960's, Jordan has been investigating economical and environmental methods for utilizing this indigenous oil shale source with the main objective of utilizing this source for either power generation or retorting at a cost competitive with other sources of energy. Oil shale deposits in Jordan represent a significant energy source that could potentially lead to an energy self sufficiency.

Oil shale technologies have been recently developed to accommodate oil shale utilization economically and cleanly. Long experience of feasibility studies and test programs have concluded that the Jordanian oil shale, due to its high organic content, is considered as a suitable source of energy either by direct burning to generate electricity or by retorting for the production of oil and gas. The conventional oil supply will not much longer be dependent upon to supply the ever increasing demand pointing to the only one permanent source of the raw oil shale material which we have to resort for our future supply.

Jordan has been involved in more than three decades of comprehensive engineering and economical studies and test experiments for both retorting and direct burning of Jordanian oil shale with several international oil shale companies providing a solid foundation for a future oil shale industry in Jordan.

Based on these facts, Jordan believes that oil shale utilization should be pursued because it will result in significant savings in foreign exchange, improve Jordan's energy supply security and create new jobs.

Major technical advances have occurred in process monitoring and control, process simulation and modeling, chemicals separation and purification, and systems and methods for reducing adverse environmental impacts.

Introduction

The situation in the energy field gives reason to believe that in the near future, fuel oil and natural gas will no longer be available as sources of sustainable energy in the quantities known today (Figure 1, Table 1). Oil shale is considered as one of the promising options to substitute conventional fuels. Oil Shale resources of the world are

abundant and next to coal and tar sands, oil shale is considered to be one of the largest fossil energy reserves in the world. (Figure 2)

"Oil shale" is a hydrocarbon bearing rock that occurs in nearly 100 major deposits in 27 countries worldwide (Figure 3, 4)

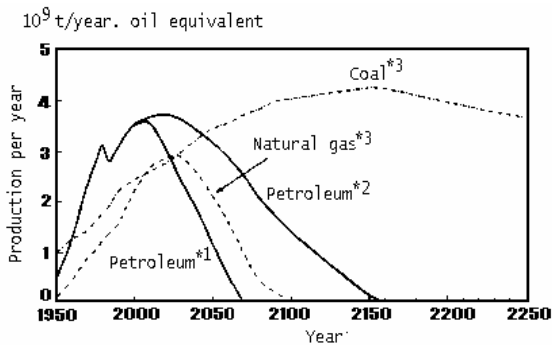


Figure 1: Projected world production of hydrocarbons

Table 1: Reserves of various petroleum resources

Fuel type	Reserves, BBOE	Years of Production*
Oil	1012	44
Natural gas	750	67
Coal	3745	223
Oil shale	1500-3400	-
Tar sand	1650	-

* at current rate of production

The largest known oil shale deposits in the world are in the Green River Formation, which covers portions of Colorado, Utah, and Wyoming. Estimates of the oil resource in place within the Green River Formation range from 1.5 to 1.8 trillion barrels. For nearly a century, oil shale in

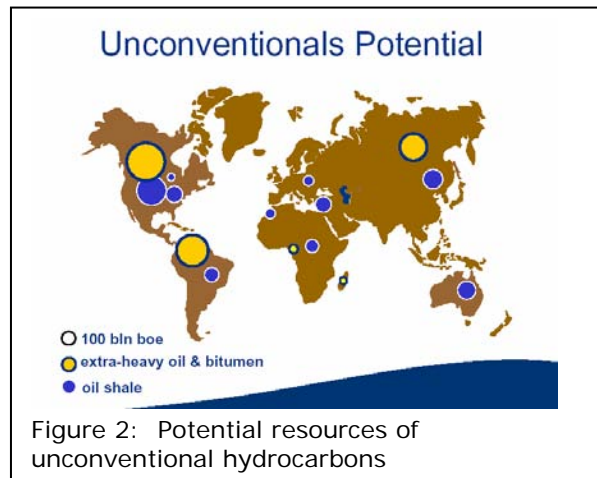
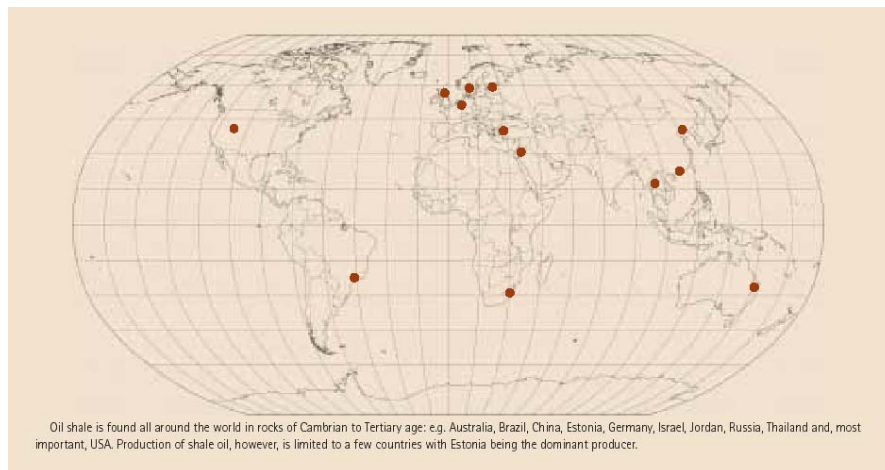


Figure 2: Potential resources of unconventional hydrocarbons

the western United States has been considered as a substitute source for conventional crude oil. But the economics of shale oil production have persistently remained behind conventional oil.

At present, oil shale is being used on commercial scale as power –generating fuel and as raw material in many countries such as Russia, Estonia, China, Australia, Canada and Spain.

Oil shale has a long past of production, starting in 1837 in France (Autun mines, which were closed in 1957), Scotland 1850-1963, Australia 1865-1952, 1998 2004, Brazil 1881-1900, 1941- 1957, 1972-, Estonia 1921-, Sweden 1921-1965, Switzerland 1921-1935, Spain 1922-1966, China 1929-, South Africa 1935-1960.



Oil shale is found all around the world in rocks of Cambrian to Tertiary age: e.g. Australia, Brazil, China, Estonia, Germany, Israel, Jordan, Russia, Thailand and, most important, USA. Production of shale oil, however, is limited to a few countries with Estonia being the dominant producer.

Figure 3: Oil shale resources of the world

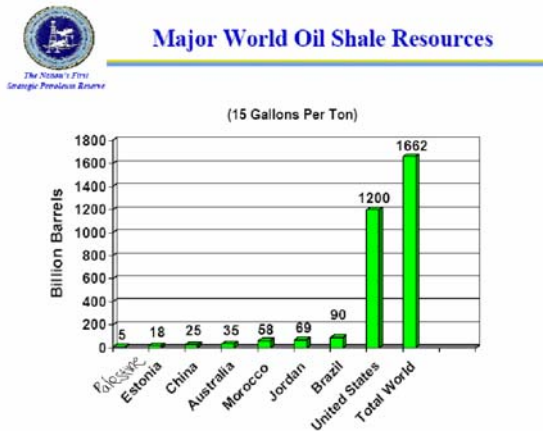


Figure 4: Major oil shale resources

In 1913, an American named William Burton patented a commercial process for “cracking” oil into its constituent parts. Since then, most of the world's industries have become reliant on these products

The enormous indigenous sources of energy in its vast low grade oil shale reserves of extractable oil in Jordan are virtually equivalent to that crude oil of the USA.

Table 2 compares Jordanian oil shale characteristics with oil shale from some other countries.

What is Oil Shale?

Oil shale is a fossil fuel where dead organic material that was buried before being oxidized by air underwent a series of slow chemical reactions that turned the organic molecules into hydrocarbons.

The term oil shale generally refers to any sedimentary rock that contains solid bituminous materials that are released as petroleum-like liquids when the rock is heated. Oil shale is a 40-50 million year old sedimentary rock which, within its structure of clay minerals, contains a solid hydrocarbon. Kerogen is basically “fossilized algae” which has been formed during the deposition of sediments in ancient lake environments. The effects of time, pressure and temperature have transformed these sediments into a hydrocarbon-bearing rock, known as oil shale (Figure 5).

The U. S. Geological Survey defines oil shale as “organic-rich shale that yields substantial quantities of oil by conventional methods of destructive distillation of the contained organic matter, which employ low confining pressures in a closed retort system. They further define oil shale to “any part of an organic-rich shale deposit that yields at least 10 gallons (3.8 percent) of oil per short ton of shale”

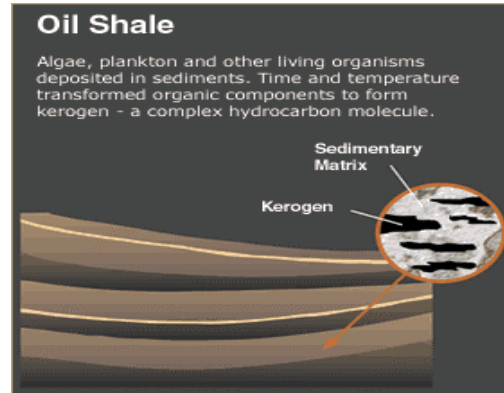


Figure 5: Formation of kerogen in oil shale

Brazil	U.S.A	Euorope	China	Estonia	Morocco	Jordan	
1340	1800	1986	1500	2000	1100	1800	C.V (k cal/kg
7	9.7	13	7	20	7	12	oil content (%)
2.6	17.3	20	12	19	11	19	Organic Carbon(%)
1.9	1.7	2.7	2	2.5	2	2	H2 (%)
2.7	2.1	11.5	7	7.5	9.6	1.8	O2 (%)
0.6	1.3	0.2	0.38	0.2	—	0.34	N2 (%)
0.6	0.65	6	0.3	1.55	1.2	3.2	S (%)
5.3	0.7	12.7	13	11.5	10	2.5	H2O (%)

Table 2: Chemical properties of various oil shales

The organic matter in oil shale is composed chiefly of carbon, hydrogen, oxygen, and small amounts of sulfur and nitrogen. It forms a complex macromolecular structure that is insoluble in common organic solvents (e.g., carbon disulfide). The organic matter is mixed with varied amounts of mineral matter consisting of fine-grained silicate and carbonate minerals (Figure 6).

The kerogen (from Greek meaning oil generator) can be converted to oil by thermal treatment, gas and coke being formed at the same time. The kerogen is generally present as fine inclusions in the mineral substances.

The organic matter in oil shale is basically

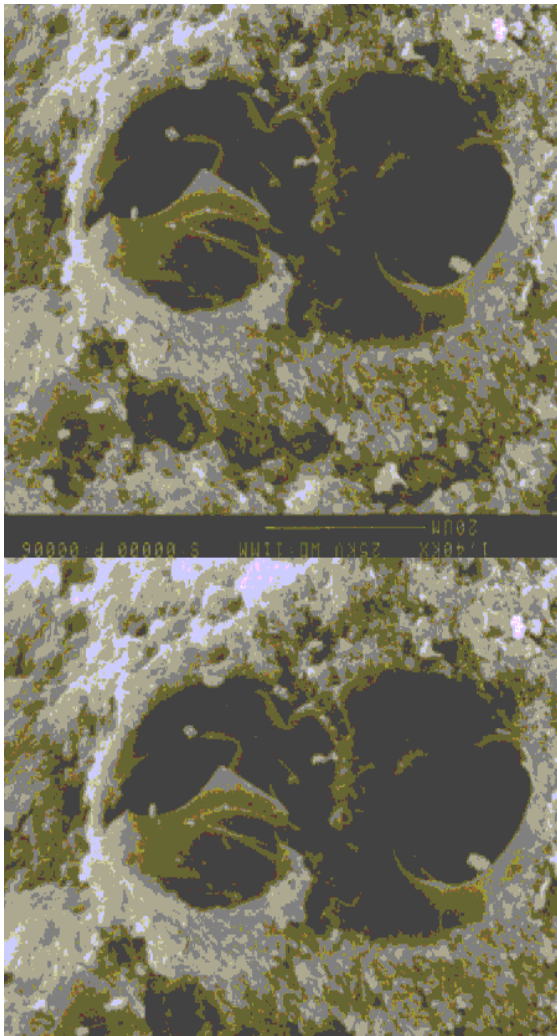


Figure 6: Photomicrograph of kerogen in oil shale

“immature” oil; fossil deposits that have not been subjected to enough heat and pressure in the earth to convert it into liquid crude oil. That means in order to obtain petroleum from oil shale by retorting, some amounts of heat energy must be applied to extract the kerogen (Figure 7).

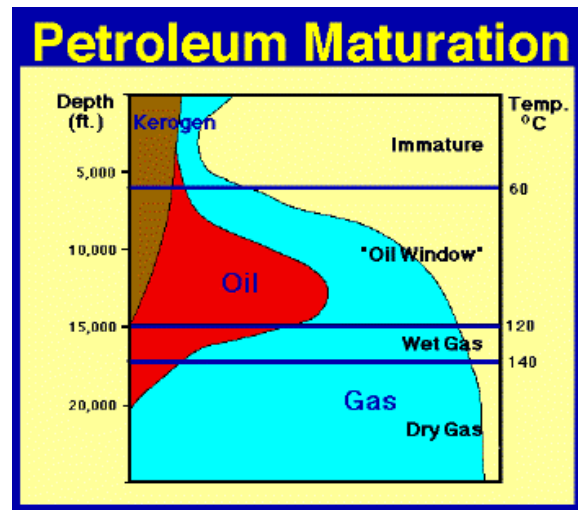


Figure 7: Maturation diagram for kerogen

To obtain oil from oil shale, the shale must be heated and resultant liquid must be captured. This process is called retorting, and the vessel in which retorting takes place is known as a retort.

Conventional oil was formed through a similar retorting process, the difference being that it has been subjected to millions of years of deposition and subterranean pressures and temperatures. Essentially, extracting the hydrocarbon from oil shale involve "speeding up" the geological process by the application of heat in controlled condition.

Oil Shale in Jordan

Jordan is non-oil producing country which is deeply affected by the world energy situation. There is a clear economic interest for Jordan to have the oil shale utilization developed as a future energy source.

Oil shale in Jordan had been known to occur from ancient times, evidence of which was found in mosaics and floors at palaces, churches and mosques from the Greek,

Roman, Byzantine and Islamic periods. The Hashemite Kingdom of Jordan possesses enormous indigenous sources of energy in its vast low grade oil shale. These reserves of extractable oil are virtually equivalent to that crude oil of the USA. Jordan ranks third in world oil shale reserves after USA and Brazil.

Large deposits of oil shale are widely distributed all over Jordan (Figures 8, 9).

Geological surveys have confirmed the existing of oil shale reserves that cover more than 60% of Jordan's land and some of the major oil shale deposits are underlain by phosphate beds. A huge proven and exploitable near surface reserves are estimated to be more than 50 billion metric tons with extractable crude oil equivalent to about 50 billion barrels of oil (Figure 10).

These major deposits of commercial scale

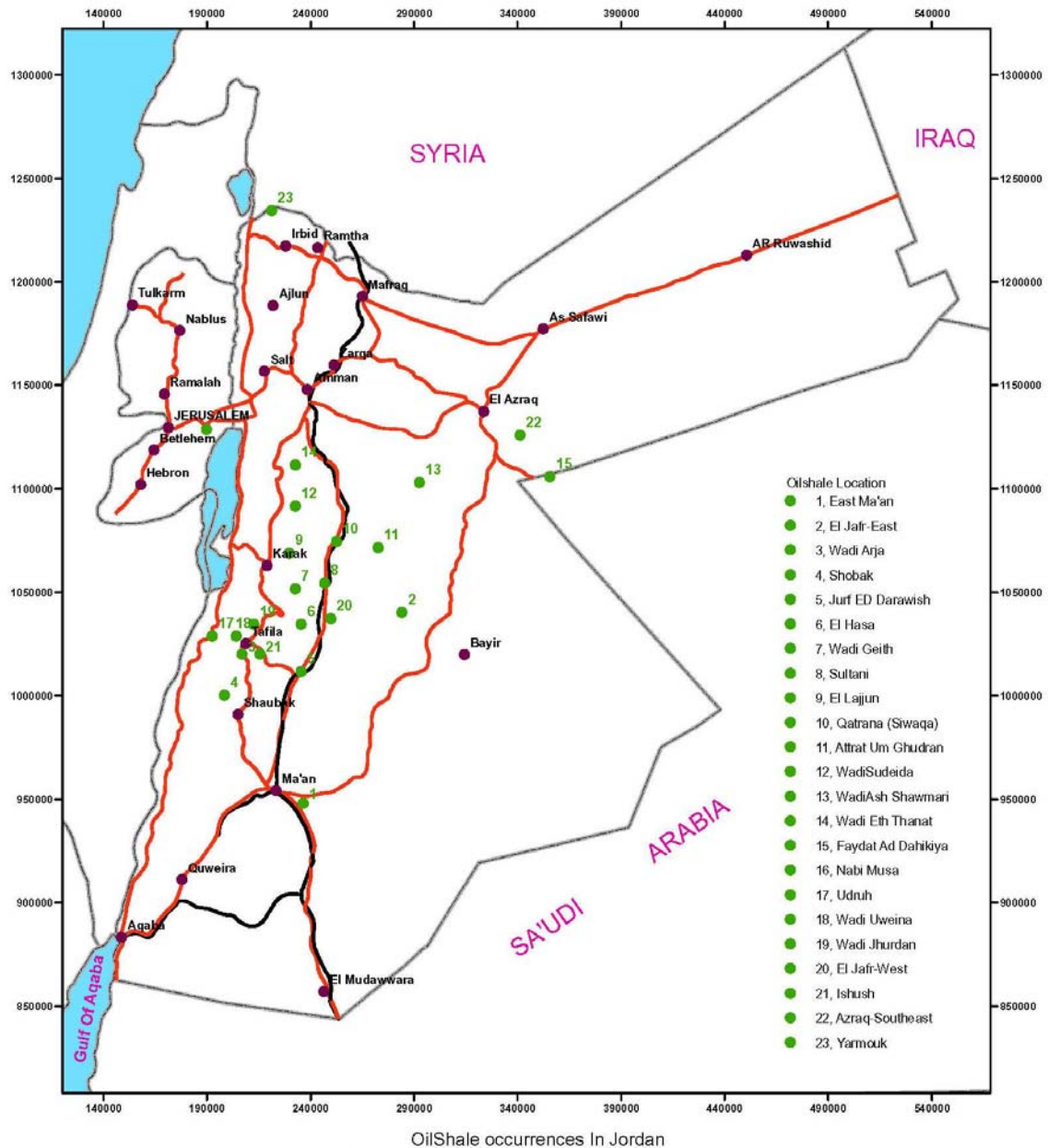


Figure 8: Oil shale occurrences in Jordan

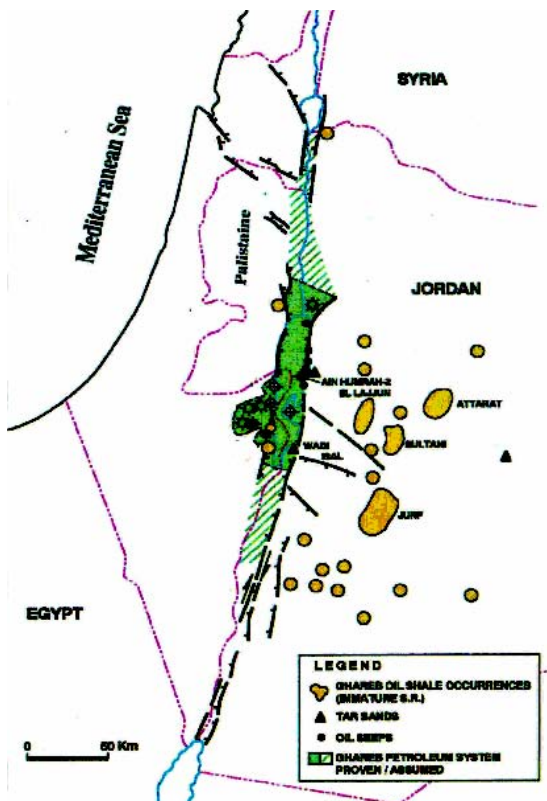


Figure 9: Major Jordanian oil shale occurrences

interest are located in the central part of Jordan and are easily accessible from the Highway. These deposits are traversed by a high voltage power transmission lines so that a substantial part of the infrastructure required for development is already in place.

British geologists investigated the oil shale of the general region after World War 1, where samples were taken and retorting

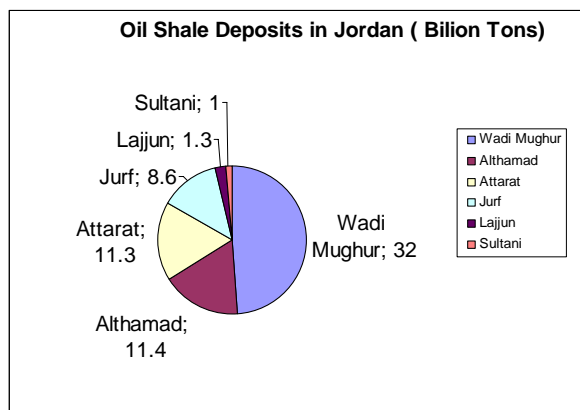


Figure 10: Oil shale resources of Jordan

tests were made. Records from the outcrop of Shallaleh deposits have indicated that villagers have used the shale for many years to heat water and to lime their homes and wells.

The declining potential of crude oil and gas reserves accompanied with increasing their prices indicates the country's strong efforts to investigate and develop sources for its replacement such as oil shale being the only fossil fuel discovered in Jordan.

Preliminary studies on Jordan oil shale began in the late 1960's but no actions were taken at that time because the level of oil prices was far too low for a viable oil shale development program. However, since 1980's the Government of Jordan (GOJ) has conducted extensive studies for the exploitation of oil shale reserves mainly of two deposits: Al-Lajjun and Sultani.

Detailed surveys were carried out by drilling core holes and performed laboratory work to determine proven geological reserves, quality, oil content and calorific value. The GOJ has also conducted many feasibility studies on oil shale that have led to the assessment of this oil shale and the suitability of the state-of-the-art technologies that have been developed so far and reached to a mature stage of commercial development.

The geological conditions *e.g.* its thickness and the structural settings, the chemical and mineralogical compositions are favorable for open-pit mining. All these factors together with the low mining and infrastructure costs render the deposit quite suitable for industrial utilization. The production of oil and electricity using oil shale could be a viable option even at today's oil prices.

There are 18 known surface- and near-surface deposits; eight of them were investigated in different levels and are regarded as commercially attractive. Those major deposits and their characteristics are summarized in Tables 3 and 4.

Table 3: Properties of Jordanian oil shale deposits

<i>Deposit</i>	<i>Geologic Reserves (Billion tons)</i>	<i>Surface Area (sq.km)</i>	<i>Overburden Thickness (m)</i>	<i>Oil Shale Thickness (m)</i>	<i>Organic Matter (%)</i>	<i>Average Oil Content (%)</i>
El-Lajjun	1.3	20	31	29	28	10.5
Sultani	0.99	24	69	32	25	9.7
Jurf Ed-Darawish	8.6	150	47	68	18	5.7
Attaraat Um-Ghudran	11.3	226	47	36	29	11.0
Wadi Maghar	32	29	40	40	20	6.8
El-Thamad	11.4	150	142 – 400	72 – 200	25	10.5
Khan Ezzabib	N.A	N.A	66	39-45	N.A	6.9

Geology of Oil Shale in Jordan

Geologically, oil shale belongs to the upper Cretaceous and lower Tertiary formations. Oil shale deposits were discovered in the central part of the country and are classified as shallow and near surface deposits. Other deeper – lying deposits which are located in the north and east part of Jordan are exploitable only by underground mining operation.

The Jordanian oil shale is bituminous and, to varying degrees, brown, grey or dark grey calcareous marls with a typical bluish light-grey color when weathered (Figure 11). Traditionally, oil shale is defined as sedimentary rock whose solid organic content (kerogen) is virtually converted by retorting which forces the decomposition of kerogen and releases hydrocarbons as a

liquid oil-like hydrocarbons when exposed to temperatures of up to 500 °C (destructive distillation). Oil shale can be burnt directly when crushed to about 5 mm grain size in modern fluidized bed technology.

Thickly bedded or concretionary limestone - locally dolomite- and chert are interlaced in the oil shale sequence; phosphate layers occur usually under the oil shale deposits.

Feasibility Studies and Test Programs

During the last two decades, the GOJ has conducted several feasibility studies and test programs through many specialized international companies either for direct burning or retorting as follow:

Table 4: Additional properties of Jordanian oil shale deposits

	<i>Number of Drilled Wells</i>	<i>Moisture Content (%)</i>	<i>Ash Content (%)</i>	<i>Sulfur Content (%)</i>	<i>Density (g/cm³)</i>	<i>Calorific Value (Kcal/kg)</i>	<i>Calorific Value (kj/kg)</i>
El-Lajjun	135	2.1	54.7	3.1	1.81	16 50	6 906
Sultani	57	5.5	55.5	2.4	1.96	15 26	6 380
Jurf Ed-Edarawish	50	4.5	58.4	2.4	2.1	11 00	4 603
Attaraat	41	3.25	53.2	2.6	1.8	1730	7.235
Wadi Maghar	21	2.9	57.5	2.6	2.03	1090	4.773
El-Thamad	12	2.5	54.7	3.2	1.8	1800	6 903



Figure 11: Jordanian oil shale

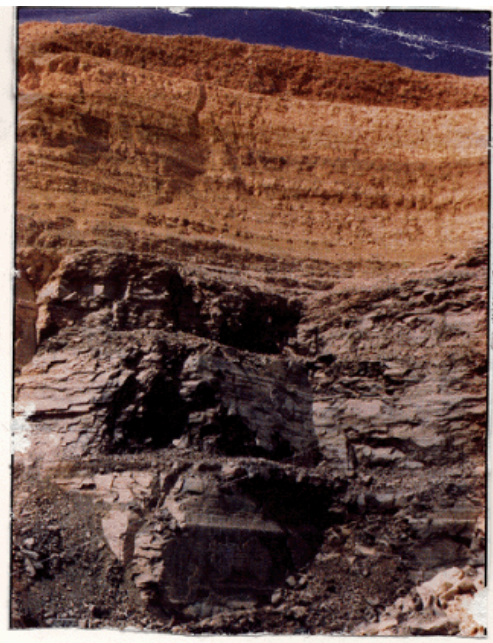


Figure 12: Outcrop of Jordanian oil shale

1. Pre-feasibility study with a former USSR company named Technopromexport to assess the potential for direct burning in a 300 MW power plant. The study concluded that the Jordanian oil shale is suitable as a fuel for direct burning and recommended the construction of an experimental demonstration plant of 200 MW.
2. Feasibility study with a German Company called Klockner / Lurgi for conducting studies and test programs for oil shale retorting to produce syncrude (50 000 b/d) and for circulating fluidized bed (CFB) for direct combustion in

power generation. The study concluded the following

- A - The geological conditions of Al-Lajjun oil shale are reliably proven for a 50 000 b/d oil shale retorting plant for 30 years.
 - B- Open cast mining method for oil shale is both technically and economically viable.
 - C- Al-Lajjun oil shale has high quantity of sulfur (3.5 %). The hydrogen sulphide produced can be converted to 99% pure elemental sulfur.
 - D- The pilot test demonstrated smooth operation.
 - E- Combustion tests on spent shale proved an almost total burn out of residual carbon at 800 °C; the residual oil shale is suitable material for building and road construction.
 - F- The economic assessments indicated that oil production cost is in the range of 20-25 USD/b and electricity production cost is 19 fils/ kWh (1988 prices).
3. Feasibility study and retorting test program with a Chinese company named Sinopec. The research into Jordanian Al-Lajjun oil shale was carried out by shipping more than 1000 tons to China. Main results indicated that oil content reaches 10%, sulfur content is about



Figure 13: Open pit mine wall in Jordanian oil shale



Figure 14: Sultani open pit mine

3%, calcium oxide content in ash accounts for 38%. The research into Jordanian oil shale showed that it can be well processed in the Chinese Fushun type retort. There arose no difficulties in connection with ash removal or separation of water from shale oil. The oil yield from the retort reaches 80-84% of Fischer assay, oil viscosity was 0.98 and impurities of 0.06%. The calorific value of the gas produced was 1050 Kcal/m³. It means that Fushun type retorts are suitable for different kinds of oil shale which makes them economically profitable, and especially suitable for small and medium scale shale oil production.

4. Test Program was conducted by a Russian company called Enin.

The preliminary results of the Jordan shale thermal processing tests conducted by Russian specialists from Enin have shown that the technology developed by ENIN makes it possible to use shale of any fractional composition and quality without preliminary sizing for producing high calorific liquid and gases fuels. The technology called UTT – 3000 has found its commercial application in

two plants which process as much as 140 tons per hour oil shale.

The study has concluded that the Jordan oil shale is fully suited for a high efficient use in plants UTT – 3000 which is a high efficient and environmentally safe facility to produce oil and fuel gas or a thermal power station where shale is used as a source fuel.

5. Feasibility study and test program with a Canadian Company "Suncor" for retorting the Jordanian oil shale. The oil shale sample was tested using Alberta Taciuk Processor (ATP). Engineering and economical analysis will be required to determine if this is a viable project. Technical indicators of similar project in Australia seem to be positive.

The ATP combines the extraction, upgrading and energy generating steps of producing oil from oil shale; it requires less capital and equipment than other traditional processing techniques. The ATP is a rotating kiln that heats oil shale to 500 °C, releasing the shale's hydrocarbon vapors. These vapors are then captured, condensed and processed into oil. The spent shale is used to fuel the

operation making it energy self-sufficient.

6. Direct burning feasibility studies

Jordan has conducted several feasibility studies for direct burning to generate electricity with some international companies. All feasibility studies and test burns have concluded that the Jordanian oil shale burned very stably, even at loads as low as 40%, low SO₂ and NO_x emission levels can be achieved in the CFB combustor, high carbon burn out, 99% can be achieved.

Oil Shale Test Burn Results

A) Test in Finland

Based on the results of combustion of 75 tons of Jordan Sultani oil shale in Finland, Pyropower concluded the following:

1. The sample of oil shale is an acceptable fuel in an Ahlstrom Pyroflow CFB where it burn cleanly and efficiently.
2. Combustion efficiency in excess of 98.5 % was demonstrated.
3. Both SO₂ and NO_x emissions and CO emissions all were acceptably low. The tests demonstrated that over 90% of the fuel sulfur was absorbed by the inherent calcium in the oil shale. Typical emissions measured during these tests were:
SO₂ below 20 ppm
NO_x in the range between 60-120 ppm
CO below 50 ppm

These values will generally meet the more stringent environmental requirements.

B) Test in Germany

Based on the results of combustion of 75 tons of oil shale from Sultani deposit, Lurgi concluded the following:

1. There were no upsets in the fluidizing behavior of the circulating material and/ or in plant operation.
2. Combustion of oil shale was self – sustained.
3. With particle size 3-5 mm, combustion of oil shale did not pose any problems.
4. Carbon burn – off reached 98%.
5. In view of CaCO₃ content of the oil shale ash it was not necessary to add limestone for desulfurization as per the following chemical reactions:
$$\text{CaCO}_3 \longrightarrow \text{CaO} + \text{CO}_2$$
$$\text{CaO} + \text{SO}_2 + \frac{1}{2} \text{O}_2 \longrightarrow \text{CaSO}_4$$

(Calcium sulfate like plaster)
6. In the view of the low combustion temperature, the SO₂, NO_x and CO emissions were according to the international standards.

Main Oil Shale Technologies

There are two main methods to exploit oil shale economically and environmentally:

A) Retorting Technologies

Common to all retorts are the processing steps taking place. First retorting (sometimes called semi coking) takes place in a pyrolysis zone where the oil shale is dried and heated to a temperature of 500 – 600°C.

The retorted shale then passes to a gasification zone where the residual organic carbon (semi – coke) is oxidized at a temperature of not more than 1000 °C, so that the inorganic materials do not fuse to form masses of slag.

Finally, the spent shale is cooled to 80-100 °C as it passes to the lower part of the retort where it is removed through a water seal. The heat required to retort the shale is principally supplied by combustion of a recycled fuel gas in the hot chamber which is equipped with special burners.

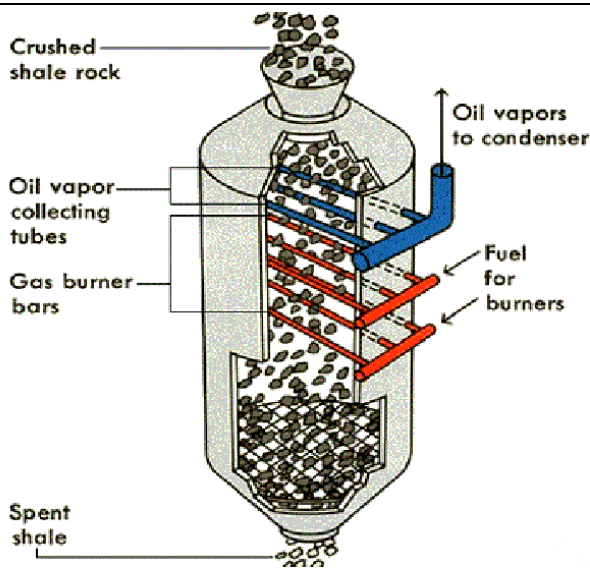


Figure 15: Standard oil shale retort

The primary products from processing oil shale in the gas producer retort are shale oil and fuel gas. The waste products for disposal are spent shale and process water.

B) Fluidized Bed Direct Burning Technology

In fluidized-bed combustion, oil shale is burned and its sulfur is recaptured in a single process, as contrasted with conventional boilers combustion where a scrubber removes the sulfur from flue gases. Due to the low combustion temperature (700 – 800 oC) and due to the solid mixing which makes this CFB superior to other conventional boilers in terms of efficiency (99%) and low SO_x and NO_x emissions.

CFB is capable of handling low-grade solid fuel with high ash content as well as its capability of in-bed capture of sulfur.

Although the EL-Lajjun oil shale has relatively high levels of calcium causes much of the sulfur to bond with the calcium to form sulfates during the process of pyrolysis and combustion causing much reduction in sulfur dioxide emissions.

The fluidization phenomenon is the state where the solid particulates move apart from each other and is kept individually suspended by the gas in a column containing a

bed of solid particles by passing gas at a certain minimum velocity. The solid bed is said to be fluidized because it behaves very much like a liquid.

As the gas velocity increases beyond the minimum fluidization velocity, the bed material begins to elutriate. Because of the turbulence in the circulating bed, any particles fed to the bed mixes quickly and uniformly with the bed material.

The primary advantages of using CFB boilers are:

- Ability to burn low grade fuels such as oil shale.
- Low emissions of SO₂ and NO_x due to the existing limestone in oil shale and due to the lower combustion temperatures.

Over 99% combustion of carbon content can be achieved due to the good mixing of gases and solids and due to the long retention time.

Material (oil shale) is entered by means of screw feeders with particle size of 3 to 7 mm into the combustion chamber where it is easily mixed with the circulating solids.

The combustion temperature (700 – 900oC) is below the ash fusion temperature and also suitable for prevention of NO_x formation.

Solids are separated from flue gas in a heat cyclone and recycled into the furnace through the hot cyclone.

Coarse bottom ash particles are withdrawn from the furnace bottom. Gases from hot cyclone are passed through superheater and economizer banks and then to a bag filter before it goes to the chimney.

The fluidization phenomenon is the state wherein the solid particulates move apart from each other and are kept individually suspended by the gas in a column containing a bed of solid particles by passing gas at a certain minimum velocity (Fig. 16). The solid bed is said to be fluidized because it behaves very much like a liquid.

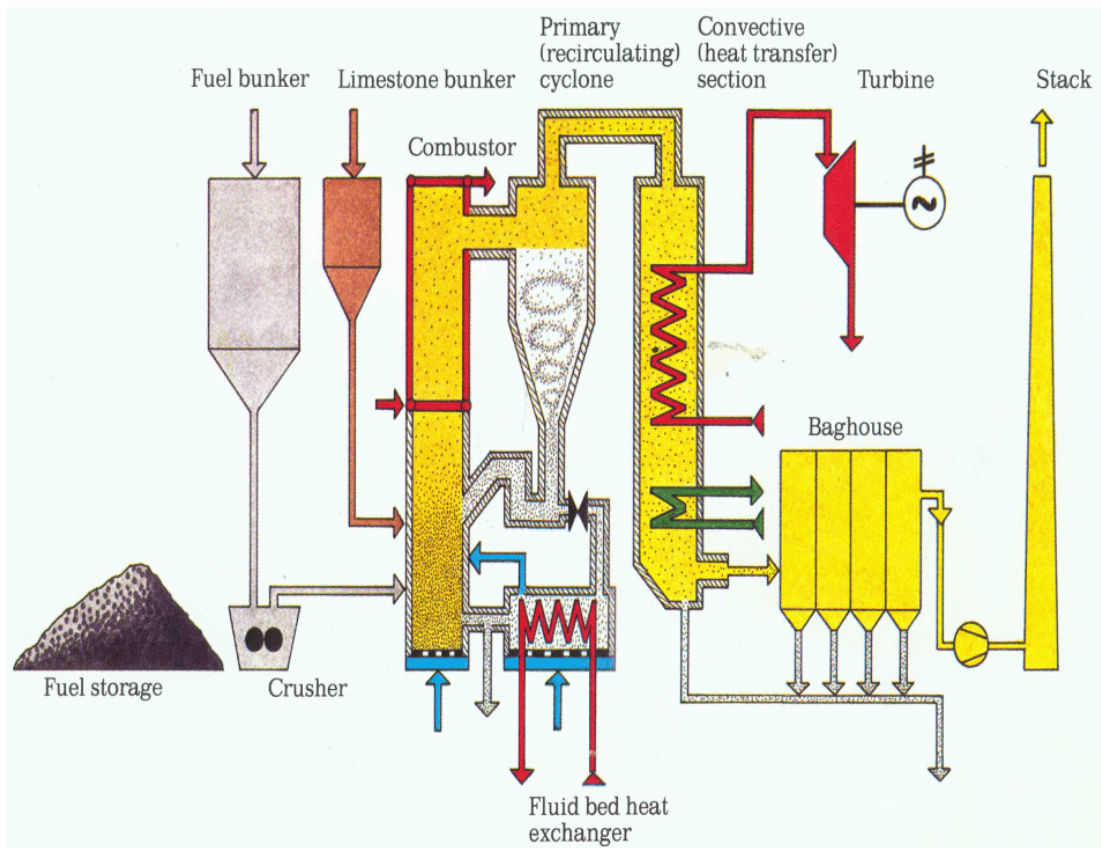


Figure 16: Fluidized bed system for oil shale burning

As the gas velocity increases beyond the minimum fluidization velocity, the bed material begins to elutriate. Because of the turbulence in the circulating bed, any particles fed to the bed mixes quickly and uniformly with the bed material.

The primary advantages of using CFB boilers are:

1. Ability to burn low grade fuels such as oil shale.
2. Control of SO₂ and NO_x emissions due to existing of limestone and the combustion at low temperatures.
3. Over 99% combustion of carbon content can be achieved due to the good mixing of gases and solids and due to long retention time.

Material (oil shale) is entered by means of screw feeders with particle size of 3 to 7 mm into the combustion chamber where it is easily mixed with the circulating solids.

The combustion temperature (700-900 °C) is below the ash fusion temperature and also suitable for NO_x reduction.

Solids are separated from flue gas in a heat cyclone and recycled into the furnace through the hot cyclone.

Coarse bottom ash particles are withdrawn from the furnace bottom. Gases from hot cyclones are passed through super heater and economizer banks and then to a bag house before it goes to the chimney.

C- Pressurized Fluid Bed Combustion (PFBC)

The PFBC principle combines fluidized bed combustion with a gas turbine. The gas turbine supplies the combustion air at high pressure to the combustor, and the gases after being cleaned in cyclones drive the gas turbine (Figure 17).

Steam is simultaneously generated in the tube bundles in the combustor and drives a

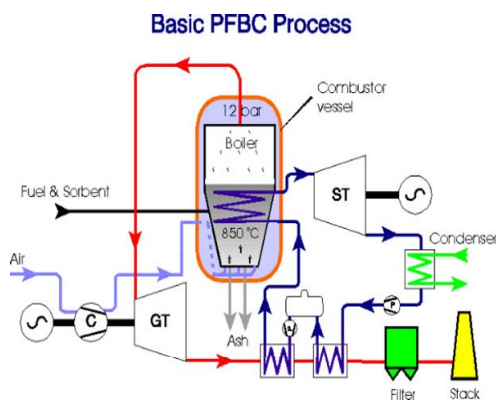


Figure 17: Pressurized fluidized bed system steam turbine. It is an oil shale-fired combined cycle where the gas turbine produces about 20% and the steam turbine about 80% of the electrical output. With this combination, a high efficiency is reached to about 50% (Compared with 30% for CFB).

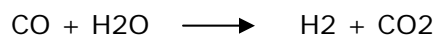
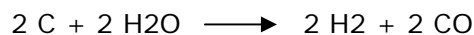
Other Oil Shale Technologies

1 - Gasification:

Although oil shale is normally considered primarily as feed stock for syncrude production, recent R&D has shown that oil shale can be gasified as well.

The gasification process employs a bed of crushed oil shale that travels downward through the gasifier, and operates at pressure up to 450 psi. Steam and oxygen are admitted through a revolving steam-cooled grate which also removes the ash produced at the bottom of the gasifier. The gases are made to pass upward through the oil shale bed, carbonizing and drying the oil shale, steam is used to prevent the ash from clinkering and the grate from over-heating and hydrogen -rich gas is produced. Because of the pressure, some of the oil shale is hydro generated into methane (in addition to that distilled from oil shale), releasing heat which in turn is given up to the oil shale, minimizing the oxygen requirement .

Gasification:



Research on catalytic gasification of Jordanian oil shale sample was carried out at the Grozneftechim in the former Soviet Union on laboratory and pilot scale plants. The catalytic system used proved to be highly selective for yield of gas containing 80% of methane against other known hydrogasification processes yielding gas and resin.

Results of the research in steam exogenous gasification have shown that it is possible to obtain synthesis gas used in motor fuel production. The gas obtained has high content hydrogen (10.5 %) and carbon oxides (64.9%).

2 - In-Situ Oil Shale Retorting Process

With certain types of oil shale deposits, recovery of the oil in-situ may be possible. The process is based on mining out part of the shale to create a large room, then emplacing explosives and blasting the overlying shale, creating a column of rubberized oil shale. A forward combustion process is then used to retort the "room".

3 - Oil Shale Extraction by Organic Solvents

Solvent extraction of organic matter is one of the common techniques for dissolving organic matter within rock composite.

Research and development activities were carried out in Jordan and have investigated El-Lajjun oil shale using a solvent mixture of 75% benzene and 25% cyclohexane by volume and found to be the best solvent of various organic solvents, such as toluene, benzene, cyclohexane, pentane, ethylether and ethylbenzene to produce 73% of high yields of extracted oil in a continuous sterling tank reactor (CSTR). It was found that extraction yield from fine particles exceeded that from the course particles by an amount which decreased with the increase in residence time. The higher the temperature to which the oil shale is preheated (less than the boiling point of the solvent), the higher is the extraction yield for the same residence time. It was found that the effect of extraction time of yield was much stronger for larger particles (diameter more than 2 mm) than for smaller ones. The op-

timum weight of solvent used per kg of oil shale was 0.5 kg solvent per kg oil shale.

In a study conducted jointly between NRA and NERC using soxhlet extractor to extract oil from the El-Lajjun oil shale using different solvents to examine the best solvent and the best technique based on the quality and quantity of the yield and solvent obtained. It is found that maximum oil recovery can be achieved and reached 23.37% by using carbon disulfide by soxhlet type extractor (Figure 18).

Eleven organic solvents were used to extract oil shale organic matter by soxhlet extractors for duration of twenty-hour extraction time. These organic solvents are: Xylene, toluene, dichloromethane, chloroform, carbon tetrachloride, ethanol, carbon disulfide, perchloroethylene, trichlorofluoromethane, petroleum spirits and a mixture of benzene and cyclohexane (75% and 25%).

The soxhlet extractor is used to extract organic compounds from solids. The center chamber of the extractor contains a porous fiber glass thimble. Inside the thimble is the solid sample to be extracted. The round

bottom flask contains a volatile organic solvent is heated to boil the organic solvent to create enough vapor pressure to produce a steady flow of liquid drops from the condenser at the top of the soxhlet extractor. Once the solvent in the upper chamber rises above the relief arm, the solvent is returned back to the round bottom flask and the process repeats it-self.

The solvent is then removed by evaporation at room temperature. Then the sample is placed in a sand bath under nitrogen evaporator to separate the solvents from the extracted organic matter. Organic matter was determined as the difference between the weight of the vial with the extracted organic matter and the weight of the empty vial. The sample which was subjected to solvent extraction is removed and dried in oven. The dried sample is then treated by Fischer Assay to determine the oil yield potential and to evaluate the loss in organic matter that is dissolved through the extraction process

Environmental Considerations

The production, conversion, transport and

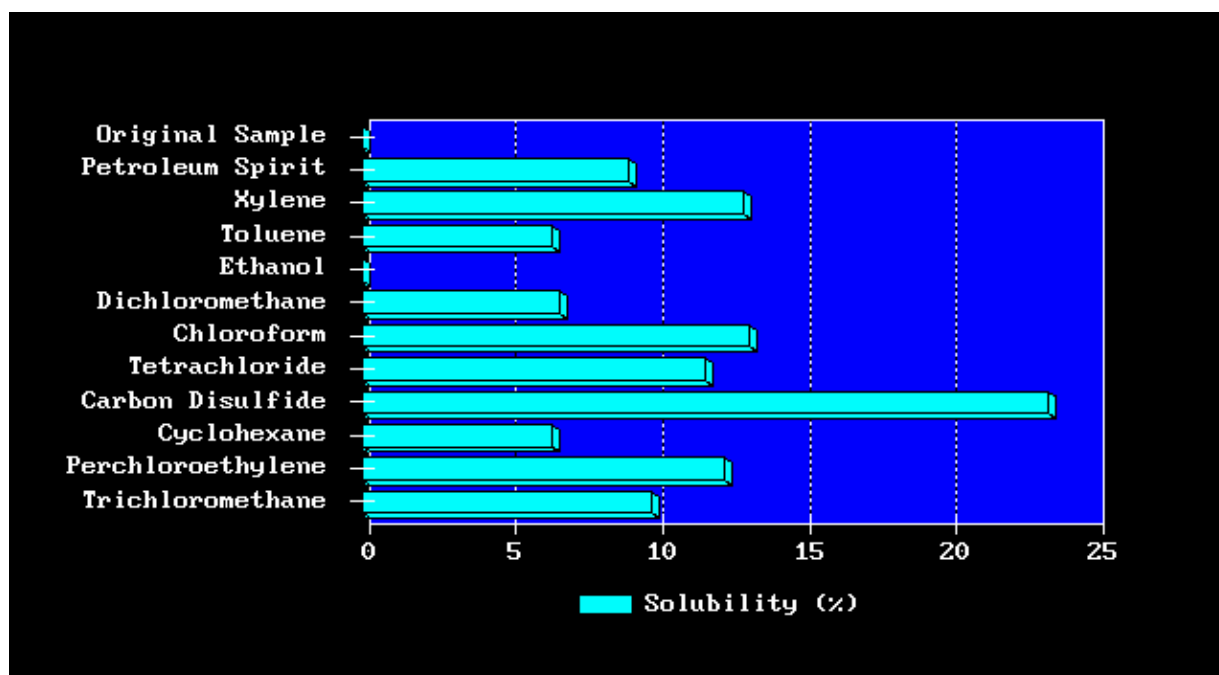


Figure 18: Solubility of oil shale organic material in various solvents.

final use of all forms of energy have certain environmental impacts. The production of syncrude and the generation of electricity based on thermal decomposition, gasification and direct combustion of oil shale, hot gases are normally discharged containing constituents.

Prior to the commencement of any oil shale operation, environment impact assessment (EIA) should be conducted to develop data in all environmental areas. The key areas to be addressed are:

Water pollution: Development of protective measures for both surface and ground water supplies and measures to mitigate surface and ground water contamination due to mining and ash disposal. Excavation of ditches around the pit area and the out-of-pit waste pile are measures to prevent rain water run-off from becoming contaminated.

Rain water run-off will be collected in sedimentation ponds and will have zero discharge. This will prevent any contaminant from entering the ground water. Leachability tests of the spent shale ash are required as well as testing of the overburden for its chemical properties.

Spent shale must leave the retorting operations through water filled lock hoppers to ensure thorough saturation prior to being hauled back to mine reclamation site.

The elution test of some ashes showed that some heavy metals of environmental concern were found in traces. Successive analysis has shown also that ground and percolating waters are highly alkaline and saturated with gypsum after contact with ashes. As a mitigation measure, ash must be layered with the overburden in the disposal plan in order to minimize wind erosion and to reduce the potential of leaching.

Atmospheric Air Emissions: Air pollution from the mine area will be mostly dust. The operation will be equipped with water tankers and the pit road will be sprayed with water regularly. The noise level due to mine blasting is minimal, as blasting the oil shale is not required. Dust collectors will be used

to prevent air pollution at the process plant.

The major pollutants arising from the processing of oil shale are smoke, SO_x, NO_x, CO, CO₂ and particulates. For particulates, typical preventive measures will be taken to prevent ash be emitted to the atmosphere. These measures include electrostatic precipitators and bag filters. They should be able to reduce the particulate matter emitted to less than 80 mg/m³ of flue gas and 12% reduction in carbon dioxide.

Gaseous Emissions: Emission standards specify the maximum amount of a given pollutant which can be released into the atmosphere. Previous oil shale studies in Jordan have used the World Bank Guidelines because of their ready available in a usable form.

All gaseous fuels produced in the process will first be treated to recover ammonia and will then be desulfurized before being used for hydrogen manufacture. Desulfurization techniques will be used to remove the sulfur from the retorted gases. The hydrogen sulfide thus recovered and will be converted to valuable elemental sulfur.

Sulfur Dioxide (SO₂): Jordan oil shale has a high alkaline ash content which requires no limestone to be added for sulfur removal. The pilot test results indicate excellent sulfur capture by the calcium in the oil shale. In the combustion process, most of the sulfur is oxidized to form SO₂ and a small fraction is further oxidized to form SO₃. The following reactions take place during combustion:

Step 1 – Limestone (CaCO₃) + Heat ---- Calcium oxide (CaO) + Carbon dioxide (CO₂)

Step 2 – Calcium oxide (CaO) + Sulfur dioxide (SO₂ + ½ O₂) ---- Calcium sulfate (CaSO₄) like plaster.

In the circulating fluid bed boiler, oil shale is mixed with limestone and suspended in a powerful air flow. Inside the boiler, the mixture is heated up and changes to lime that captures sulfur dioxide and forms calcium sulfate known as gypsum.

Nitrogen Oxides (NO_x): The two most important nitrogen oxide air pollutants are nitric oxide (NO) and nitrous oxide (NO₂). Both are produced in combustion process arising from the high temperature reaction between N₂ and O₂ in the combustion air and from the oxidation of organically – bound nitrogen in certain fuels. The NO_x emission levels increases with increasing temperature.

The pilot test results indicate acceptable NO_x emissions. The low NO_x emissions is brought about by the low combustion temperature of only 800 OC. The NO_x emission levels increased with increasing furnace temperature.

Prospects for Ash Utilization

The basic materials which are normally blended to form cement, such as limestone, clay, fluorite, iron oxide, are already inherent in the oil shale ash

Chemical composition of Jordanian oil shale ash indicates that almost 87% of cement raw materials do exist in oil shale ash as shown in Table 5.

Common products made from oil shale from these early operations were kerosene and lamb oil, paraffin, fuel oil, Lubricating oil and grease, naphtha, illuminating gas, the fertilizer chemical and ammonium sulfate.

Other potential by -products from oil shale include specialty carbon fibers, absorbent

Table 5: Composition of Jordanian oil shale ash

<i>Compound</i>	<i>wt %</i>
Calcium oxide	48
Silicon dioxide	29
Aluminum oxide	7
Iron	3
MgO	3.3
CO ₂	3.5
Na ₂ O	0.6
P ₂ O ₅	4
K ₂ O	0.8

carbons, carbon black, bricks, construction and decorative building blocks, soil additive fertilizers, rock wool insulating materials and glass. Many of these by-products are still in the experimental stage, but the economic potential for their manufacture seems big.

Preliminary R&D concludes that the high-calcium ash of Jordanian oil shale is suitable for a wide range of utilizations such as:

- Construction material including bricks, tiles, light weight aggregate cement mixing for manufacturing of concrete products.
- Construction of road bases, use filler in asphalt mixtures.
- Stabilization of soils conditioner and fertilizer production (liming of acid soils).
- Production of foundry cores.
- Animal supplement in animal food.

Oil Shale Ash Utilization in Cement Manufacturing

Oil shale ash is characterized as a binding material (clinker minerals). Studies conducted by Bechtel concluded that shale ash binding matter does not respond to the standard requirements for Portland cements with respect to the regularity of volume variation during the first week of hardening.

Moreover, a sample of shale ash from combustion of Sultani oil shale deposit was tested chemically and physically at the Jordan Cement Lab in 1988 and concluded the following results:

The tested oil shale ash has shown good ability for grinding which assist in increasing the earlier strengthening for the cement.

Test proved that the cement contained some ash became more strength after 3-7 days.

When ash ratio mixed with cement with more than 20%, some negative impact appeared due to the high content of P₂O₅ in the ash.

Byproducts can add considerable value to some oil shale deposits. Uranium, vana-

dium, zinc, alumina, phosphate, sodium carbonate minerals, ammonium sulfate and sulfur add potential value to some deposits. The spent shale obtained from retorting may also find use in the construction industry as cement. Germany and China have used oil shale as a source of cement.

Another secondary constituent for the manufacture of cement is produced from oil shale combustion in fluidized bed furnace.

The energy that is released when oil shale is burnt is used to generate electricity or heat and the ash produced is ground with cement clinker to provide oil shale cement characterized as a binding material.

Rohrbach Zement in Southern Germany is the only cement factory in Europe which produces Portland shale cement using burnt oil shale as a feed stock that is certified according to the DIN 1164, Part 100 ISO 9001 specifications which is high quality cement from limestone and oil shale.

The most important raw materials for the manufacturing of cement are limestone and clay in which both components are already naturally mixed. The mixture is ground and subsequently fired in a rotary furnace to cement clinkers. The cement industry started using oil shale to improve the quality and economy of cement production. Research has drawn attention to the fact that large quantity of high calcium ash of Jordanian oil shale is suitable for a wide range of utilization such as cement production, construction of roads and manufacturing of bricks and tiles. Cement is made from a mixture of raw materials which mainly contains calcium oxide, silicon dioxide, aluminum oxide and iron in definite proportions.

Chemical composition of oil shale ash indicates that almost 87% of cement raw materials do exist in oil shale ash as follow:

It is highly recommended to conduct R&D activities to study all factors and components such as mechanical properties, high strength, permeability and self-binding properties to avoid any technical obstacles that might appear to utilize the fly ash as a

cement substitute in concrete and improve the efficiency of shale ash use in cement and building material industry. The chemical composition of the ashes may vary to a certain extent depending on the type of oil shale used.

Use of oil shale in bricks and cement production was successfully carried out in the German oil shale industry. Deutsche Babcock AG closely cooperates with Portland Zementwerk Dotternhausen Rudolf Rohrbach KG, where two fluidized bed fired power station units have been operating for a number of years, each generating 3 MW by oil shale combustion to provide power for the cement works, making it less independent of the public grid. The combustion residues are delivered to the cement works where they are ground together with cement clinker. In this way oil shale has a dual function as a source of energy and raw material for cement production.

By grinding 70 parts of Portland cement clinker together with 30 parts of oil shale combustion residues, the so-called oil shale cement is produced in Dotternhausen which hardens quickly and has pozzolanitic properties.

It has some properties as normal Portland cement and the heat of hydration of this type of cement is low. More than 300 000 tons of oil shale cements are produced annually while the power station generates 84000 MWh annually. The history of this plant began in the year 1939 by the founder of the company Eng. Rudolf Rohrbach.

Private Investment Approaches

The energy sector is considered as an infrastructure service sector, which is crucial to economic growth. In 1985, the Jordan Council of Ministers took a decision to adopt privatization and outlined the ideas and actions as to convert a number of public corporations to shareholding companies that work on commercial basis and to allow the private sector to participate in the ownership of some public corporations and participate in its management. Jordan has also

adopted the economic reform program, which includes the restructuring and privatization of a number of public enterprises including the power sector.

In 1996, a new electricity law was issued that allows the private sector to participate in building, operating and owning power generation facilities to highlight potential investments in Jordan with special emphasis on the new investment ventures such as Build, Operate and Transfer (BOT), Build, Own and Operate (BOO).

Jordan through the modification of its investment and electricity laws aimed at creating a suitable environment to attract private investment within the country and from abroad in financing and operating the proposed infrastructure projects, this includes oil shale projects. This approach injects elements of new source of capital and enhances competition into sectors to provide lower costs, better levels of services and transfer of financial and technical risks which the private sector is better able to handle.

Oil shale utilization processes require large financial expenditures beyond Jordan's means therefore, the BOO or BOT schemes seems to be the perfect solution.

The project concept is that the investor/contractor constructs a facility that utilizes oil shale through the known technologies mainly; direct burning for power production or by retorting for oil and gas production. This will require that the government should provide the necessary guarantees to enable the contractor to sell the output products for a period of time. Fig. 13 is a schematic diagram of the BOT concept for an oil shale retorting plant.

Jordan's Strategy for Oil Shale Use

Triggered by the fact that Jordan imports 95% of its energy needs and coupled with the impact of the current rising oil prices, the need for developing indigenous energy resource is set as a high priority on the national agenda of the government of Jordan. The Government of Jordan has adopted a new policy for the development

of oil shale resources with minimum risks to the country. The Ministry of Energy and Mineral Resources (MEMR) has invited qualified companies to submit their proposals with proven technology and experience in oil shale to establish a privately owned oil shale projects based on a Build, Own and Operate (BOO) scheme to produce oil and electricity. The requested proposals shall include comprehensive feasibility study, basic financial terms and conditions along with total benefits to Jordan.

A decision was made after the most attractive and acceptable three offers were received by MEMR from interested parties after a transparent evaluation process. This will be followed by good faith negotiations on concluding oil shale agreements.

The Government's approach / policy for oil shale is summarized as follows :

- Provide all available related data free of charge.
- Keep the door open for any company who is interested to invest in the oil shale development.
- Grant exploration and mining rights for areas with adequate deposits, whether for pilot or commercial projects; for either oil extraction or power generation.
- Sign long term purchase agreements of the energy product of any oil shale project.
- Facilitate all the logistics needed for oil shale utilization.

The GOJ is becoming more aware of the critical energy situation and the associated environmental problems related to the conventional oil that are considered as pressing factor toward searching for various alternative options to suit Jordan's economy. The focus of attention will be directed towards the practical issues of the offer that will be submitted by the Canadian company Sunco for implementing a retorting oil shale project rated 17000 b/d. If this initial stage demonstrated success along with the first operational oil shale project in Australia rated 4,500 b/d, the GOJ will look favorably

on granting the development firms the right to continue expanding in other projects based on BOO scheme.

Conclusion

The recent increases in world oil prices and the certain lately achieved technology developments present a rich opportunity to consider issues and options for taking a strategic approach to oil shale development, to ensure, among other goals, that economically, technologically, and environmentally sound approaches to resource development are pursued.

Oil shale technologies have been rapidly developed to accommodate oil shale utilization economically and cleanly to a point where the cost of extraction and processing of oil shale is competitive with conventional crude oil.

At current level of conventional crude oil of \$60/bbl, producing oil from shale becomes economically viable.

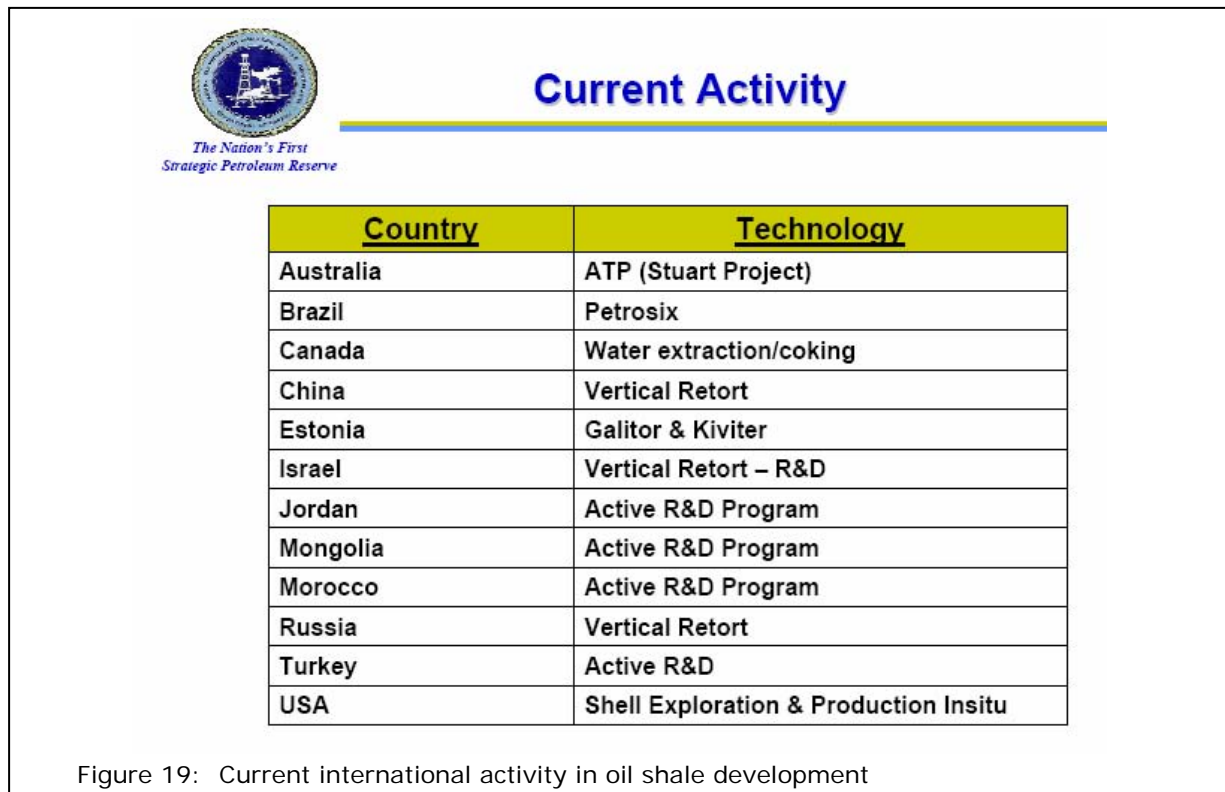
With this improvement in technology, Jordan will be able to become self-sufficient in

oil production, consumption and exporting. The GOJ has taken essential measures to encourage foreign investments in oil shale processing and utilization. The new investment law and the new electricity law will provide equal opportunities to capable developers to establish a privately owned oil shale projects.

Due to the importance of oil shale to Jordan as the only major proven indigenous energy source, extensive studies were carried out with an objective to assess the quality and the quantity and the suitability of using oil shale as a reliable energy source.

The studies have indicated that Jordan possesses a large quantity of good quality oil shale. All tests have proven the environmental, technical and economical feasibility and the studies have recommended that pilot demonstration plants should be constructed prior to embarking upon any commercial scale project.

Once clear indications are in hand that major firms are ready to invest in scaling up and demonstrating oil shale technolo-



gies, government attention should be directed at gathering long lead time information required to support future oil shale utilization.

The R&D that took place worldwide, combined with the ongoing operations and recent testing abroad, supports the judgment that mining and surface retorting is a technically viable approach for producing strategically significant amounts of oil.

The government of Jordan believes that oil shale utilization for power generation and retorting should be pursued because it will result in significant energy supply security and savings in foreign exchange and create new jobs.

The oil shales in Jordan are considered by international standard as highest grade oil shales which are available at shallow overburden near the existing infrastructure needed for an oil shale industry.

It is appropriate to begin the demonstration stage when basic uncertainties have been resolved and the new information gained indicates that the demonstration will generate information about other remaining uncertainties associated with a much larger scale effort.

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