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Future Policies and Strategies for Oil Shale Development in Jordan

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Abstract

Indigenous oil shale deposits could satisfy Jordan's demand for liquid and gaseous fuels as well as electricity for many centuries. Markets also exist for raw and retorted oil shale, spent shale, and for sulfur recovered during the upgrading and refining of crude shale oil. Although the potential benefits of oil shale development are substantial, complex and expensive facilities would be required, and these have serious economic, environmental, and social implications for the Kingdom and its people. In January 2006, the United States Trade and Development Agency (USTDA) awarded a grant to the Jordanian Ministry of Planning and International Cooperation to support the analysis of current oil shale processing technologies and the application of international expertise to the development of a oil shale industry in Jordan. The goal of the technical assistance project was to help the Governement of Jordan (GoJ) establish short- and long-term strategies for oil shale development and to facilitate the commercial production of shale oil in the country. This paper discusses the results of the project. The Kingdom's current energy situation and its previous work on oil shale are summarized, and the incentives and restraints on oil shale commercialization are described. Impediments to development are identified, and possible governmental responses are assessed.

Keywords: Oil Shale; Jordan; Retorting; Electricity; Environment; Economic Analysis;

1. Background

The Hashemite Kingdom of Jordan is about the size of Indiana in the United States of America or Portugal or Hungary in Europe. Jordan is landlocked except for about 26 km of shoreline on the Gulf of Aqaba in the Red Sea. Most of the land is on an arid desert plateau. Precipitation is sparse. Less than 4% of the land is capable of growing crops. The scarce surface water is fully utilized, and the large groundwater resources are being depleted.

Jordan is a "lower middle income country" according to the World Bank. There are about 6 million Jordanian citizens and about one million Iraqi refugees and/or visitors. The largest cities are the capital Amman (1.9 million people), Zarqa (0.5 million), and Irbid (0.28). Major economic activities are agriculture, light manufacturing, mining and quarrying, commercial services and tourism. The exchange rate for Jordanian Dinar is about USD 1.41. In 2006, the average gross domestic product per capita was about US$ 2500; inflation rate approximately 6.25%; and unemployment reached 12.5% of the total workforce [1, 2].

In 2006, the average daily energy consumption was about 107,000 barrels of liquid fuels, and electricity demand peaked at about two GW. Except for a small amount of natural gas, in the northeastern corner near the Iraqi border, almost all of needed primary energy is imported. This caused a heavy burden on the national economy, with an energy bill of more than three billion US$, in 2006 [3]. Crude oil and some refined products are imported from neighboring Arab countries through Aqaba port, and then transported to the only refinery, nearby Zarqa. Natural gas comes in a pipeline, from Egypt and runs up to the Syrian border, which at present supplies main power stations. The huge cost of imported energy, because of prevailing high prices of crude oil in the international market, has encouraged GoJ to exploit its vast resources of oil shale and renewable sources, such as solar and wind energy.

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2. Oil Shale Resources and Their Quality

Oil shale is a rock that contains kerogen, which is a complex organic substance that breaks down when retorted (heated) to form crude shale oil, gases, and char. Four of Jordan's best-known deposits, i.e. El Lajjun, Sultani, Jurf Ed-Darawish, and Attarat Um Ghudran, are located about 100-120 km south of Amman, close to the town of Qatrana - see Fig. 1. These contain more than 22 billion tonnes of raw oil shale [4]. Tables 1 and 2 summarize estimated reserves and characteristics of main oil shale deposits in Jordan [5]. At average oil yield of about 9.0% (roughly 22 gallons per ton (gal/t)) the potential oil yield, from the previous four deposits only, is approximately 14 billion barrels, which could satisfy Jordan's liquid fuel and electricity needs for centuries. It is clear that the all deposits have acceptable stripping ratio of about unity, which makes open-cast mining attractive, with relatively low cost.

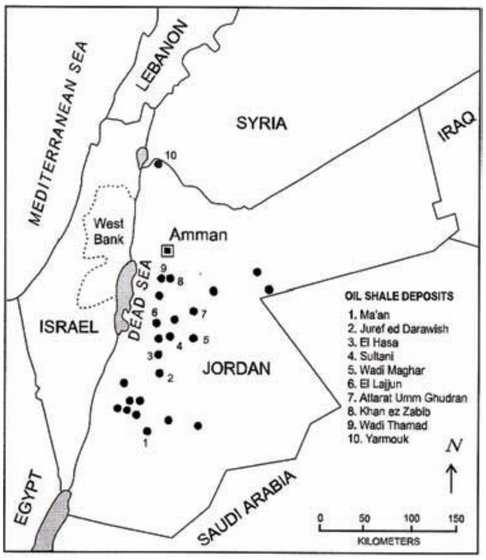

Fig. 1. Oil shale occurrences in Jordan

Nevertheless, the sulfur content is high and the ash yield is about four times that of a medium grade of bituminous coal with similar sulfur content. This makes oil shale a difficult and expensive solid fuel. Compared with Colorado shale oil (see Table 3), oil from El Lajjun deposit has (i) less nitrogen, which is good for refining, (ii) a lower pour point, i.e. flows at lower temperatures, and (iii) a lower initial boiling point: it may contain lighter hydrocarbons, which is generally good [6]. It is also heavier, which is considered relatively bad, and it contains about 15 times as much sulfur.

The high sulfur content is a very serious defect, because it makes the oil corrosive and unstable, increases the cost of refining, and it is almost impossible for the finished products to meet modern quality standards. Sulfur also inhibits the potential use of the crude shale oil as a fuel for industrial or utility applications [7, 8]. When the crude shale oil is distilled, the sulfur is distributed through all of the fractions produced, especially in heavy cuts. This, would require further treatment, upgrading and special configuration in refineries in order to meet more stringent specifications of refined products, consequently associated costs are escalated [9].

3. Development Factors

The principal factors that could affect commercialization of Jordan's vast oil shale resources are the readiness and costs of available extraction and processing technologies, the quality of the markets for the products and byproducts, the implications of development for the Kingdom's social and physical environments, and the compatibility of Jordan's laws and regulations including those related to health and environment.

Table 1. Estimated reserves of the oil shale deposits

	El-Lajjun	Sultani	Attarat Um Ghudran	Wadi Maghar	Jurf Ed Darawish	Eth-Thamad
Area (km^2)	20.4	24	348	660	90.6	66
Av. thickness oil shale OS (m)	29.6	31.6	45	40	63.8	72-200
Av. thickness of overburden (m)	28.8	69.3	53.2	40.5	47.3	142-400
Av. Stripping Ratio	1	1.6	1.2	1	-	-
Geological reserves (Mt)	1196	1130	24500	31600	8000	11400
Calculated & Indicated reserve (Mt)	1170	989	(24500)*	21600	2500	-

* NRA current investigation.

Table 2. Summary of chemical and physical properties of main oil shale deposits

	El-Lajjun	Sultani	Attarat Um Ghudran	Wadi Maghar*	Jurf Ed Darawish	Eth-Thamad*
Av. oil content (wt %)	10.5	7.5	8	6.8	5.7	10.5
Total organic content (Wt %)	22.1	21.5	23.16	20.8	18	-
Calorific value (kcal/kg)	1590	1210	--	780-1270	864	-
$CaCO_3$ (wt %)	54.3	46.96	52.2	48	69.1	-
S (wt %)	3.1	2.4	2.6	2.6	2.2	3.2
Density (g/cm^3)	1.81	1.96	1.8	2.03	2.1	1.8
Moisture (wt %)	2.43	2.6	1.71	2.7	2.8	2.5

* Information is from few boreholes drilled in the area.

Table 3. Fischer assays of oil shale from El-Lajjun and Colorado

Item	El Lajjun	Colorado
Oil yield (wt. %)	10.5	10.34
Oil yield (gal/ton)	26.0	26.7
Oil yield (bbl/ton)	0.62	0.64
Properties of shale oil		
Specific gravity (g/cm^3)	0.968	0.920
Gravity (^{o}API)	14.7	22.3
Nitrogen (wt. %)	0.66 - 0.9	1.96
Sulfur (wt. %)	8.5 to 10.2	0.61
Pour point (^{o}F)	30	75
Pour point (^{o}C)	-1.1	24
Initial boiling point (^{o}F)	171	192
Initial boiling point (^{o}C)	77	89

4. Technology

4.1. Power Generation

Tests with Jordanian oil shale, mainly from El Lujjun and Sultani, indicate that circulating fluidized bed combustion boilers (CFBC) are more suitable than traditional pulverized fuel power boilers because they can burn larger fuel particles more completely; they tolerate variations in fuel properties and operating rates; they are less susceptible to fouling; and they produce less air pollution. CFBC boilers, in a wide range of sizes, are now used commercially for various fuels. They are used to generate electricity from oil shale in Estonia, and their use with Jordanian oil shale has been examined by several firms [10]. Jordanian oil shale has burned well in pilot-scale CFBC plants, despite the levels of ash and sulfur, and the technical risk is low. However the estimated costs for commercial plants are high [11, 12]. A large power plant (e.g. 400 MW) might be practical if low-cost financing is obtained and the Kingdom can tolerate higher power prices. Small power plants (50 MW or less) would be too expensive. Subsidies would probably be required for any plant, and these may be difficult to justify, since low-cost natural gas is available for power generation. In a previous paper, it was reported that the unit electricity produced from oil shale powered plant would far exceed those generated from traditional thermal power stations fired by heavy fuel oil or combined cycle plants supplied with imported natural gas [13]. Moreover, when environmental costs are taken into consideration natural gas represents the best option, because there is no need for pollution abatement technologies. Additional costs will incur in other types of power plants due to the combustion of heavy fuel oil or oil shale.

4.2. Liquid Fuels Production

In the retorting area, Jordan is presently engaged with five potential project developers under memoranda of understanding (MOUs) initiated in 2006 and early 2007 [14]. Four firms are considering aboveground processing, in which oil shale is mined and crushed and then heated in vessels, and one firm is considering heating the oil shale in situ (i.e. in place). If an MOU study produces encouraging results, the GoJ could negotiate a production sharing agreement with the developer. The developer would then construct a small mine and a pilot processing plant containing a single production module. Experiments would be conducted with that module to ensure that the employed technology is practical and beneficial. A commercial-scale plant, containing many modules, could then be built. The leading technologies available to the developers are discussed below.

4.3. Petrosix Retorting

The Petrosix process was developed by Petrobras, the national oil company of Brazil, beginning in 1956. The intent was to exploit the huge Irati oil shale deposits and thereby reduce Brazil's absolute dependency on imported petroleum. Today Brazil produces most of its liquid fuels from offshore oil wells, ethanol plants, and its two Petrosix retorts. The Petrosix process heats coarse oil shale in a vertical cylindrical vessel. Oil shale enters through the top and is heated with reheated recycled gases as it moves down, and is discharged from the bottom. Oil vapors and gases are discharged through the top. Part of the gas is burned to heat the other part, which is returned to the vessel to heat the oil shale. Oil recoveries are high and produced shale oil quality is good – see Fig. 2. Fine oil shale and the solid pyrolysis product are currently discarded, but they could be exploited in other projects [15, 16].

Fig. 2. Petrosix Complex in Brazil

One retort, built in 1981, can process 1600 tonnes per day. The other was completed in 1991 and could process 6200 tonnes per day. The facility's total production capacity is about 3870 barrels per day (bbl/d) of shale oil (480 t/d of fuel oil and 90 t/d of industrial naphtha, 120 t/d of fuel gas, 45 t/d of liquefied petroleum gases, and 75 t/d of sulfur). Waste vehicle tires are also retorted to recover fuels and materials [17]. The Petrosix technology is advanced and efficient. It has been operated at near-commercial scale for more than two decades. Irati oil shale has high sulfur, as does oil shale in Jordan, so the Brazilian experience is relevant to Jordan's resources.

4.4. Estonian Retorts

Estonia has a diverse and vigorous industry that exploits the Kukersite oil shale to generate electricity and produce liquid fuels as well as manufacture alternative and new materials. About 1.5 million tonnes per year of oil shale are retorted to produce 8000 bbl/d of shale oil. Utilities burn approximately 10.5 million t/yr of raw oil shale to produce almost 90% of Estonia's electrical demand, and 200 thousand t/yr of oil shale is used in cement industry – see Fig. 3 - [18-20].

Fig. 3. Oil shale plant at Narva, Estonia

Two retorting technologies are used. The Kiviter retort is a vertical cylindrical vessel that heats coarse oil shale with recycled gases, steam, and air. Oil shale enters through the top and is heated with recycled gases flowing across the moving bed. Pyrolysis is completed in the lower section of the retort, where the oil shale is contacted with more hot gas, steam and air to gasify and burn the residual carbon, i.e. char. Processed shale is discharged from the bottom. Oil recoveries are relatively low, but the equipment is rugged and its availability is high. Thermal efficiency should be slightly higher than in the Petrosix retort. Fine oil shale and some of the solid pyrolysis products are currently wasted. Viru Chemistry Group Ltd. (VKG) runs two plants that use Kiviter retorts, and it is planning to increase shale oil production, but with a different retort. Eesti Energia AS (the national utility) uses two TSK140 or Galoter retorts in its shale oil factory. The Galoter was first built in early 1980s. It pyrolyzes fine oil shale particles by mixing them with hot spent shale in an inclined rotary kiln. Oil vapor is withdrawn and condensed to yield liquid fuel and non-condensable fraction is considered a medium-energy fuel gas. Retorted shale is burned, and the hot ash is returned to the retort as a heat carrier. Surplus gases and some of the heavier oil fractions, e.g. tar, are burned to produce electric power. Oil quality is good, thermal efficiency and oil recovery ratios are high. However, the equipment is complicated and capacity factors are relatively low. Both the Kiviter and Galoter retorts have been operated at large scale for more than 20 years [21]. Their performance characteristics should be well understood; therefore, expected technical risk should be low.

4.5. Alberta-Taciuk Retorting Process (ATP)

The ATP was developed primarily to process Canadian tar sands. The processor consists of two horizontal concentric tubes, rotating together. Oil shale is charged into one end of the inner tube, moves horizontally to the other end of that tube, and then it is transferred to the outer tube (where it burns in air), moves backwards between the tubes, and is discharged when it reaches the feed end. Retorting heat is provided by transferring part of the hot-burned shale into the inner tube where it contacts the incoming fresh oil shale. The wall between the tubes is heated by contacting the retorted oil shale and the hot pyrolysis gases. This heat also is transferred to the feed material [22-24].

The ATP was first used in 1989 to clean contaminated soils. Its first, and, so far, only use in the mining industry was in the Stuart oil shale project at Queensland, Australia – see Fig. 4. Stuart was developed by Suncor, the Canadian tar sands firm, and Southern Pacific Petroleum (SPP), an Australian firm. Stuart's single ATP retort was designed to produce 4500 bbl/d of shale oil from 6000 t/d of oil shale. Commissioning began in July 1999. There were problems with the retort and other equipment, especially the oil shale dryer. Although operations were difficult throughout the life of the of the Stuart project, by the end of 2003 the plant had run for more than 500 days (up to 96 days without stopping) and produced more than 1.3 million barrels. Production rates reached about 82% of the nominal capacity, and oil recovery ratio touched 94% of targeted design [25]. The high quality oil was sold as feed to refineries and as heating oil.

Fig. 4. 210 ton per hour Alberta Taciuk Process (ATP) Retort

There were many complaints from neighbors about odor and noise, and Greenpeace Australia launched a persistent campaign to stop the project, citing its environmental effects and especially the release of greenhouse gases [26]. Suncor withdrew and SPP continued until February 2004, when SPP's secured creditor, Sandefer Capital Partners, placed the project into receivership. Sandefer acquired the project's assets through a new company, Queensland Energy Resources Limited. The plant has been shut down since mid-2004. Just before the shutdown, a large quantity of oil shale was carefully crushed and dried to the plant's design specifications. When processing this feed material, the ATP retort did achieve its design capacity as well as expected oil recovery efficiency.

4.6. Paraho Retort

The Paraho retort is a vertical shaft kiln in which coarse oil shale moves downward through the vessel and is gradually heated to the desired retorting temperatures in a rising stream of hot gases. Paraho has two configurations: direct heating and indirect heating retorting systems. In a directly heated retort, the heat-carrier gas is generated by burning recycled pyrolysis gas and the retorted shale in the lower portion of the vessel. The indirectly heated configuration has a similar mechanical design but uses an external furnace to heat the heat carrier gas and does not burn the retorted shale – see Fig. 5. It is similar to the Petrosix retort. In the 1970s, a 25-ton per day pilot plant and a 250-ton per day semi-works plant were built in Colorado and tested with Green River oil shale [27-30]. The semi-works plant was demolished in 1980s, but the pilot plant has been used to make additives for asphalt and to process oil shale from different countries, such as Morocco, Australia, and the United States. Although the Paraho technology has not been demonstrated at commercial scale, it has been used in extended operations, with oil shales from several countries, for more than 30 years. A detailed engineering design study was completed for the retorting section of a commercial plant that would use the technology. A preliminary design for a commercial mine and the balance of the processing plant was completed. These are important steps towards preparing the technology for commercial application. However, the project remained on paper.

Fig. 5. The Paraho 250 t/d Semiworks Plant in Colorado, ca. 1979

4.7. In Situ Processing

With in situ retorting, oil shale is heated underground, and the oil is drawn to the surface through wells. “True” in situ processes do no mining but may fracture the oil shale or drill boreholes into it to accelerate the rate of heating. “Modified” in situ (MIS) processes mine some of the shale, break the rest, and retort the broken material underground. MIS processing was tested in 1970s and 1980s, but results were inconsistent and not encouraging [27-30]. Three true in situ processes are currently being developed in Colorado. The most advanced is the In-Situ Conversion Process (ICP) of Shell Oil Company. Shell’s process involves drilling holes into the oil shale, inserting heaters, and gradually heating the entire zone to retorting temperatures. Oil and gas are drawn to the surface for processing [31, 32]. Shell uses a wall of ice to exclude groundwater from the zone to be retorted – see Fig. 6. A ring of boreholes is drilled around the zone, and a refrigerated liquid is circulated through the holes to freeze the water between the boreholes into a barrier wall. Water is pumped out, and heating commences. The ICP technology is not ready for commercial applications, yet. Its potential advantages include the avoidance of mining and the aboveground disposal of processing wastes and very high quality of produced oil. Potential disadvantages include high demand for electricity and water, surface subsidence, groundwater contamination, and difficulty reaching the underground waste disposal areas in case something goes wrong.

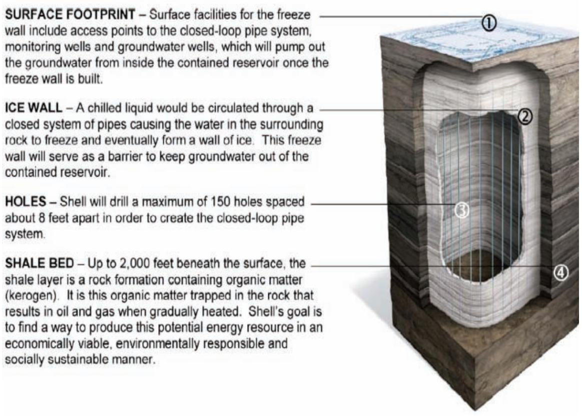

Fig. 6. In-Situ Conversion Process of Shell Oil Company

5. Economic Analysis

The cost of building chemical plants has soared since 2001, especially in terms of the U.S. dollar. Most important reasons behind this are (i) general inflation, and (ii) deterioration of the dollar, which has lost 47% of its value compared with a basket of other tradable currencies (50% against the Euro; and about 59% against the Australian dollar). Equally important is the unprecedented demand for materials, goods, and services by China, India, the energy industry, and the oil exporting countries. High capital costs impede the feasibility of capital-intensive projects, as has been well demonstrated for gas-to-liquids plants in the Middle East. Oil shale’s situation may be even more precarious, because the technologies have not been proven at commercial scale, and operating problems are likely. Shale oil will have to compete with conventional crude oil, which costs much less to produce.

To assess the implications of capital cost escalation and financing strategies, the authors updated previous cost estimates for oil shale power plants and syncrude facilities in Jordan and for an oil shale syncrude project in the United States [27-30,33,34]. The product prices needed to cover operating expenses and debt service were calculated and compared to prices with current and forecast prices of energy products in Jordan. The results suggest that electricity production is not practical right now, because the breakeven power cost would be much larger than the present wholesale price of electricity. Aboveground retorting to produce synthetic crude oil does seem promising, so that technology was chosen for further study. An economic model was developed for a plant to produce 50,000 barrels per day of high quality synthetic crude, i.e. shale oil, from the El Lajjun oil shale deposit. The model was used to test the sensitivity of the plant’s performance to the following key parameters:

- Facility cost
- Equity share of investment
- Debt interest rate
- Debt tenure
- Plant capacity factor
- Syncrude price
- Price of byproduct sulfur
- Cost of mining
- Other operating costs

- Rates of taxation and tax relief schemes
- Inflation

A simpler plant, which would ship crude shale oil rather than syncrude, was also examined. This would work only if the oil were destined for low-price markets (such as cement kilns) or if a robust refinery, capable of processing the poor-quality crude, will be available in Jordan. Tables 4, 5, and 6 summarize the results of the sensitivity studies.

- Efficient aboveground mining can be used in Jordan, which should reduce the syncrude price by about $5 per barrel, compared with underground mining of oil shale in the U.S.A.
- Based on previous estimates, it might cost $3.2 billion to engineer and build a syncrude plant with a design capacity of 50,000 barrels per day. If the project takes 42 months to complete, the total investment cost might reach $4 billion, including interest during construction, financing fees and expenses, taxes, and initial working capital.
- At a high availability factor of about 90.3% (330 days per year at design capacity), the facility would mine 68,000 t/d of oil shale and ship 43,500 bbl/d of syncrude and 675 t/d of elemental sulfur. Mining might cost $4.48 per tone ($4.06 per ton), and other operations and maintenance activities could cost $284 million per year.
- If the investment were financed 30% with equity and 70% with a 10-year loan earning 11%, the breakeven price of the syncrude would be around US$ 53 per barrel. If the oil were sold for $61.48 per barrel, which is the average price forecast through 2030 by the U.S. Energy Information Agency, the after-tax cash flow would generate approximately 14% internal rate of return (IRR) on the invested equity. With a 10% annual discount rate, the present value of the equity cash flow, which includes the original equity investment plus dividends to the owners, is around US$ 512 million over 20 years. The present value of royalties and other taxes collected by GoJ is estimated to be about $589 million. The minimum coverage of the debt service by operating profit is 1.29.
- IRR is most sensitive to syncrude revenue, which is determined by syncrude price and the plant's capacity factor. IRR is less sensitive to the capital cost and the non-mining operating costs. It is least sensitive to mining costs and to the price of the sulfur byproduct. IRR is very sensitive to the terms of the debt: with 10-year loan tenure, it varies from 18% with a 5% interest rate to 10% with 17% interest. With 11% interest, the IRR varies from 14% with a 10-year term to 17% with a 20-year term.
- Returns are also sensitive to the size of the equity share. Both dividends and taxes rise with equity share, but IRR declines. With 10% equity, the IRR is 21%. With 50% equity, the IRR is 12%. An all-equity deal would have an IRR of only about 10.6%.
- A viable oil shale industry could convey great financial benefits to the Kingdom. A 100,000 bbl/d industry would produce about as liquid fuel as Jordan currently consumes. During the first ten operating years of that industry, GoJ would collect, on average, approximately US$114 million per year in royalties, income taxes, and other similar payments. In addition, the Government could eliminate the subsidies it pays to fund energy price equalization pool. For 2007, paid subsidies to that pool are expected to be JD 170 million, equivalent to US$239 million [35]. The total benefit of a 100,000 bbl/d industry (taxes plus reduced subsidies) might reach US$ 353 million per year, or nearly US$ 11 for each barrel of syncrude that would be produced. Even if Jordan paid the same for the syncrude as it would otherwise have to pay for imported crude, US$ 11 per barrel of those payments would stay in the Kingdom. Much more would be retained in the form of salaries for the workers, satellite businesses, taxes on those salaries, purchases of goods and services to supply the industry and the satellite businesses, taxes on those purchases, and so on.
- The tax relief offered by Jordan's Investment Promotion Law (IPL) could enhance returns. The maximum incentive–exemption from up to 75% of income taxes for 10 years would increase IRR from 14% to 15%. To raise IRR to about 16% would cost Jordan US$ 926 million in lost taxes over 20 years, the equivalent of $2.80 per barrel of syncrude shipped. Exemption from all taxes would raise IRR to nearly 17.4%.
- Jordan has initiated MOUs with five developers and has released a document that suggests terms for production sharing agreements. That document proposes to replace existing taxes with a "petroleum tax" of up to 65% of profits and a production royalty of up to 7% of revenues. Compared with the IPL scheme, the Government would have to give up more tax revenues to induce the same increase in IRR. However, the Government could share any windfall profits. Incentives apply for the full life of a project and not just the first 10 years.
- Inflation could help a project, but only if revenues inflate as quickly as expenses. This may not happen, because oil prices do not respond to inflation. If uniformly applied, inflation of 3.5% per year would increase the IRR from 14% to 19.5%. Jordan's 2006 inflation rate of 6.5% would raise it to 24%. If oil prices did not rise as rapidly as operating costs, a project could soon collapse. If oil remained at US$ 55 per barrel while costs rose by 6.5% per year, the project would have to survive 14 years of negative cash flow. This vulnerability is troublesome, because Saudi Arabia has indicated a preference for a steady price of about $50 per barrel.
- Jordan's need for an oil refinery offers an interesting opportunity. If the new refinery could process crude shale oil, much of the market risk would be removed from an oil shale project. Capital and operating costs would be substantially reduced for the project, and it might obtain cheaper financing. However, revenues would also decrease, because less oil would be sold and at a lower price. A robust refinery for Jordan should be investigated, because even without oil shale, Jordan could reduce its energy costs by shopping for inexpensive refinery feedstocks.

Table 4: Summary Results of Sensitivity Studies

		Unit	Base Value	New Value	IRR Value	IRR Change	PV of AT Cash	Minimum DSCR
Base Case Results:			**–**	**–**	***14.0%***	**–**	***512***	***1.29***
Decrease by 10%	Syncrude price	$/bbl	61.48	55.33	9%	-33%	(73)	1.08
	Capacity factor	–	90.3%	81.3%	10%	-29%	(13)	1.10
	Facility cost	M$	3,220	2,898	17%	23%	816	1.43
	Non-mining O&M	M$/yr	284	255	17%	19%	836	1.41
	Debt interest rate	%/yr	11.0%	9.9%	15%	6%	603	1.35
	Equity share	–	30%	27%	14%	2%	528	1.24
	Debt tenure	years	10	9	14%	-2%	507	1.21
Increase by 10%	Syncrude price	$/bbl	61.48	67.63	19%	34%	1,100	1.50
	Capacity factor	–	90.3%	99.4%	18%	31%	1,038	1.48
	Facility cost	M$	3,220	3,542	11%	-18%	209	1.18
	Non-mining O&M	M$/yr	284	312	11%	-20%	155	1.16
	Debt interest rate	%/yr	11.0%	12.1%	13%	-6%	420	1.23
	Equity share	–	30%	33%	14%	-2%	497	1.35
	Debt tenure	years	10	11	14%	2%	518	1.36
	Notes:	–	–	–	**a**	**a**	**b**	**c**

a. Internal rate of return (IRR) on equity investment from dividends
b. Present value (PV) of after-tax (AT) cash flow at 10% discount rate
c. Minimum debt service coverage ratio (DSCR): operating profit divided by debt service payment

Table 5: Threshold Values for Project Failure (a)

	Units	Value	Value	Change from Base	IRR	Years with Negative Cash Flow	PV of AT Cash, M$	Minimum DSCR	PV of Taxes, M$
		Base Case	**Worse Cases**						
Base Case		**--**	**--**	**--**	**14%**	**0**	**512**	**1.29**	**589**
Oil price	$/bbl	61.48	53.02	Down 14%	8%	10	(252)	1.00	324
Capacity factor	--	90.3%	76.5%	Down 15%	8%	10	(252)	1.00	322
Investment	M$	4,027	5,190	Up 29%	8%	10	(326)	1.00	408
Non-mining O&M	M$/yr	284	345	Up 21%	8%	10	(251)	1.00	338
Debt term	Years	10	6	Down 4 years	15%	6	778	0.93	681
Debt interest	%/yr	11.0%	17.5%	Up 59%	10%	10	(27)	1.00	405
Notes:	**--**		**--**	**--**	**b**	**a**	**c**	**d**	**e**

a. Project fails when one or more operating years has negative cash flow
b. Internal rate of return (IRR) on equity investment from dividends
c. Present value (PV) of after-tax (AT) cash flow at 10% annual discount rate
d. Debt service coverage ratio (DSCR) : operating profit divided by debt service payment
e. Present value (PV) of Government taxes and other collections at 10% annual discount rate

Table 6: Sensitivity Cases

		Value	Change from Base	IRR	Years with Negative Cash Flow	PV of AT Cash, M$	Minimum DSCR	PV of Taxes, M$
Pessimistic Case	–	–	–	9%	9	(99)	0.95	378
Oil price	$/bbl	58.81	Down 4.35%	–	–	–	–	–
Capacity factor	–	86.4%	Down 4.35%	–	–	–	–	–
Investment	M$	4,203	Up 4.35%	–	–	–	–	–
Non-mining O&M	M$/yr	296	Up 4.35%	–	–	–	–	–
Debt term	years	9	Down 1 year	–	–	–	–	–
Debt interest	%/yr	11.5%	Up 4.35%	–	–	–	–	–
Base Case	–	–	--	14%	0	512	1.29	589
Oil price	$/bbl	61.48	None	–	–	–	–	–
Capacity factor	–	90.3%	None	–	–	–	–	–
Investment	M$	4,027	None	–	–	–	–	–
Non-mining O&M	M$/yr	284	None	–	–	–	–	–
Debt term	years	10	None	–	–	–	–	–
Debt interest	%/yr	11.0%	None	–	–	–	–	–
Optimistic Case	–	–	--	22%	0	1,329	1.71	831
Oil price	$/bbl	64.15	Up 4.35%	–	–	–	–	–
Capacity factor	–	94.3%	Up 4.35%	–	–	–	–	–
Investment	M$	3,852	Down 4.35%	–	–	–	–	–
Non-mining O&M	M$/yr	271	Down 4.35%	–	–	–	–	–
Debt term	years	11	Up 1 year	–	–	–	–	–
Debt interest	%/yr	10.5%	Down 4.35%	–	–	–	–	–
Notes:	–	–	–	**a**	–	**b**	**c**	**d**

a. Internal rate of return (IRR) on equity investment from dividends
b. Present value (PV) of after-tax (AT) cash flow at 10% annual discount rate
c. Debt service coverage ratio (DSCR) : operating profit divided by debt service payment
d. Present value (PV) of taxes and other Governmental collections at 10% annual discount rate

In summary, the economic outlook for an oil shale syncrude project in Jordan is cautiously optimistic. There is optimism because conservative modeling suggests the project could be economically feasible. There is caution because the feasibility is delicate, and a project could collapse if substantial but conceivable changes occur in investment cost, oil price, capacity factor, or operating costs; or if the debt is unfavorably structured. A project could also be destroyed if several key variables changed by small increments in the wrong direction at the same time. An adverse shift of less than 4.5% in capital cost, oil revenue, operating costs, and debt payments could transform a good if not spectacular business into a project that cannot pay its bills and has a present value of minus US$ 99 million.

6. Environmental and Legal Issues

6.1. The Environment

Jordan's renewable natural water resources are 800 to 850 million m^3 per year. The water is provided by precipitation, by the in-flowing Yarmuk and Jordan rivers, and by renewable and fossil aquifers. Priorities for water use are human needs first and then followed by municipal, tourism, industries, and irrigated agriculture. Despite its low priority, agriculture used 64% of Jordan’s water supply in 2006. Agricultural use is declining as well drilling is restricted, water meters are mandated, and farmland is converted to other uses. At the same time, water use by municipalities and tourism is rising rapidly. Although Jordanians use little water, the Kingdom has a serious water problem: water master plan expects consumption in 2020 to be nearly twice the available supply of renewable natural water, so supply shortfalls are likely [36]. A deficit of 320 million m^3 is forecasted at year 2010, when the first small oil shale plants may appear in the country. Possible mitigation methods include water reclamation, use of more treated wastewater in industries and for irrigation, desalination of seawater and brackish water, and development of new sources of groundwater and of surface water, including increased deliveries from Syria [37]. Despite these efforts, shortfalls are likely, and large investments will be needed to reduce them.

Oil shale facilities will use water in mining, retorting, upgrading, refining, power generation, waste disposal, site reclamation, and in the cities where new workers and their families will live. They will also produce water, by draining wet mines and from drying and retorting the oil shale. Both water production and water consumption vary with scale of operation and the nature of the extraction and processing technologies. Large plants to produce electric power from oil shale will use about 35% more water to produce the same amount of energy as a shale oil plant. However, electricity may be considered more useful and therefore entitled to more water. There is essentially no surface water in the oil shale areas, except during flash floods. There are two large aquifers, which are already important water sources for cities, farms, mines, and industries. If an oil shale industry emerges in Jordan in the near future, it will probably use surface mining and heated aboveground retorts. The average net water usage could be approximately 3.2 barrels of water per barrel of upgraded shale oil produced. A 100,000 barrel per day industry might consume approximately 18.9 million m^3 per year: as much as 0.5 million Jordanians, as many as lived in the city of Zarqa. If this industry happens, it could raise Jordan’s water supply deficit in 2020 by 5%, at least.

A commercial-scale oil shale project would reshape the social, economic, and political life of the communities in the oil shale region. Development will occur in remote, sparsely populated, and non-industrialized areas with only limited infrastructure in place. If development is rapid, the local communities may suffer from inadequate utility services and insufficient public services, such as public transportation, education, health care, and police and fire protection. The GoJ and the developers should provide resources, such as planning assistance and money, in advance of development. Oil shale development could also have negative effects on air, land, and water in the oil shale region. Specific concerns include [38]:

- Mining – release of silica, metallic and organic salts, mercury, methane, carbon monoxide, nitrogen oxides (NOx), unburned fuels, and nuisance dusts during blasting, crushing, transportation, and materials handling. Leaching of salts and organic compounds from disturbed overburden and oil shale.
- Retorting and upgrading – release of hydrogen sulfide, carbonyl sulfide, carbon disulfide, sulfur dioxide, polycyclic organic matter, trace metals, NOx, and particulate matter, especially from the retorts during discharging and maintenance. Accidental discharge of process water condensates. Venting and loss of hydrocarbon vapors from poorly sealed storage tanks and pipelines. Discharge of heavy metals during catalyst regeneration.
- Thermal energy and power systems – emissions of sulfur dioxide, NOx, and particulate matter in stack gases. Discharge of blow downs and water treatment chemicals.
- Waste management – disposal of retorted oil shale, spent shale, spent catalysts, process waters and sludge, chemicals from treatment of water and wastewater, fly ash, and domestic wastes from worker facilities and related municipal growth.

Severity of the impacts will vary with employed technology, scale of operation, and types and efficiencies of environmental control systems. The most obvious concerns are air pollution from mining and processing the high-sulfur oil shale, as well as the potential leaching of contaminants from waste disposal areas. Both air-borne releases and leaching could threaten the aquifers that are Jordan’s principal source of potable water [39]. Control methods are available for all of the areas of concern. For example:

- Dust – water sprays, wetting agents, paving, enclosures, filters, wet and dry scrubbers, precipitators
- Gases – combustion controls and selective catalytic reduction for NOx. Oxidation and chemical and physical absorption processes for sulfur compounds. Catalytic thermal oxidation for hydrocarbons and floating head tanks for product storage.

- Liquid and solid wastes – conventional wastewater treatment systems, evaporation ponds, landfill liners, filters, leachate collection and treatment systems, compaction, and solidification.

Except for high sulfur content, there is nothing particularly difficult about managing oil shale wastes, because they are similar to those produced in other industries. Scarcity of water and the scale of operations will complicate matters. Although standard control technologies may work well, they have not been validated with Jordanian oil shale at commercial scale. This concern should be addressed during pilot plant and modular testing programs. Another important issue is the quality of final products from the shale oil, which usually have high contents of aromatics, constitute, especially the light cut, i.e. mainly gasoline and kerosene produced from shale oil [40-43]. Many researchers reported that high levels of nitrogen, sulfur, ash, and toxic inorganic matter in the derived shale oil by pyrolysis, particularly if they are present in high concentration, might limit the use of this fuel as a direct substitute for petroleum-derived commercial fuels, since the fuel would represent a health hazard [44-46]. For example, polycyclic aromatic hydrocarbons containing sulfur and nitrogen are important because of their carcinogenic and/or mutagenic activity. Also, increased concentrations of such compounds have been shown to give increased soot and pollutant emissions in combustion systems, therefore, it requires more extensive refining, e.g. cleaning and hydro-treatment, than crude oil [8].

Jordan has endorsed many of the international conventions that promote environmental protection and sustainable development. The Ministry of Environment has central responsibility for environmental protection, in cooperation with the Ministry of Energy and Mineral Resources and the Ministry of Health. A long series of laws has established criteria for protecting the environment. For oil shale, the most relevant of these are the Air Protection By-Law No. 28 (2005), the Environment Impact Assessment (EIA) By-Law No. 37 (2005), and the Jordanian Emissions Standards for Electricity Generation (1999). By-Law No. 37 is particularly important because it requires a comprehensive EIA for large projects such as oil shale plants. The framework for Jordan's EIA process is in keeping with global standards. Regulations have evolved which will likely require extensive study of the baseline conditions in the area to be affected by oil shale development. They will also require thorough definition of the expected range of gross emissions, evaluation of proposed control technologies, analysis of alternatives, atmospheric dispersion modeling, evaluation of water requirements and impacts on water quality, consultation with concerned stakeholders and the public at large, and evaluation of archaeological, social, and natural values. Although the assessment process has been unevenly applied, progress is apparent. The inclusion of non-governmental organizations (NGOs), which can represent broad-based community concerns, is especially significant. The Stuart oil shale project in Australia was subjected to an intense campaign by an activist organization because of greenhouse gas releases and their implications for global warming [26]. Oil shale projects in Jordan may also be troubled by such activities. GoJ should pay attention to monitoring the effects of industrial developments and enforcing regulations where monitoring exposes violations. Bonding to guarantee adequate reclamation and closure at the end of a project's life is also needed. Although there are no international standards, many governments require an irrevocable letter of credit, full cash bond, or bond insurance policy.

International mining and energy companies are becoming increasingly involved in Jordan's minerals businesses. Their involvement in Jordan's oil shale industry is very likely, because of the complexity, long lead times, and investment requirements. This is significant, because good governance is a priority for many of these companies, and they have the technical and financial resources to provide for environmental and social sustainability. Their participation, and the support of multilateral financial institutions, may depend on compliance with the Equator Principles. These are voluntary guidelines for evaluating the social and environmental risks associated with the financing of projects to develop natural resources. The Principles evolved from practices of the World Bank and, as of May 2007, had been adopted by 51 global financial institutions, including the great majority of lenders that might be drawn to oil shale projects in Jordan. Although there are no specific standards for oil shale activities, the general standards for social and environmental assessment, analysis of labor and working conditions, waste management, pollution prevention and abatement, occupational health and safety, indigenous peoples, and other topics would certainly apply. If an oil shale project does not comply with the Equator Principles, the participating financial institutions will not issue loans. Those 51 institutions comprise approximately 90% (i.e. about $28 billion in 2006) of the private global project finance capacity for natural resources projects.

6.2. Legal Framework

Jordan's emerging oil shale industry will be shaped by mandates covering mining, environmental protection, land ownership, property rights limitations, financial subsidies and other incentives. The companies that will constitute this industry, including foreign investors, will be organized and registered under the Companies Law No. 22 of 1997, as amended. The standard corporate structures can be accommodated under this law and its amendments, and other arrangements could probably be negotiated if in the mutual interest of the developers and the Kingdom. The mining sector is governed by the Organization of Natural Resources Affairs Law (Law No. 12 for the year 1968) and Mining Regulation No. 131 for the year 1966. These establish that all minerals in Jordan are owned by the Government and may be used in trade only with the consent of the Government. Limits are imposed on the geographical extent of an extraction activity. Procedures are defined for accessing and using a site and for protecting water resources, holy sites and other special areas, and the health and safety of workers as well as the public.

Two new draft laws, (i) the Law for the Minerals and Petroleum Regulatory Commission and (ii) the Law for the

Jordanian Geologic Survey Commission, are under development. The first commission will regulate and monitor the industry and facilitate the establishment of projects, including those that have MOUs with the GoJ. The second commission will be responsible for research, surveys, and the promotion of mineral products. These laws are intended to overcome regulatory weaknesses and to clarify the framework under which projects will be developed. The principal environmental mandates are provided under the Environmental Protection Law No. 1 for the year 2003. In which the Ministry of Environment is designated to be the responsible authority in the area of environmental protection and the competent reference for permitting, monitoring, and regulating the industry, specifically as related to waste management, hazardous materials, and protection of the quality of soils and water resources.

An oil shale project is very likely to be affected by the Equator Principles. Jordan's existing laws and regulations do comply with the Principles, except in the areas of cumulative impacts and the efficient production, delivery, and use of energy. Thus, the GoJ should correct this deficiency. The mining sector is important to Jordan's economy. Foreigners are allowed to invest in the industry under "special agreements" which provide secure title and rights and assure stability of the fiscal regime over a project's lifetime. That regime offers relatively low tax rates, competitive royalties, and profit sharing on an equitable basis. The principal concerns of many investors (foreign exchange, repatriation of capital and profits, ownership rights, assignation, rights to operate and market, arbitration of disputes, and regulatory stability) are included in the regime, which should provide a reasonable level of comfort to investors in the oil shale industry. Jordan's laws also cover labor and employment matters, arbitration, protection of intellectual property, and public and occupational health.

7. Conclusions and Recommendations

Jordan's domestic recoverable energy resources are limited and lag far behind the demands of increasing population and economic growth. Thus, the country currently relies, and will continue to do so in the near future, almost solely on the combustion of imported fossil fuels in order to satisfy its national energy demand. This adds on pressure on government to act swiftly and adopt wise plans in order to ensure a reliable and secure energy supply for economic and social developments with serious considerations to minimize adverse environmental consequences associated with oil shale development [47].

7.1. Technology

Currently, the GoJ is engaged with five potential oil shale developers. Its approach to enlisting external help to create local oil shale industries appears sound. This should result in the evaluation of a broad range of aboveground retorting technologies for Jordan's near-surface deposits, and in the positioning of a leading in situ technology for the deeper and thicker ones. The modular progression, where a developer uses one retort to generate essential data and then scales up if appropriate, is sound and prudent. However, it will introduce delays and probably will increase costs. It also may result in production of a difficult waste product: small quantities of crude shale oil. The GoJ could ease this waste problem by providing a refinery capable of converting that material into useful products. Jordan should also build its technical capacity to facilitate and monitor the industry. It may be difficult to add staff, improve facilities, and enhance training, given Jordan has limited resources. Many of Jordan's neighbors in the Middle East and North Africa face similar challenges, in that they have oil shale resources but lack the expertise and capacity to benefit from them. The GoJ should consider leading an international effort to overcome the constraints, by creating an international oil shale commercialization center. The primary aims of such center are (i) to enhance understanding of the world's oil shale resources, (ii) to improve the commercial practicality of existing conversion technology, and (iii) to explore and perfect new, beneficial, and sustainable ways to extract useful energy and materials from oil shale in Jordan and elsewhere.

7.2. Economics

Oil shale retorting and power plants will be expensive, and their energy products are likely to cost more than what can be obtained from conventional sources which Jordanians are accustomed to paying. Feasibility of a retorting facility will be strongly sensitive to oil prices, availability and capacity factors, which the Government cannot control. However the Government can do other things to influence a project's feasibility, principally by participating in the emerging industry and helping it to secure a place in Jordan's energy economy and, most importantly, to obtain low cost financing. Specifically, the GoJ could:

- Install a refinery capable of handling a plant's output, thereby reducing costs and market risk.
- Reduce investment cost by helping developers secure debt and equity, thereby reducing fund-raising fees and expenses.
- Take positions in the projects (as done in the phosphate mining and potash industries), thereby providing access to inexpensive multilateral financing, with lower interest rates and longer terms.
- Solicit grants from concerned nations and foundations to pay for planning, infrastructure construction, and training programs.
- Provide appropriate forms of tax relief to encourage efficient, profitable operations without removing technical and managerial risks, which should be retained by the developers.

7.3. Water

A sizable shale oil industry would substantially aggravate the water supply problem in Jordan. Diversion of water to oil shale development will influence current users and increase the expected supply shortfalls. The following activities are recommended to ease this problem:

- For planning purposes, the GoJ should obtain water use estimates for Jordanian conditions. Existing estimates

were developed for the U.S.A. and Estonia. Even if the same technologies were used in Jordan, substantially different amounts of water would be required.
- Water conservation should be emphasized in the Government's negotiations with developers. Rates of water use should be weighed when evaluating competing proposals. Design changes could substantially reduce water consumption.
- Water should be priced appropriately. A tiered pricing structure that discourages waste may be an acceptable solution.
- Developers should be encouraged to cooperate with each other and with other users to develop non-conventional water resources, such as treated wastewater. Sharing of resources would provide economies of scale and could make water reclamation and reuse much more practical.

7.4. Environment

The framework and nature of laws regarding environmental and social sustainability issues is good. Needed agencies and institutional framework exist to administer the laws. Proper regulations to supply details for administering the laws appear to exist as well. However, improvements are still needed in the following areas:
- Give more attention to the monitoring and enforcement of environmental regulation of major industrial projects.
- Strengthen agency staffing, training, capacity building, data, and tools for effective regulation.
- Improve baseline studies and impact modeling, which are of uneven quality.
- Standardize procedures to bond projects for reclamation and closure, security, health and safety, and enforcement.
- Carefully consider the Equator Principles in structuring environmental management programs for oil shale projects.

7.5. Strategic Implementation Plan

The Government has taken an important step by inviting private firms to participate as developers of oil shale projects and suppliers of energy to the Kingdom. Accomplishing the rest of the Government's goals will require a large number of discrete tasks, which can be arranged into any number of strategic plans. This study divided the tasks into five categories and forty tasks, as shown in table 7. The overall process is estimated to take 120 months, from the start of the regulatory reforms and studies in January 2008 until the first commercial shale oil is produced at the end of 2017. The time could be reduced by about four years by eliminating the intermediate modular phase, but substantial risks of technical and economic failure and social and environmental damage would result.

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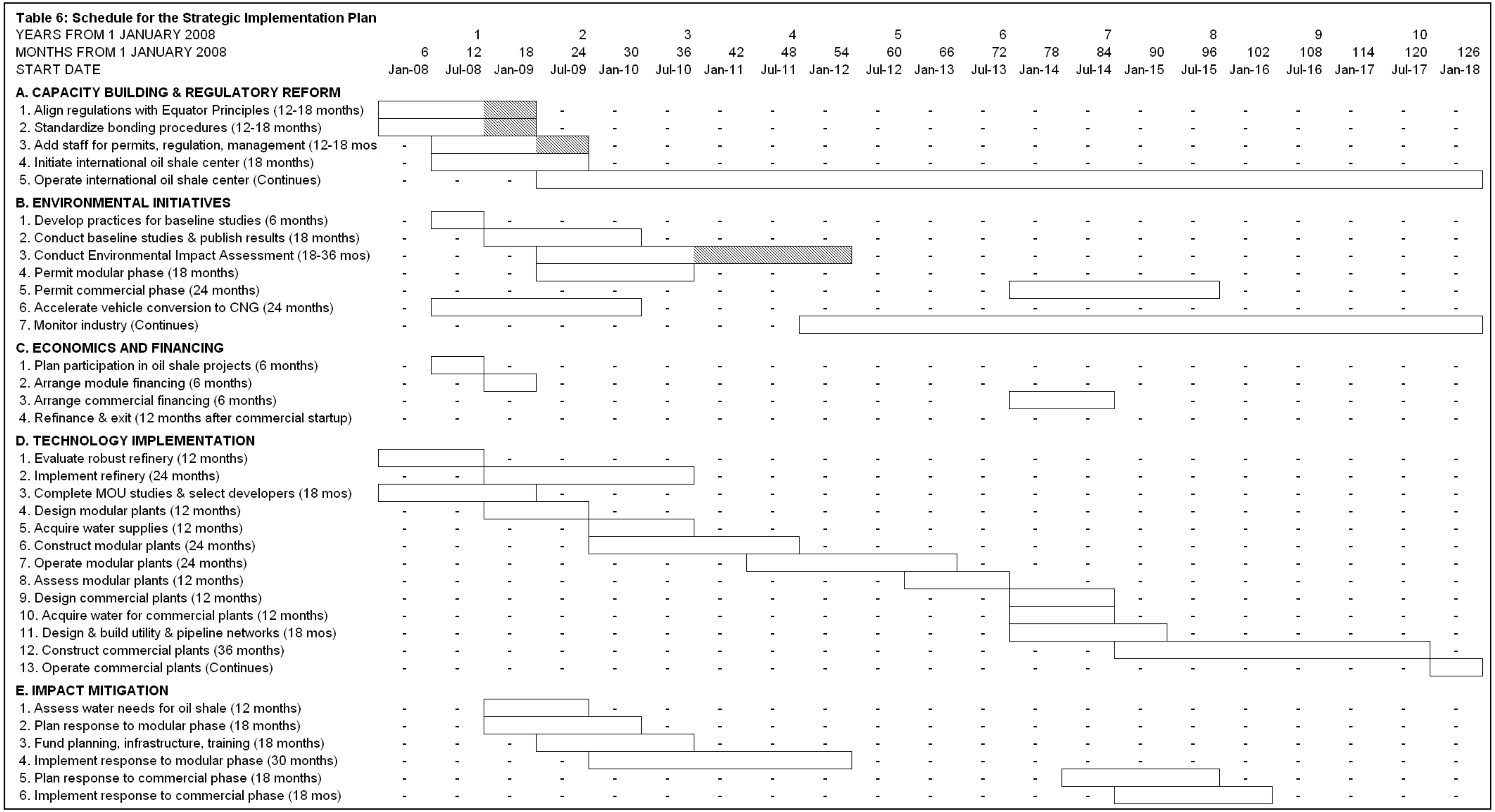

Table 6: Schedule for the Strategic Implementation Plan

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