Strategies for Oil Shale Development in the Hashemite Kingdom of Jordan

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Abstract

Oil shale deposits in the Hashemite Kingdom of Jordan could satisfy the Kingdom's demand for liquid fuels and electricity for centuries. Markets also exist for raw and retorted oil shale, for oil shale ash, 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 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 shale oil industry in Jordan. In January 2007, Jordan's Ministry of Energy and Mineral Resources engaged a professional team led by Behre Dolbear & Company (USA) Inc. to identify and analyze the diverse opportunities and challenges. Behre Dolbear's principal subcontractor was Interdisciplinary Research Consultants, of Amman, Jordan.

The goal of the technical assistance project was to help the Ministry establish short-term and long-term strategies for oil shale development and to facilitate the commercial production of shale oil in Jordan. 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.

Background

The Hashemite Kingdom of Jordan is about the size of Indiana in the United States or Portugal or Hungary in Europe. (Figure 1) Jordan is landlocked except for 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 visitors. The largest cities are the capital Amman (1.9 million people), Az Zarqa (473,000), and Irbid

Figure 1: Jordan (from CIA 2007)

(273,000). Major industries are agriculture, fertilizers, light manufacturing, and tourism. The Jordanian dinar trades at JD 1.0 to US$ 1.41. In 2006, the gross domestic product was about $5,100 per capita; inflation was 6.25%; and unemployment was 12.5%. Arabic is the official language. Ninety-two percent of the people are Sunni Muslim. The government is a constitutional monarchy. The legal system is based on Islamic law and French codes.

Jordan's people consume about 107,000 barrels of liquid fuels per day. Electricity demand peaks at about two gigawatts. Except for a small amount of natural gas, all of the primary energy resources are imported. Oil and oil products are trucked from the port at Aqaba. Natural gas comes in a pipeline from Egypt. The cost of imported energy has encouraged the Government of Jordan to exploit its large resources of oil shale.

Resources and Their Quality

Oil shale is a rock that contains kerogen – 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 – El Lajjun, Sultani, Jurf Ed-Darawish, and Attarat Umm Ghudran – are located about 100 km south of Amman, near the towns of Karak and Qatrana. (Figure 2) They contain about 22 billion tonnes (te) of oil shale (Table 1). At the average oil yield of 8.9% (roughly 22 gallons per ton (gal/t)) the potential oil yield is 14 billion barrels, which could satisfy Jordan's liquid fuel and electricity needs for centuries.

There are limitations, however. Although the rock could be mined at low cost, the sulfur level is high and the ash yield is about four times that of a medium grade of bituminous coal with similar sulfur content. This makes the rock a difficult and expensive solid fuel. Compared with Colorado shale oil (Table 2), oil from El Lajjun oil shale has less nitrogen (good for refining) and a lower pour point (it flows at lower temperatures) and a lower initial boiling point (it may contain lighter hydrocarbons, which is generally good). It is also heavier (which is bad), and it contains 14 to 17 times as much sulfur. The high sulfur is a very serious defect, because it makes the oil corrosive and unstable, increases the

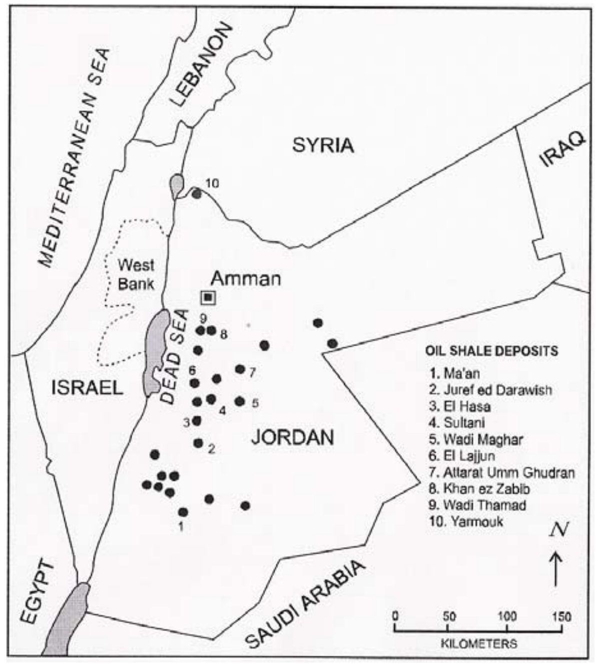


Figure 2: Jordan's Oil Shale (from Dyni, 2005)

Table 1: Properties of Four Oil Shale Deposits in Jordan

	***Sum* or Mean**
Geologic reserves, billion te	*22*
Surface area, km^2	*420*
Overburden thickness, m	47
Oil shale thickness, m	48
Average composition, wt.%	
Organic matter	24
Oil yield	8.9
Moisture	3.8
Ash	55.4
Sulfur	2.5
Density, g/cm^3	1.9
Heating value	
kcal/kg	1,472
kJ/kg	6,158
Btu/lb	2,650

Table 2: Fischer Assays of Oil Shale from Jordan and Colorado

		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
Oil yield	bbl/te	0.68	0.70
Oil Properties			
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 - 10.2	0.61
Pour point	^{o}F	30	75
Pour point	^{o}C	-1.1	24
Initial boiling pt.	^{o}F	171	192
Initial boiling pt.	^{o}C	77	89

cost of refining, and makes it difficult 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. When the crude oil is distilled, the sulfur distributes itself through all of the fractions produced. Refining would be easier if the sulfur preferred one end of a distillation column or the other, because then the other fractions could be refined with relative ease.

Development Factors

The principal factors that could affect commercialization of Jordan's oil shale resources are the readiness and costs of available extraction technologies, the quality of the markets for the products and by-products, the implications of development for the Kingdom's social and physical environments, and the compatibility of Jordan's law and regulations.

Technology for Electricity

Tests with Jordanian oil shale indicate that circulating fluidized bed combustion boilers (CFBC boilers) 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. 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. A big power plant (400 megawatts (MW) or so) might be practical if low-cost financing is obtained and the Kingdom can tolerate higher power prices. Small 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.

Technology for Liquid Fuel

In the retorting area, Jordan is presently engaged with five potential project developers under memoranda of understanding (MOUs) initiated in 2006 and early 2007. Four of the firms are considering above-ground processing, in which oil shale is mined (see Figure 3) and crushed and then heated in vessels, and one firm is considering heating the oil shale *in situ* (in place). If an MOU study produces encouraging results, the Government could negotiate a production sharing agreement with the developer. That developer would then construct a small mine and a small processing plant containing a single production module. Experiments would be conducted with that module to ensure the 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.

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

Figure 3: Open Cast Oil Shale Mine in Estonia (from Liive, 2007)

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, 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 oil quality is good. Fine oil shale and the solid pyrolysis product are currently discarded, but they could be exploited in other projects.

One retort, built in 1981, can process 1600 tonnes per day (te/d). The other was completed in 1991 and can process 6200 te/d (Figure 4). The facility's total production capacity is 3,870 barrels per day

Figure 4: Petrosix Complex in Brazil (from Petrobras, 2007)

(bbl/d) of shale oil (480 te/d of fuel oil and 90 te/d of industrial naphtha), 120 te/d of fuel gas, 45 te/d of liquefied petroleum gases, and 75 te/d of sulfur. Waste vehicle tires are also retorted to recover fuels and materials.

The Petrosix technology is advanced and efficient. It has been operated at near-commercial scale for more than 25 years. Irati oil shale has high sulfur, as does oil shale in Jordan, so the Brazilian experience is relevant to Jordan's resources. No information is available on capital or operating costs.

Estonian Retorts: Estonia has a diverse and vigorous industry that exploits the kukersite oil shale to produce electricity and manufacture liquid fuels. About 1.5 million tonnes per year (te/yr) of oil shale is retorted to produce 8,000 bbl/d of shale oil. Utilities burn 10.5 million te/yr to produce 90% of Estonia's electricity, and 200,000 te/yr of oil shale is converted to cement. Figure 5 shows the Estonian oil shale factory at Narva.

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, where the oil shale is contacted with more hot gas and with steam and air to gasify and burn the char. Processed shale is discharged from the bottom. Oil recoveries are relatively low, but the equipment is

Figure 5: The Oil Factory at Narva, Estonia. (from Liive, 2007)

rugged and availability is high. Thermal efficiency should be higher than in the Petrosix retort. Fine oil shale and some of the solid pyrolysis products are currently wasted. Viru Keemia Group Ltd. (VKG) runs two plants that use Kiviter retorts. VKG plans 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 the 1980s. It pyrolyzes fine oil shale particles by mixing them with hot spent shale in an inclined rotary kiln. Oil vapors are withdrawn and are condensed and processed in a series of disengagement vessels. Retorted shale is burned, and the hot ash is returned to the retort. A medium-energy fuel gas is produced. Surplus gases and some of the heavier oil fractions are burned to make electric power. Oil quality is good, and thermal efficiency and oil recovery efficiency are high. However the equipment is complicated, and capacity factors are low.

Both the Kiviter and Galoter retorts have been operated at large scale for more than 20 years. Their performance characteristics should be well understood, so technical risk should be low. No information is available on capital or operating costs.

Alberta-Taciuk Retorting Process (ATP): The ATP was developed to process Canadian tar sands. The processor consists of two horizontal concentric tubes, rotating together (Figure 6). Oil shale is charged into one end of the inner tube, moves horizontally to the other end of that tube, 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 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.

The ATP was first used in 1989 to clean contaminated soils. The first (and, so far, only) use in the mining industry was in the Stuart oil shale project, in Australia's Queensland State. 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 4,500 bbl/d of shale oil from 6,000 te/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, 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 82% of design capacity, and oil recoveries reached 94% of design. The high quality oil was sold to refineries and as heating oil.

There were many complaints from neighbors about odor and noise, and Greenpeace Australia (an environmental activist group) launched a persistent campaign to stop the project, citing its environmental effects and especially the release of greenhouse gases. Suncor withdrew in April 1991. SPP continued until February 2004, when SPP's secured creditor, Sandefer Capital Partners, placed the

Figure 6: 210 ton per hour Alberta Taciuk Process (ATP) Retort (from AECOM, 2007)

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 and oil recovery efficiency and produced high quality products. In some runs, the oil recovery reached 105% of Fischer assay.

The 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 retorting temperatures in a rising stream of hot gases. Paraho has two configurations – direct heating and indirect heating. 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. 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. The semi-works plant was demolished in the 1980s, but the pilot plant has been used to make additives for asphalt and to process oil shale from Israel, 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 shale 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 was completed for a commercial mine and the balance of the processing plant. A preliminary cost estimate was prepared for the entire facility. These are important steps towards preparing the technology for commercial application.

Figure 7: The Paraho 250 t/d Semiworks Plant in Colorado, ca. 1979 (from Sladek and others, 1980)

The estimates have not been released to the public.

In Situ Processing: With *in situ* ("in place") 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 the 1970s and 1980s, but results were inconsistent and not encouraging. Three true *in situ* processes are currently being developed in Colorado. The most advanced is the In-Situ Conversion Process of Shell Oil Company (Shell, 2007 – see Figure 8). 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.

Shell uses a wall of ice to exclude groundwater from the zone to be retorted. 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 application. Its potential advantages include the avoidance of mining and the aboveground disposal of processing wastes and the very high quality of the 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.

Economics

The cost of building chemical plants has soared since 2001, especially in U.S. dollars. One reason is general inflation. Another is the deterioration of the dollar, which has lost 47% of its value compared with a basket of other tradeable currencies (50% against the euro; 59% against the Australian dollar). The most significant, and perhaps most enduring, factor 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, we 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, calculated the product prices needed to cover operating expenses and debt service, and compared those 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.

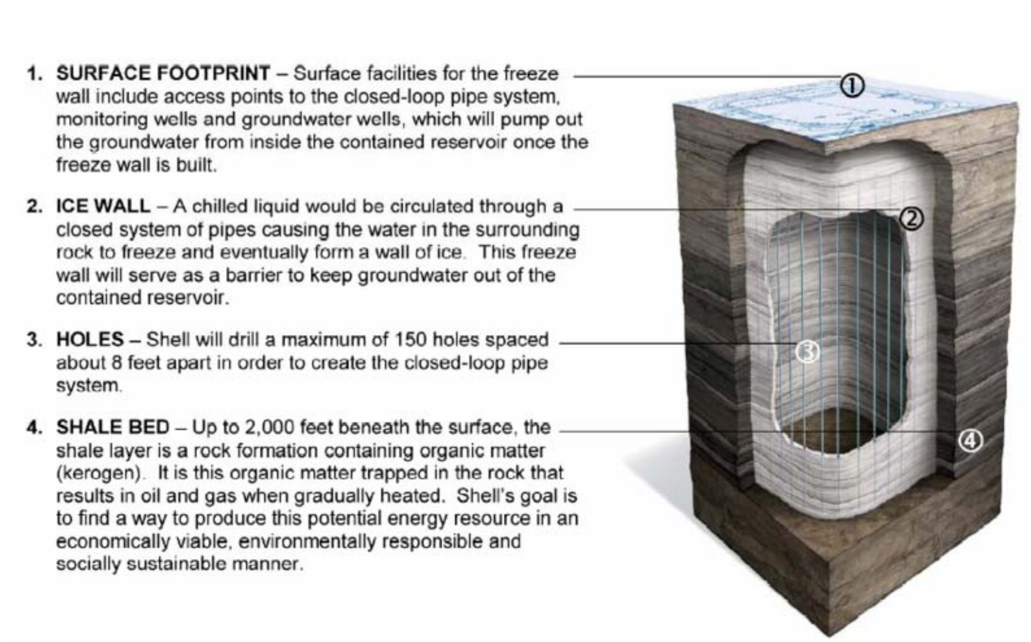


Figure 8: Shell's ICP Oil Shale Concept (From Shell, 2007)

An economic model was developed for a plant to produce 50,000 barrels per day of high quality synthetic crude (syncrude) from El Lajjun oil shale. The model was used to test the sensitivity of the plant's performance to these parameters:

- Facility cost
- Price of byproduct sulfur
- Equity share of investment
- Cost of mining
- Debt interest rate
- Other operating costs
- Debt tenure
- Rates of taxation and tax relief schemes
- Plant capacity factor
- Inflation
- Syncrude price

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, were available in Jordan.

Following are the major findings of the studies. Tables 3, 4, and 5 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 capacity factor of 90.3% (330 days per year at design capacity), the facility would mine 68,000 te/d of oil shale and ship 43,500 bbl/d of syncrude and 675 te/d of elemental sulfur. Mining might cost $4.48 per tonne ($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 $53 per barrel. If the oil were sold for $61.48 per barrel (the average price forecast through 2030 by the U.S. Energy Information Agency), the after-tax cash flow would generate a 14% internal rate of return (IRR) on the invested equity. With a 10% annual discount rate, the present value of the equity cash flow (the original equity investment plus dividends to the owners) is $512 million over 20 years. The present value of royalties and other taxes collected by Jordan is $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 a 10-year loan tenure, IRR 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 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 much liquid fuel as Jordan currently consumes. During the first ten operating years of that industry, Jordanian governments would collect, on average, approximately $114 million

Table 4: Threshold Values for Project Failure (a)

		Value	Change from Base	IRR	Years of Negative Cash Flow	PV of AT Cash, M$	Minimum DSCR	PV of Taxes, M$
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	–	–	–	–	–
Worse Cases								
1. Oil price down	$/bbl	53.02	Down 14%	8%	10	(252)	1.00	324
2. Capacity factor down	--	76.5%	Down 15%	8%	10	(252)	1.00	322
3. Investment up	M$	5,190	Up 29%	8%	10	(326)	1.00	408
4. Non-mining O&M costs up	M$/yr	345	Up 21%	8%	10	(251)	1.00	338
5. Debt term down	Years	6	Down 4 years	15%	6	778	0.93	681
6. Debt interest up	%/yr	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

per year in royalties, income taxes, and other similar payments. Also, the Government could eliminate the subsidies it pays to fund the energy price equalization pool. For 2007, subsidies paid to that pool are expected to be JD 170 million, equivalent to $239 million. The total benefit of a 100,000 bbl/d industry (taxes plus reduced subsidies) might reach $353 million per year, or nearly $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, $11 per barrel of those payments would stay in the Kingdom. Much more would be retained in the form of salaries for the workers, salaries of workers in 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 16% would cost Jordan $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 17.4%.

Table 3: Summary Results of Sensitivity Studies

		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

- 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 don't 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 $55 per barrel while costs rose 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.

In summary, the economic outlook for an oil shale syncrude project in Jordan is cautiously optimistic. There is optimism because fairly 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, <u>or</u> operating costs; <u>or</u> 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

Table 5: Sensitivity Cases

		Value	Change from Base	IRR	Years of 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 yr	–	–	–	–	–
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 yr	–	–	–	–	–
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 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 $99 million.

Water

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. Three agencies administer the water. Private firms are also involved; for example, one runs Amman's water system. The agencies are:

- The Ministry of Water and Irrigation, which plans, promotes, and manages water programs and maintains the National Water Master Plan;
- The Water Authority of Jordan which provides water and wastewater services; and
- The Jordan Valley Authority, which oversees water in the Jordan Rift Valley.

Priorities for water use are human needs first and then (in order) municipal use, tourism, industries, and irrigated agriculture. Despite its low priority, agriculture used 64% of Jordan's water supply in 2002. Agricultural use is declining as well drilling is restricted, water meters are mandated, and farm land is converted to other uses. At the same time, water use by municipalities and tourism is rising rapidly.

Oil shale will be an "industrial" user. There are already 18,400 industrial concerns in Jordan. Most use little water and rely on municipal systems. Most of the others operate their own groundwater wells. Some of the larger users have initiated water recycling programs to reduce their use of fresh water.

Although Jordanians use little water, the Kingdom has a serious water problem. The Kingdom's water master plan expects consumption in 2020 to be nearly twice the available supply of renewable natural water, so supply shortfalls are likely. A deficit of 320 million m^3 is forecast for 2010, when the first small oil shale plants may appear. The Jordanian Embassy in Washington warns of "a water catastrophe." The World Health Organization cautions against withdrawing more groundwater, which would be the logical water source for oil shale plants.

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 Israel and Turkey. 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, waste disposal, site reclamation, and in the cities where new workers 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 to be 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. Water augmentation programs are underway in the region. More are planned, and even more will be needed if the industry is installed.

If an industry emerges in Jordan in the near term, it will probably use surface mining and indirectly-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 574,000 Jordanians, as many as lived in the cities of Balqa and Aqaba in 2005. If this industry comes to pass, it could raise Jordan's water supply deficit in 2020 by 5%.

The Environment

The topography in the oil shale region is generally flat, and the climate is semi-desert. Summers are hot, dry, and dusty. Winters are cold and almost dry. There are no protected-habitat areas for wildlife that would conflict with early development. An archaeological reconnaissance will be required to ensure development does not disturb historically significant sites.

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 Government 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:

- 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, NO_x, 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, NO_x, and particulate matter in stack gases. Discharge of blowdowns and water treatment chemicals.
- Waste management – Disposal of retorted oil shale, spent shale, spent catalysts, process water 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 technology, scale of operation, and the types and efficiencies of environmental control systems. The most obvious concerns are air pollution from mining and from processing the high-sulfur oil shale, and 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. Control methods are available for all of the areas of concern, including:

- For dust – Water sprays, wetting agents, paving, enclosures, filters, wet and dry scrubbers, precipitators
- For gases – Combustion controls and selective catalytic reduction for NO_x. Oxidation and chemical and physical absorption processes for sulfur compounds. Catalytic thermal oxidation for hydrocarbons. Floating head tanks for product storage. Filters and wet and dry scrubbers.
- For 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, there is nothing particularly difficult about managing oil shale wastes, because they are similar to those produced in similar industries. Scarcity of water and the scale of the 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.

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 Regulation (2005), and the Jordanian Emissions Standards for Electricity Generation (1999). The Environmental Impact Assessment (EIA) Regulation 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.

Jordan 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 are 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 (Equator Principles, 2007). 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, 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 <u>not</u> issue loans. Those 51 institutions comprise approximately 90% of the private global project finance capacity for natural resources projects (about $28 billion in 2006).

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. Oil shale projects in

Jordan may also be troubled by such activities.

Regulation

Jordan's emerging oil shale industry will be shaped by mandates covering mining, environmental protection, land ownership, property rights limitations, and subsidies and other incentives. The companies that will constitute this industry (including foreign companies) 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 by 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 and the public.

Two new laws – the Law for the Minerals and Petroleum Regulatory Commission and 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 Government. 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. These designate the Ministry of Environment 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. The Government should correct this deficiency.

Creating large blocks of land for development projects is likely to involve expropriation – the taking of property from one party for the benefit of another. Jordan's Mining Law provides mechanisms for expropriation and sets guidelines for legal procedures, exclusions, and compensation. Nevertheless, the expropriation of property so that it can be used by an oil shale developer is likely to cause controversy, even if it fully complies with the law.

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.

Conclusions and Recommendations

Technology

As noted, the Government of Jordan currently is engaged with five potential oil shale developers. The Government's approach to enlisting external help to create its industry appears sound. It 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 Government 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's 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. Jordan should consider leading an international effort to overcome the constraints, by creating an international oil shale commercialization center.

Economics

Oil shale retorting plants and power plants will be expensive, and their energy products are likely to cost more than Jordanians are accustomed to paying. Feasibility of a retorting facility will be strongly sensitive to oil prices 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 Government 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 was 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;
- Continue to include oil shale in the Government's strategic plans.

Water

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

- For planning purposes, the Government of Jordan 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 re-use much more practical.

Environment

The framework and nature of laws regarding environmental and social sustainability matters is good. Proper agencies (the Ministries) exist to administer the laws. Proper regulations to supply details for administering the laws appear to exist as well. Improvements are needed in these areas:

- Give more attention to the monitoring and enforcement of environmental regulation of major industrial projects.
- Strengthen agency staffing, training, 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.

Regulation

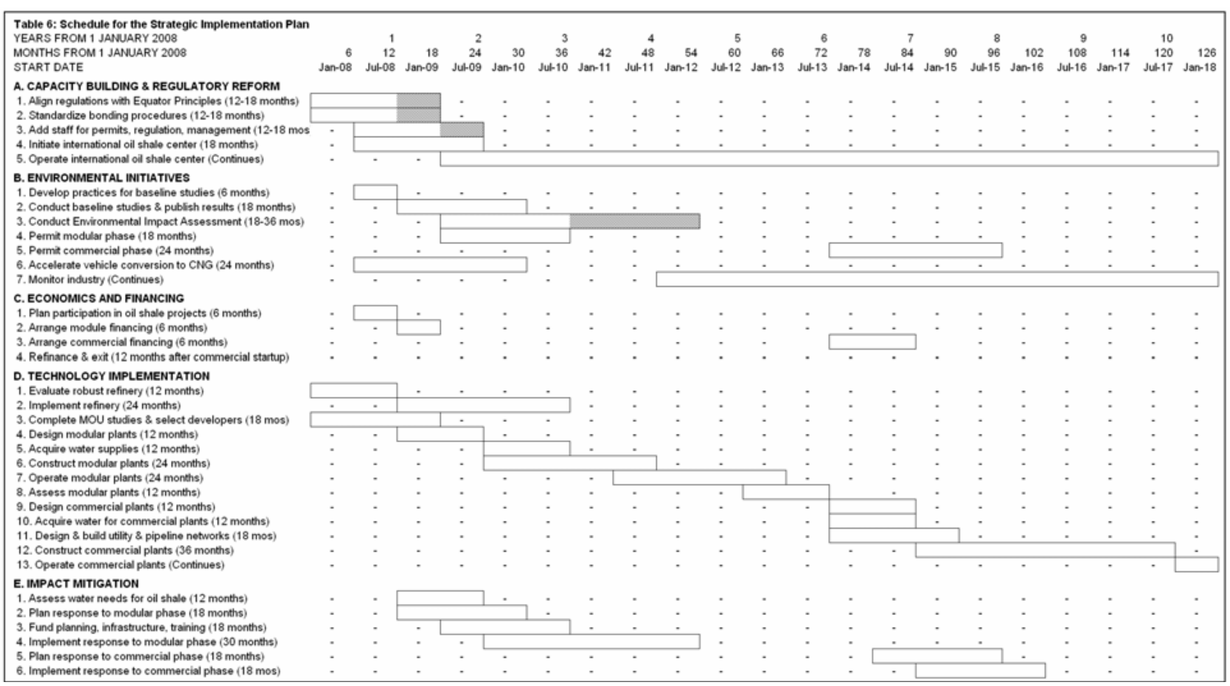
Existing regulations are adequate in most of the crucial areas, at least in principle. The Government should amend its environmental regulations to comply with the provisions of the Equator Principles regarding cumulative impacts and the efficient production, delivery, and use of energy.

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 35 tasks, as shown in Table 6.

The overall process is estimated to take 120 months, from the start of the regulatory reforms and studies in January 2008

Table 6: Schedule for the Jordanian Oil Shale Strategic Implementation Plan



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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