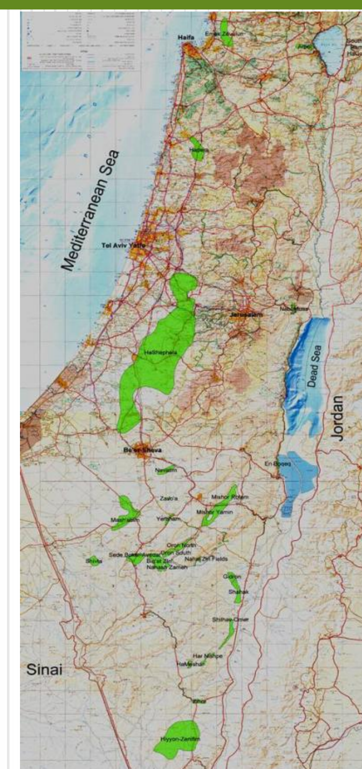
Converting Oil Shale to Liquid Fuels: Findings on Energy and GHG Impacts



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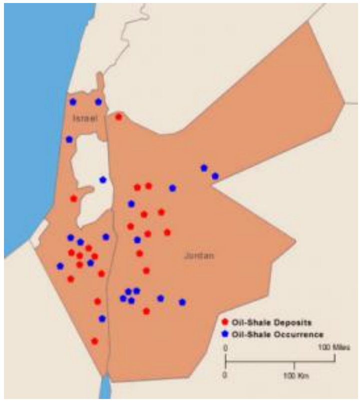
Why Oil Shale?

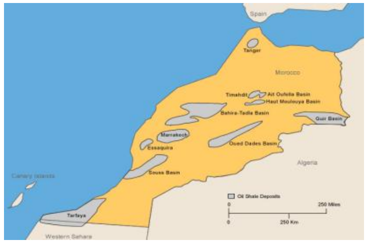
- Oil shale refers to a sedimentary rock formation rich in non-soluble organic matter called **kerogen**, which can be processed into gaseous and liquid hydrocarbons

- Global reserves of oil from shale formations are quite large
  - Global estimate (2009): 3.2 trillion barrels of oil from shale
  - Global reserves of conventional oil (2009): 1.3 trillion barrels
  - Current US estimates: over 2.8 trillion barrels

- Major oil shale operations can be found in Brazil, Canada, China, Estonia, the U.S. and more

- The World Energy Council estimates that the 'Shfela Basin' in Israel contains up to 250 billion barrels of shale oil
  - Third largest world shale oil reserves behind the U.S. and China





Oil Shale Extraction Methods

- Oil shale is very difficult to extract
  - To release the oil from the kerogen, the rock must be heated to about 340-390°C in an oxygen-free environment ("retorting")

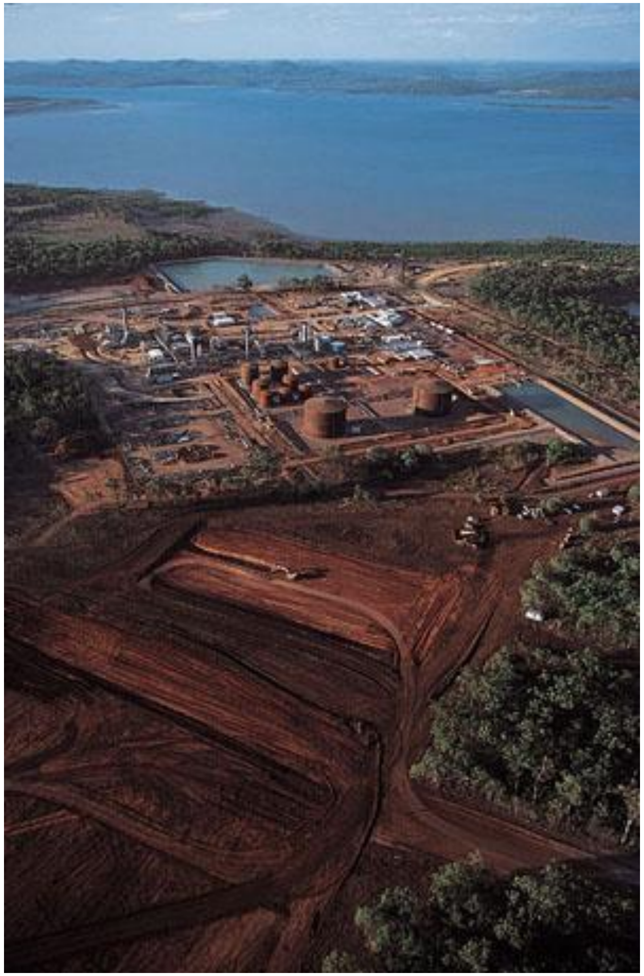
Queensland Australia Syn-Crude Plant

- Process and extraction methods typically are:
  - *Ex-situ or surface retorting methods:* shale oil is mined and pyrolized to produce oil that is suitable as a feedstock for refined products
  - *In-situ retorting methods:* kerogen is heated in place and then piped to the surface through production wells for gathering and further processing
  - In-situ processes may also involve fracturing the rock beds to facilitate the flow of the released oil
- Most current commercial operations utilize ex-situ processing

Rock pyrolysis

Oil Shale Extraction Issues: Ex-Situ Methods

- Ex-situ methods require mining of the raw oil shale - either on the surface or underground.
  - Surface mining - results in higher production rates but creates irreversible ecological damage
  - Underground mining – is more ecologically friendly but does not allow for high-volume processing
  - Underground mining - makes for easier ecological restoration



Stuart oil-shale development project near Gladstone, Australia.

Oil Shale Extraction Issues: In-Situ Methods

- In-situ methods of extraction attempt to mitigate the environmental impact while maintaining a high energy output
  - Six of the ten pilot oil shale projects in the U.S. utilize in-situ mining
  - In-situ processes include the ability to extract more shale oil even from lower-grade deposits as well as from deeper deposits

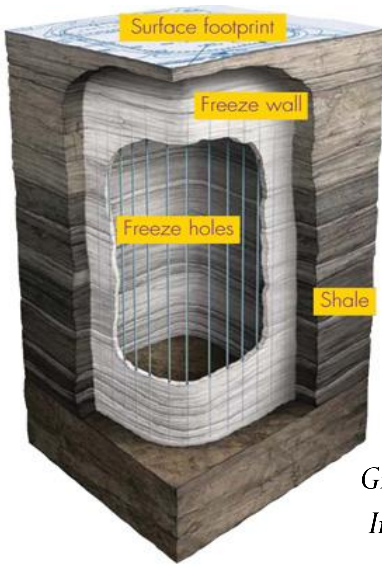
- In-situ techniques require the drilling of a large number of wells
  - Significant energy input is required to convert kerogen into extractable liquid

Colorado Test Site

Colorado Test Site

In-situ Conversion Process (ICP)

- "Shell" has been working on the ICP since 1981 (not commercial yet)
  - ➢ An array of heating wells with electrical heaters raise the oil shale temperature to 340-400°C to convert the kerogen to shale oil
  - ➢ More wells are dug to remove groundwater before heating, extract the vapor and liquid hydrocarbons, and monitor the groundwater
  - ➢ **A "freeze wall" is created to reduce the risk of groundwater contamination from released hydrocarbons and other pollutants**
    - The "freeze wall" is a series of wells around the perimeter of the extraction site
    - They are filled with a coolant kept at -40°C to create an impenetrable frozen barrier
    - It prevents groundwater from entering the extraction zone and hydrocarbons from escaping



Graphic representations of Shell's In situ Conversion Process

EcoShale™ In-Capsule Technology

- The EcoShale In-Capsule technology is a hybrid between traditional mining methods and the in-situ (in-place) process
  - The rock is dug from the ground by traditional mining methods into a clay capsule
  - Hot natural gas is pumped through the capsule in a looped pipe circuit
  - The rock inside the capsule is slowly heated to ~ 480°C until the kerogen is extracted (Oil of ~29 API gravity, and Condensate oil of ~ 39 API gravity)

- This technology claims to require no process water, protects groundwater and vegetation, and allows for rapid site reclamation
  - The entire process takes an estimated 90 days and it may be possible to immediately begin to re-vegetate the area

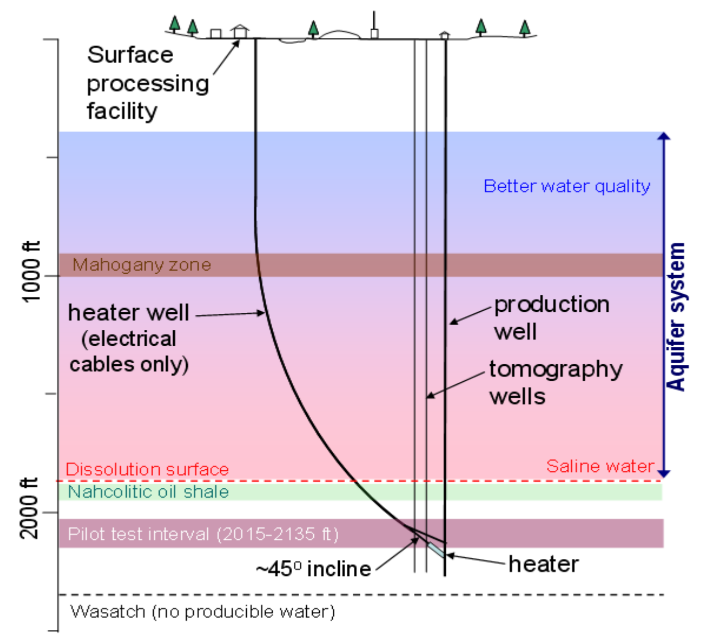
- The process received an initial operating permit from the State of Utah in March 2012 but it was suspended in June 2012 for further investigation of ground water contamination

Demonstration site
In Utah

Conduction, Convection, Reflux (CCR^{TM}) Process

- The CCR process is targeted at obtaining shale oil from deeper deposits with less surface activity
  - Suitable for extracting oil shale at depths where the shale deposit is isolated from ground water by a cap rock
  - Heat is applied by a vertical heating well to below the shale deposit and then horizontally underneath it
  - When heated at 340°C, kerogen will convert into oil, which will boil, rise, cool, and condense in a convection and reflux pattern
  - Secondary wells (either horizontal or vertical) will collect the freed hydrocarbons

- The CCR technology is expected to result in:
  - Less surface impact
  - Lower water usage
  - Lower emissions



Potential Negative Impacts of Oil Shale Development

- Oil Shale extraction techniques involve high energy consumption and associated greenhouse gas emissions

- Additional environmental concerns include:
  - High water usage
  - Disposal of wastes
  - Contamination of aquifers
  - Stress on surrounding communities
  - Land and wildlife disturbance
  - Air and groundwater pollution from operations

Energy Life Cycle Assessment (LCA) Framework for ICP Process

- Energy Balance Considerations
  1. 'Freeze Wall' construction and soil cooling
  2. Heating until the average bulk shale temperature reaches the calculated conversion temperature
  3. Electricity generation from co-produced HC gas burned on-site (combined-cycle natural gas turbine, 45% efficiency) while remaining demand is met with external electricity
  4. Recoverable 'Oil in Place' which is based on the depth of the oil shale resource multiplied by the heated area, assuming an average richness of 110.4 Liters/ton

- From the energy balance one can compute the net energy ratio (NER) which compares all energy inputs to net outputs.

$$NER = E_{out} / (E_{ext} + E_{int})$$

E_{out} - HHV of the final refined product output,
E_{ext} - the primary energy input from the outside energy system,
E_{int} - the primary energy input from the feedstock resource itself

LCA Findings for Oil Shale ICP

- Analysis conducted for two hypothetical commercial-scale cases of ICP deployment, representing "low" and "high" energy and GHG intensity
- Values refer to the production site input only
- Oil shale development could result in 25 – 45% higher GHG emission intensity for the production phase as compared to conventional crude oil
  - For Israel, this should be compared with the energy intensity of importing crude oil for refining

Low Case		High Case	
(MJ/tonne)		(MJ/tonne)	
Input	Output	Input	Output
1,310	2,630	1,640	2,540
NER	(Crude Production Only)		
2.0		1.6	

Based on A. R . Brandt, "Converting Oil Shale to Liquid Fuels: Energy Inputs and Greenhouse Gas Emissions of the Shell in Situ Conversion Process", Environ. Sci. Technol. 2008, 42, 7489–7495

Impact Evaluation Recommendations

1. **Water quantity**
   - Before commercial leasing commences, governmental agencies should fund independent assessments of how much water would be required for commercial development

2. **Water quality**
   - Commercial development poses challenges for protecting surface water and groundwater quality.
   - To properly evaluate the effects of commercial development, and to adopt appropriate mitigation measures, governmental agencies should:
     a. establish independent baseline assessments of existing stream conditions for aquatic life, and
     b. require industry to provide quantifiable data on the potential impacts of development on surface water and groundwater quality

Impact Evaluation (cont'd)

3. **Air quality**
   - Governmental agencies should evaluate air quality baseline data
   - Operating permits must address enforceable mitigation measures to prevent adverse health and environmental impacts of oil shale operations cycle

4. **Energy sources**
   - Independent assessment of electricity and energy resources demands, necessary to support oil shale development (and their impacts) should be conducted
   - Evaluation needs to include the potential of using renewable energy to provide the required energy over the long run

5. **Climate**
   - Independent analyses show that, depending on the technology utilized, development would produce 25% to 75% more GHG per barrel of oil from oil shale than from conventional fuel
   - More analysis of oil shale's contribution to climate change is needed, and regulatory agencies should specify how its impact would be mitigated

In Summary

- Oil shale development in Israel may contribute towards reduced dependence on imported oil

- There is currently no track record of commercial implementation of oil shale in-situ conversion techniques anywhere in the world

- Any development should be accompanied by careful planning and deliberate analyses and evaluations of a myriad of potential impacts

- Development plans should include specific indicators and monitoring to evaluate mitigation of impacts

- Periodic assessments should be required in the development time-line to incorporate new information as it becomes available

Thank you for your attention

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