Technical Aspects of Oil Shale Production and Processing

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Shale Composition

- Composition varies from deposit to deposit and even within deposit
Energy Values

- **Crude Oil** – 45 MJ/kg
  - Price $10/MMBTU (at $60/barrel)
- **Coal** – 27-31 MJ/kg
  - Price $1.5/MMBTU
- **Natural Gas** ~55 MJ/kg
  - Price $6-10/MMBTU
- **Shale oil** ~ 42 MJ/kg
- **Shale** ~ 4.3 – 8 MJ/kg
- **Value is added by making liquid hydrocarbons**
• Without any heat losses the ratio of energy out/energy in = 13
• This is the absolute maximum that one can hope to achieve
• Energy-in values for conventional oil/gas type operations have to be added along with heat losses to compute more practical ratios which will be in the 3-6 range
Production potential

- **OIL**
  - One ton of sandstone
  - Porosity 20%
  - Grain density = 2.65 g/cc
  - Oil saturation 80%
  - Oil quantity = 25 gallons/ton

- **OIL SAND**
  - One ton of oil sand
  - Bitumen wt fraction (10%)
  - Bulk density = 2.2 g/cc
  - Oil quantity = 28 gallons/ton

- **OIL SHALE**
  - One ton of oil shale
  - Organic content (9.5%)
  - Shale density = 2.67 g/cc
  - Complete conversion
  - 25 gallons/ton shale oil
Shale Production Potential

- Average thickness = 550 feet
- Density = 2.67 g/cc
- Average oil content = 30 gallons/ton
- Barrel of Oil Equivalent/Acre = 1.3 million

From T. Dammer
Oil Shale

To produce 100,000 barrels of oil/day
- 140,000 tons of oil shale/day will have to be processed, if surface production facilities are used
- Kennecott processes 500,000 tons of material/day
- For a 1000 MW power plant, about 10,000 tons of coal is required/day

Large-scale operation – operations at such scales exist
Processing Options

Ex-Situ
- Underground
  - Room & Pillar
  - Cut and Fill
  - Block Carving
- Open-Pit

Mining → Crushing → Retorting → Spent Shale

In-Situ
- Fracturing
  - Natural
  - Hydraulic
  - Explosive
  - Electocarbonization
  - Drilling & Dewatering

Retorting
- In-Formation
  - Combustion
  - Hot gases
  - Steam
  - Gradual Heating
  - Pyrolysis

Product Recovery
- Gas Drive
- Artificial Lift
- Kerogen Oil
- Hydrocarbon Gases

Refining
- Liquid Fuels
- By-Product

Control on Operational Parameter

Source: Strategic Significance of America’s Oil Shale resources, Vol II, 2004
Ex-Situ Process Diagram

S + others

Combustor

CS: Combusted Shale Direct or Indirect

Retort

K + S

S: Feed Shale

P: Product

CH₄ depending on the kerogen conversion

KU + S + CS + coke + char

KU: kerogen Unreacted
Direct and Indirect Processes

From the U.S. Office of Technology Assessment Reports
The Petrosix Retort

From the U.S. Office of Technology Assessment Reports
## Sample Products (based on 100% conversion)

<table>
<thead>
<tr>
<th>Products</th>
<th>Weight Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha</td>
<td>28.5 %</td>
</tr>
<tr>
<td>Distillate</td>
<td>15.9 %</td>
</tr>
<tr>
<td>Gas oil</td>
<td>1.8 %</td>
</tr>
<tr>
<td>Char</td>
<td>18.8 %</td>
</tr>
<tr>
<td>Coke</td>
<td>8.9 %</td>
</tr>
<tr>
<td>Other</td>
<td>26.1 %</td>
</tr>
</tbody>
</table>
Surface Processing Issues

- Knowledge-experience in the 70s-80s
  - Scattered, not integrated
- Solids handling
  - Oil mists
- Problem of fines in the oil
- Scale of operation
  - Must be large to overcome the oil-price threshold
Oil Shale – Insitu Processes

- Rubble in-situ extraction
  - Create a rubble
  - Air and steam injection at the top
  - Large scale experiments run
    - Yields of about 7 gpt – 40% of the oil in place

- Modern in-situ processes
  - Electric heating - Shell
  - Other forms of heating
  - Porosity creation, in-situ

- Hybrid processes (Redleaf – Ecoshale)
Shell ICP (Insitu Conversion Process)

From www.shell.com
In-situ Issues

- Porosity, permeability creation
- Conversion and recovery
- Question of residual oil
- Heat losses and energy efficiency
- Impact on water
- Carbon footprint
Upgrading Shale Oil

Objectives
- Nitrogen removal
- Molecular weight reduction
- Hydrogenation

Some modifications to the existing hydro-processing technologies may be required

Similar costs
Resources

Water

- No direct water input required
- Surface processing
  - Water for mining operations
  - Same order as a refinery or chemical process plant
- In-situ processing
  - Water required for drilling/associated activities

Carbon footprint

- Process and fuel dependent
# Carbon Footprint Kilograms of CO₂ Per Barrel

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Oil Sands Mining/Extraction</th>
<th>Oil Sands In-Situ</th>
<th>Oil Shale Mining/Extraction</th>
<th>Oil Shale In-Situ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td>25</td>
<td>45</td>
<td>95</td>
<td>85</td>
<td>66 (NG) 261 (Coal)</td>
</tr>
<tr>
<td><strong>Upgrading</strong></td>
<td>28</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>35</td>
</tr>
<tr>
<td><strong>Transportation</strong> (gasoline, Diesel, jet fuel)</td>
<td>450</td>
<td>450</td>
<td>450</td>
<td>450</td>
<td>450</td>
</tr>
</tbody>
</table>

*Preliminary Estimates Only*

*Oil sands numbers from Professor Murray Gray, University of Alberta*
Process Possibilities

- **Surface Production**
  - Energy self-sufficient

- **In-situ**

  ![Diagram of process possibilities]

  - Kerogen
  - Heat
  - Retort to produce Fuels
  - CH4 supply if necessary
  - Heat from kerogen Combustion
  - Kerogen Unreacted Coke
  - Air

  **Shale Deposit**

  - Heat
  - Gas
  - Liquid Hydrocarbons

  - Sequester CO2

  - Re-use, recycle all water

  - Sequester CO2
Ongoing Research at U of U

- Depositional heterogeneity and in-situ modeling
- Fundamental transformation kinetics and compositions of oils
- Kerogen-asphaltene atomistic modeling
- Impact on water quality
- Oxy-fuel combustion for providing the energy
- Pore-scale analysis
- Climate change legislation
- Market analysis
- Data repository

Summary
Fundamental kinetics and compositional understanding
Summary

- Possible to institute environmentally responsible, energy-efficient processes.
- Key issues need to be resolved with respect to both surface extraction and in-situ technologies.
- A lot to be learnt from previous research – particularly on ex-situ processes.
- Fundamental and applied research on resource characterization pyrolysis, environmental and policy aspects underway at the University of Utah.