Demonstration and Commercial Design of the Clean Shale Oil Surface Process

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  - Robert Jackson
  - Ambar M. Ochoa

- Intertek PARC, Inc
  Shale Oil Upgrading Tests
• Contract Objective – Demonstrate and Evaluate an Advanced Technology for Surface Processing of Oil Shale

• Presentation
  - Process Description
  - Pilot Plant Process Testing and Modeling
  - Preliminary Commercial Design and Cost
C-SOS General Flow Diagram

2. Shale Oil Production

3. Shale Oil Upgrading

1. H₂ Production

5 ton/day Pilot Plant
Simple Process Option for Production of Crude Shale Oil

C-SOS Process (Simple Option)
• Simple, low capital cost, horizontal design
• Commercially-available components
• Unique, high-capacity kiln
• Processing of fines
• Projected low process water use
• Minimum shale carbonate decomposition
• Option for on-site production of motor fuels
• Option for little or no carbon dioxide emissions
• Option for on-site hydrogen production
Aft-End Oil Product Separation Unit
- Indirect-Fired Rotary Kiln
- 0.83 ft diameter shell
- 7 ft shell heated length
- Natural gas
- Patent-pending firing configuration
- Medium grade 28 gal/ton
- Shale Feed Rate – 2-6 TPD
- Shell rotation rate, 6-18 rpm
- Shell temperature, 800-500 °C
- Residence time, 5-15 min
- Avg. particle dia., 1.9-2.2 mm
- Steam sweep gas, 0-5 %
- Feedstock shale properties
- Kiln exit solid temperature
- Kiln shell temperature along length
- Mass flowrate/properties
  * Spent shale
  * Shale oil/cuts
  * Fuel gas
• 36 Tests (Past 10 months)
• Optimum Conditions
  - 4–5 tons/day
  - 1.9 mm diameter shale
  - 12 rpm
  - 94 % (F/A) oil conversion
  - 5 min residence time
• Test Challenges
  - Small Particle Separation
  - Sharp Oil Cuts (heat loss)
Potential for Kiln Capacity Increase

- Larger Burner Capacity
- Higher Wall Temperatures
- Preheat Feedstock Shale
- Two Stage Cyclone
Test Conditions Input
- 94% F/A oil conversion
- 700 °C initial shell temperature
- 500 °C solid exit temperature
- 12 rpm
- 5% steam, 400 °C

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<tr>
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<th>Pilot Test</th>
<th>Kiln Code</th>
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<tr>
<td>Shale Feedrate, TPD</td>
<td>4.2</td>
<td>4.4</td>
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<tr>
<td>Residence Time, min</td>
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<td>4.6</td>
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<tr>
<td>Fill Fraction</td>
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<td>0.09</td>
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<td>% Carbonate Decomposition (CO₂)</td>
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<td>3.5</td>
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4.4 Tons/day (CH4 Fuel)

Final Values:
Ts = 492 C
Tg = 502 C
% CO₂ released = 3.5
FR = 0.94
• 6000 TPD Oil Shale Plant
  - Three Kilns
• 6000 TPD with Onsite Oil Upgrading
• 2000 TPD – Waste Fines
  - Single Kiln

Common Conditions
Shell:
  12 ft shell diameter
  127 ft heated shell length
  2 rpm, 1° slope
  Residence time – 50 min

Shale:
  1.9 mm diameter
  36 gal/ton
  Fuel gas/Natural gas
  Total Oil Collection
Commercial Indirect Fired Rotary Kiln
(3.5 ft diameter, 35.4 ft long, Photo Courtesy Heyl and Patterson, Inc.)
• **Test Conditions Input**
  - 98 % F/A oil conversion
  - 900 °C initial shell temp.
  - ca. 500 °C solid exit temp.
  - 2 rpm
  - 3.5% steam, 400 °C

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<td>Shale Feedrate, TPD</td>
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<td>Fill Fraction</td>
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<td>% Carbonate Decomposition (CO₂)</td>
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Reference Case - 2000 Tons/day (CH4 Fuel)

Final Values:
- $T_s = 456$ °C
- $T_g = 505$ °C
- % CO₂ released = 10.7
• **Indirect-Fired Rotary Kiln**
  
  Cross-fired burners
  
  12 ft diameter
  
  127 ft long
  
  HB 800 alloy
  
  900°C peak shell temperature
  
  500°C peak shale temperature
  
  36 gal/ton shale oil
  
  2 mm shale diameter
  
  3.5 % sweep steam
Assumptions

- NREL guidelines
- Eastern Utah location
- Open pit mining
- Installed costs 2.7 x equip. cost
- 15 % project contingency
- 10 % process contingency
- 5 % construction interest
- 10 % owner costs/startup

- 330 days/year
- Current: wage rates, utilities, depreciation
- 20 year plant life
- 30 % discount, if no oil upgrade
- Fuel gas 60 % of kiln need
- Recovery of sulfur
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<th>Opt. 1</th>
<th>Opt. 2</th>
<th>Opt. 3</th>
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<td>Three kilns 6000 TPD crude</td>
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<tr>
<td>oil</td>
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<tr>
<td>Cap. Cost ($ millions)</td>
<td>198</td>
<td>254</td>
<td>48</td>
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<td>Cap. Cost per (bbl/year)</td>
<td>116</td>
<td>135</td>
<td>85</td>
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<td>Oil produced (1000 bbl/year)</td>
<td>1700</td>
<td>1885</td>
<td>566</td>
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<td>Annual Operating Costs ($ millions)</td>
<td>57</td>
<td>86</td>
<td>11</td>
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<tr>
<td>Product price ($/bbl)</td>
<td>57</td>
<td>80</td>
<td>68</td>
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<tr>
<td>Annual Revenue ($ millions)</td>
<td>95</td>
<td>151</td>
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<td>Net Annual Revenue (less op. cost)</td>
<td>38</td>
<td>65</td>
<td>27</td>
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<tr>
<td>% Net Annual revenue before taxes/cap. cost</td>
<td>20</td>
<td>26</td>
<td>32</td>
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• Phase II DOE/SBIR nearly complete
• Pilot plant demonstrated process
• Kiln code/process code – vital tools
• Attractive Options
  - Upgrading oil onsite
  - Process fines stockpile
• Intermediate-Scale Testing Required
• Improve Oil Recovery
• Verify discoveries for kiln capacity increase
• Increase fine particulate removal
Doug Smoot, Kent Hatfield, Craig Eatough
Combustion Resources, Inc.

To Obtain Copy of
Preliminary Commercial Design/Cost Report

Give Business Card to
Doug Smoot or Craig Eatough or
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