Evaluation Model for Choice of Oil Shale Mining and Processing Technologies

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- Mining / in-situ extraction methods
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- Reserves and Technology Evaluation Model – RESOURCE
Contribution of Atomenergoproekt to sustainable oil shale industry of Estonia

**ATOMENERGPROEKT’s reference list**

<table>
<thead>
<tr>
<th>Plant, Facility</th>
<th>Site &amp; Time of Design &amp; Launching</th>
<th>Equipment</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahtme PP</td>
<td>Near to Ahtme, 1951</td>
<td></td>
<td>46.5 MW</td>
</tr>
<tr>
<td>Baltic PP</td>
<td>5 km near to Narva, 1955-60</td>
<td>8 x TP-17 + 8 x BK-100 + 4 x TP-67 + 4 x K-200</td>
<td>1290 MW power, 505 MW heat</td>
</tr>
<tr>
<td>Estonia PP</td>
<td>25 km to Narva, 1968-73</td>
<td>8 x TP-101 + 8 x K-200</td>
<td>1610 MW power, 84 MW heat</td>
</tr>
<tr>
<td>Kiviyl Vol. 35</td>
<td>Kiviyl, 1950-53</td>
<td>R&amp;D UTT-200 facility</td>
<td>150-200 t/day</td>
</tr>
<tr>
<td>Kiviyl Vol. 53</td>
<td>Kiviyl, 1963</td>
<td>R&amp;D UTT-500 facility</td>
<td>500 t/day</td>
</tr>
</tbody>
</table>

**Plant, Facility**

<table>
<thead>
<tr>
<th>Plant, Facility</th>
<th>Site &amp; Time of Design &amp; Launching</th>
<th>Equipment</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Factory</td>
<td>Narva, 1975-1980, 1980-1984</td>
<td>Two commercial UTT-3000 facilities</td>
<td>6000 t/day (in operations now)</td>
</tr>
<tr>
<td>Power Plant</td>
<td>Slantsy, 1994-2007</td>
<td>Project 3xUTT-3000</td>
<td>9000 t/day (start in 2007)</td>
</tr>
<tr>
<td>Viru Keemia Group Galter Project</td>
<td>Kohila Yarve, 2000-2007</td>
<td>Project 1xUTT-3000</td>
<td>3000 t/day (start in 2007)</td>
</tr>
</tbody>
</table>

*Oil Factory in Narva, Estonia, built under ATOMENERGPROEKT’s design, 1980-84*

*Foundation of UTT-3000 on Viru Keemia Group Galter Project Site in Kohila Yarve, Estonia, made under ATOMENERGPROEKT’s design, 9th Oct, 2007*
Construction UTT-3000 (Galoter Project) designed by Atomenergoproekt for VKG Oil AS in Estonia
Construction UTT-3000 (Galoter Project) designed by Atomenergoproekt for VKG Oil AS in Estonia
Manufacturing of UTT-3000 Equipment
Manufacturing of UTT-3000 Equipment
Mining methods (ex-situ)

Oil shale is usually mined and then transported to be processed elsewhere (ex situ), although several newer technologies extract its useful components underground (in situ).

Several mining methods are used, which all begin by fragmenting the oil shale, so that it may be transported to a power plant or a retorting facility. The most-often used methods of surface mining are open pit mining and strip mining, while underground mining of oil shale employs the room-and-pillar method and longwall method.

Strip mining (right)
Mining methods (ex-situ)

Underground mining methods:

- Longwall
- orthogonal room-and-pillar
- diagonal room-and-pillar
Mining / in-situ extraction methods

Shell’ In-situ Conversion Process (ICP) based on heating oil shale by electric heaters. Freeze Wall scheme (right) used for avoiding oil leakages to ground water. (Mahogany Research Project).

In situ process (true horizontal process above left) Occidental and Tenneco Modified In-situ (MIS) vertical retort (left) at federal C-b tract Demonstration Plant, based on in-situ combustion of shale. In fact, MIS retort method is combination of mining and in-situ methods.
# Mining / extraction methods comparison

<table>
<thead>
<tr>
<th>Operations and conditions</th>
<th>Open pit mining</th>
<th>Strip mining</th>
<th>Underground</th>
<th>In-situ combustion</th>
<th>In-situ heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracturing of overburden</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Fracturing of oil shale</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Transportation of OB</td>
<td>yes</td>
<td>limited</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Transportation of oil shale</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>limited</td>
<td>no</td>
</tr>
<tr>
<td>Shallow horizontal deposit</td>
<td>good</td>
<td>good</td>
<td>no</td>
<td>yes</td>
<td>No</td>
</tr>
<tr>
<td>Deep horizontal deposit</td>
<td>Limited by strip ratio</td>
<td>Limited by size</td>
<td>yes</td>
<td>yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Thin deposits</td>
<td>Limited by strip ratio</td>
<td>Limited by strip ratio</td>
<td>yes</td>
<td>Limited by permeability</td>
<td>No because of dissipation</td>
</tr>
<tr>
<td>Inclined deposit</td>
<td>until limited by strip ratio</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>In-situ losses</td>
<td>Very low</td>
<td>Very low</td>
<td>15-20%</td>
<td>30-40%</td>
<td>50%</td>
</tr>
<tr>
<td>Impact on groundwater</td>
<td>depression</td>
<td>Depression</td>
<td>depression</td>
<td>Depression and expensive defence</td>
<td>Expensive defence</td>
</tr>
<tr>
<td>Reclamation</td>
<td>Mined-out space and OB stocks</td>
<td>Mined surface</td>
<td>Not significant</td>
<td>Significant</td>
<td>Significant for plugging and washing out</td>
</tr>
</tbody>
</table>
Processing methods 1

**Process TTT** (Science Application):


Since 1920s used by Nevada Texas Utah, 150 tpd shale 13-152 mm, designed for Morocco

**Process Superior Oil** with internal heating:


Tested 230 tpd shale 6.4-102 mm, planned 20,000 tpd
Processing methods 2

**Process Union B (Unocal):**

1 – retort, 2 – liquid (oil) lock, 3 – feeder (rock pump), 4 – gas heater

In 1940 pilot plant 50 tpd, in 1955 – 1080 tpd, in 1980-83 was built installation 11,600 tpd shale 30-130 mm at Parachute Creek, CO

**Vertical retorts – Gas Generators** with cross flow (left - 60 tpd) and central flow of gaseous heat carrier (right – Kiviter Process retort 1000 tpd):


Beginning from first Pinch retort in 1943 method was modified and in 1980-83 was built retort 1000 tpd shale 25-125 mm in Estonia, variants also used in Russia and China
Process GCR:
Cameron Engineering, Bureau of Mines. Variations of GCR – Paraho designed with capacity 16,1000 tpd operating with 9-75 mm shale, Petrosix operating with 6-64 mm shale capacity 2200 tpd. Designed plant of 20 retorts 6200 tpd each.
Process *Lurghi-Rurgas*:


Process *Chevron STB*:

**Galoter Process** (in Russian - UTT, in English - SHC solid heat carrier installation, in Estonian - TKS) :


Operates with 0-25 mm shale 3330 tpd, passed through tests 200 tpd in 1953-62, 500 tpd in 1963-81, two commercial plants UTT 3330 tpd were launched in 1980-1984 in Narva, Estonia, at present are operating, one more under construction in Kohtla Jarve, 10 plants in design stage. Tens are in FS stage. UTT-7000 and UTT-10000 in R&D stage.
Processing methods 6

Process IGT:
Pilot plant 1 tpd.

Oxy and Tenneco Modified In-situ Process (MIS) retort:
Developed by Shell Petroleum
Currently in “pilot” phase in north-western Colorado
Shell to apply technology at three other sites in Colorado

Extraction of potential chemical heat – 50% from which 45-50% is spent for heating. Power need for freeze wall is not assessed yet; no simultaneous tests for heating-freezing were conducted. After exhausting of oil block will be washed out by water before melting freezewall.
Pilot tests under development in Colorado. Issues are like in Shell ICP tests.
Initially designed for extracting bitumen from tar sands. Selected for oil shale conversion in Australia (Stewart Project). OSEC to apply ATP for its RD&D efforts in Utah. Fushun Co. is going to put ATP in China. Placing of drying, pyrolysis and combustion zones in one vessel has caused problems with locking leakages of gases from one zone to another that
The Essence of Processing

Thermal destruction of kerogen is the basis of all processing methods.

Maximum liquid yield can be achieved at the end point of destruction of thermobitumen.

The more temperature the more coke and gas are being formed. Heavy oil in conditions of tough permeability of fractured rock or in coarse fragmented shale is also condensed and polymerized forming coke and gas and lowering liquid yield.

The point of complete decomposition of the thermobitumen varies for different kinds of oil shale both in temperature and in yield of coke which depends on H/C ratio. This is the reason why in-situ heating process will never exceed energy efficiency 40-50%, leaving carbon and heavy oil in-situ.

Transformations of kerogen in kukersite, A.Aarna, 1979
Transformations of kerogen in kukersite, A.Aarna, 1979

**Essence of the processing**

Thermal destruction of kerogen is laid in base of all processing methods.

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The more temperature the more coke and gas are being formed. Heavy oil in conditions of tough permeability of fractured rock or in coarse fragmented shale is also condensed and polymerized forming coke and gas and lowering liquid yield.

This is the reason why in-situ heating process will not exceed energy efficiency 40-50% leaving carbon and heavy oil in-situ.
Many processing methods invented & developed

- movable or immovable shale,
- gaseous or solid heat carrier,
- vertical or horizontal movements of shale and heat carrier in all combinations, crossing, colateral or reverse,
- rotating or immobile reactor,
- pneumatic, gravitational or mechanical transport of oil shale & heat carrier,
- external or internal heating,
- in-situ or ex-situ heating,
- different sources of heat
  - combustion (of shale, coke or gas),
  - electricity,
  - explosion,
  - microwaves,
  - plasma,
- allowing and not allowing co-processing,
- using physical, chemical properties or both,
- more or less friendly to environment,
- with different capacity, capital and operational costs, different products of different quality and prices.
How to compare and choose?

• By final result – which one brings more profit for the same block of resource.

• For this purpose TTU elaborated a model

• RESOURCE - Evaluation Model for Choice of Oil Shale Processing Technology
## Evaluation Model - RESOURCE

### RESOURCE - Evaluation Model for Choice of Oil Shale Processing Technology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Definition</th>
<th>ICP</th>
<th>Galiner</th>
<th>Kiviter / Fushun / Union</th>
<th>Petrosix</th>
<th>ATP</th>
<th>Tosko II</th>
<th>IGT</th>
<th>Lurghi - Rurgas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processed share of Resources</td>
<td>R</td>
<td>( R = ) Processed oil shale / Resources of oil shale</td>
<td>1</td>
<td>0.75</td>
<td>0.3</td>
<td>0.65</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Energy extracted and used</td>
<td>E</td>
<td>( E = () Extracted + Recovered Energy) / HHV of oil shale processed</td>
<td>0.5</td>
<td>0.91</td>
<td>0.7</td>
<td>0.7</td>
<td>0.86</td>
<td>0.91</td>
<td>0.9</td>
<td>0.87</td>
</tr>
<tr>
<td>Spent Energy used for mining &amp; processing</td>
<td>S</td>
<td>( S = ) Energy spent for mining &amp; processing / Energy Extracted &amp; recovered</td>
<td>0.5</td>
<td>0.125</td>
<td>0.33</td>
<td>0.33</td>
<td>0.13</td>
<td>0.12</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Energy Output</td>
<td>O</td>
<td>( O = R \times E \times (1 - S) )</td>
<td>0.25</td>
<td>0.60</td>
<td>0.14</td>
<td>0.30</td>
<td>0.65</td>
<td>0.60</td>
<td>0.64</td>
<td>0.65</td>
</tr>
<tr>
<td>Unit Profit</td>
<td>U</td>
<td>( U = () Unit Price - Unit Full Cost) / Oil Price (\text{where Unit - B.O.E. of Energy Output})</td>
<td>0.67</td>
<td>0.56</td>
<td>0.33</td>
<td>0.44</td>
<td>0.50</td>
<td>0.44</td>
<td>0.44</td>
<td>0.5</td>
</tr>
<tr>
<td>Rate of Resources Use</td>
<td>R</td>
<td>( R = O \times U ) (shows which part of used Resources being paid at market price makes net profit)</td>
<td>0.17</td>
<td>0.33</td>
<td>0.05</td>
<td>0.14</td>
<td>0.20</td>
<td>0.27</td>
<td>0.24</td>
<td>0.20</td>
</tr>
<tr>
<td>Commodity by-products</td>
<td>C</td>
<td>( C = ) Specific Receipts from Commodity By-Products per one BOE / Oil Price</td>
<td>-</td>
<td>0.14</td>
<td>0.05</td>
<td>0.06</td>
<td>0.10</td>
<td>0.10</td>
<td>0.20</td>
<td>0.14</td>
</tr>
<tr>
<td>Environmental Charges</td>
<td>E</td>
<td>( E = ) Specific Environmental Costs (Reclamation, FreezWall, etc) / Oil Price</td>
<td>0.10</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Final Result</strong></td>
<td></td>
<td></td>
<td>0.07</td>
<td>0.43</td>
<td>0.05</td>
<td>0.14</td>
<td>0.33</td>
<td>0.32</td>
<td>0.39</td>
<td>0.37</td>
</tr>
</tbody>
</table>