Carbon intensity, water use and EROI of production of upgraded shale oil products using the Enefit280 technology

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Outline

1. Enefit overview
2. Objectives of the study
3. Enefit shale oil industry CO$_2$ intensity study by JACOBS Consultancy
4. EROI of the Enefit shale oil industry in Estonia
5. Enefit shale oil industry water requirements
# Enefit Overview

<table>
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<th>Enefit</th>
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</table>
| • Vertically integrated utility (oil shale mining, shale oil production, generation, distribution, supply)  
• S&P credit rating of BBB+/stable outlook, Moody’s credit rating A3/stable outlook (as at 26 July 2010)  
• State owned, Bonds listed on the London Stock Exchange |  |

## Oil Shale Mining
- Over 100 years operations, more than 1 bn tonnes of oil shale mined to date  
- Reserves of more than 1 bn tons  
- Annual production ca. 15-17 M tons  
- 4 operating mines: 2 surface, 2 underground  
- 3 000 mining employees  
- Experienced in remediation 12 000 hectares restored

## Oil Shale Power Generation
- Provides 91% of Estonia’s electricity, more than 550 TWh produced to date  
- 2380 MW of oil shale fired capacity world largest oil shale power plants  
- Allows significant electricity exports to Baltic region and Finland  
- Ensures security of supply  
- Approx 1200 employees

## Shale Oil Production
- 50 years of surface retort production, more than 200 M bbl oil produced to date  
- Technology involves:  
  - Drying unit  
  - Rotary kiln reactor  
  - Combustion unit for spent shale  
- 2 x Enefit140 units (operating)  
- New Enefit280 unit under construction

## International development
- Enefit international development projects are based on Enefit280 shale oil production technology  
- Jordan 38 000 bbl/d shale oil production, 600-900 MW power production under concession  
- USA 50 000 bbl/d shale oil production, resource ownership  
- Enefit280 technology is available for licensing
Oil shale industry scheme
Construction of Enefit280
Objectives of the study

• Calculate, through LCA, the carbon intensity for diesel and gasoline derived from Estonian oil shale using the Enefit280 technology, subsequent oil upgrading and downstream refinery processing.
• Determine Energy Return on Investment (EROI) for production of synthetic crude oil derived from Estonian oil shale using the Enefit280 technology and subsequent oil upgrading.
• Calculate the direct water usage of oil shale based synthetic crude oil production.
• Compare carbon intensity, EROI and water use values against those obtained for oil products derived from conventional and alternative fuels

• Study is made for Estonian shale oil industry,
• Data presented are based on Enefit280 technology and shale oil upgrader
Life Cycle carbon intensity of shale oil derived liquid fuels

Mine-to-wheel LCA emissions and offsets based on Estonian oil shale:

- **Oil shale**
  - Mining: 280 t/h
- **Refinery**
  - Transportation of upgraded oil
  - Shale oil upgrading
  - Transportation to market
  - Gas station: Final consumption 33.9 t/h

- **Enefit280 oil shale retorting and condensation**
  - Power: 33-42 MW
  - Ash
  - Steam

- **Cement production**
CO₂ study results

- Enefit, power offset
- Crude oil
- Oil Sands
- CTL
- Enefit, power & ash offset

Carbon intensity, gCO₂/MJ

- Mine to Pump
- Oil shale mining
- Oil shale transport
- Retorting
- Upgrading
- Transport to refinery
- Refining
- Transport to market

Carbon in fuel
EROI of shale oil derived liquid fuels

Energy return on investment (EROI) is the ratio of energy produced to energy consumed. Data are based on Estonian oil shale.

\[
EROI = \frac{E_{\text{net}}}{E_{\text{consumed}}}
\]
Consideration of co-products

- The net power export from Enefit280 process and upgrading process is taken into account.

- The average efficiency for Estonian grid power generation mix is 32%, which gives primary energy credits of **11.25 MJpr / kWeI**
**EROI study results**

**EROI of shale oil derived liquid fuels in Estonia.**

- Liquid fuel products: 4753 MJ
- Net Power Export: 118 kW
- Energy consumed: 545.2 MJ
- EROI: 11.16

**ER0I for different technologies**

- Enefit Estonia
- Enefit Utah
- ATP Utah
- Shell ICP Utah
- Oil Sands

**References:**

Water requirement of Enefit shale oil industry (bbl / bbl SCO)

Cooling cycle
River water

Oil shale mining

Oil shale retorting

Shale oil condensation

Shale oil upgrading

Waste water treatment

Turbine

Steam cycle

Waste water

Wastewater treatment

Condensation

Upgrading

Non-consumptive water use

Consumptive water use

Water from process

1.26 - 0.2 = 1.06 bbl / bbl SCO

1 bbl SCO

0.48

0.425

0.134

0.025

0.142

0.058

0.2
Technological alternatives that influence water utilization

Ash removal in Estonia uses hydro pulp transportation system, where water is constantly recycled in the system by means of transportation pipes, canals and settling ponds.

For all projects outside of Estonia Enefit plans to use dry ash removal systems with minimal water use for dust prevention. Estimated water usage of this system is ~0.26 bbl per bbl of oil.

In Estonia turbine cooling is done by means of open river cooling. For future projects Enefit plans to utilize other cooling schemes for reducing cooling water needs, eg. air cooling (zero water usage) or closed circuit water cooling with cooling towers (estimated water usage 2.99 bbl per bbl of oil) depending upon the specific location.
Water requirement results

<table>
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<tr>
<th>Comparison of Water consumption</th>
<th>Enefit industry water consumption in Estonia</th>
<th>1.06 bbl / bbl</th>
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<tbody>
<tr>
<td></td>
<td>Enefit industry water usage with turbine air cooling and ash granulation option</td>
<td>0.84 bbl / bbl</td>
</tr>
</tbody>
</table>

References:

1. C. Eatough, K. E. Hatfield, A. M. Ochoa, L. D. Smoot; "Hydrogen and water requirements for the Clean Shale Oil Surface Process (C-SOS)", 29th Oil Shale Symposium, Colorado School of Mines, 2009
2. J. Boak, E. Mattson; "Water use for in situ production of oil from oil shale", 29th Oil Shale Symposium, Colorado School of Mines, 2009
Conclusions

• Impact of marketable co-products to the global CO$_2$ balance should be taken into account when analyzing carbon intensity of oil shale derived liquid fuels.
• CO$_2$ intensity of Estonian oil shale derived liquid fuels is approximately 128 gCO$_2$/MJ and is comparable to those derived from oil sands.
• EROI values (EER) for Estonian oil shale derived liquid fuels in Estonia is 11.2 whereas export of electricity as co-product from the Enefit process has been taken into account.
• Water consumption for production of oil shale derived liquid fuels in Estonia is 1.06 bbl/bbl.
Thank you!

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