Converting Green River oil shale to liquid fuels with ATP and ICP technologies

A life-cycle comparison of energy efficiency and GHG emissions

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Outline

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1. Introduction and context

- Past oil shale development hindered by high risk, uncertain technology, and environmental concerns
- Two prominent technologies appear to be moving forward: Alberta Taciuk Processor (OSEC) and In situ Conversion Process (Shell oil)
- I was hired by Natural Resources Defense Council to study oil shale
  - Have put in an additional year of time on this project (part of Ph.D. dissertation)
- This is a brief outline of two working papers available on my website: http://abrandt.berkeley.edu
2. Research questions

• What are the energy inputs and outputs from key above ground and in situ oil shale production processes?
• What are the associated greenhouse gas emissions?
3. Research methods - LCA

- I compare the Alberta Taciuk Processor (ATP) to the Shell In situ Conversion Process (ICP) using life cycle analysis
  1. Compute material and energy inputs to stages of each process
  2. Convert material requirements into energy requirements (for prominent materials, e.g. steel, cement)
  3. Sum direct and indirect energy requirements, compare to energy outputs
  4. Compute GHG emissions from direct and indirect energy requirements
- Multiple cases calculated: I will show high and low primary cases
ATP modeling

- Define ATP-based process with stages
  - Mining/transporting/crushing
  - Retorting
  - Post-retorting processes (spent shale disposal, upgrading of SCO)
  - Refining SCO into finished liquid fuel
- For each stage calculate materials and energy flows per tonne
  - Retorting uses detailed mass and energy balance
- Include material energy embodied in steel, cement, mining equipment
ATP retort mass and energy flow diagram

Preheat Zone
- Energy flow

Retort Zone
- Solid mass flow

Combustion Zone
- Gas and vapor flow

Qj

Preheated Air
Energy contained in vapors
Energy added to pre-heat air

Preheat vapor exhaust (H₂O, air)

Shale input to pre-heat tube

Flue gases from combustion and mineral decomposition

Energy contained in flue gas

Energy losses through shell

Dry, hot shale moves to retorting zone

Hot, burned shale recycle

Spent shale moved to combustion zone, burned

Recycled HC gas and additional fuel as needed

Oil vapors
HC gas
Water vapor
CO
CO₂
Minor pollutants

Spent and burned shale rejected

Energy contained in spent and burned shale

Burned shale moves toward exit, transferring heat to pre-heat zone

Preheated air
Energy contained in vapors
ATP difficulties and uncertainties

• Mining inputs are uncertain, as no large-scale industry exists
  – Use tar sands (Johnson et al.) and coal mining as analogues
• Retort process is tunable to meet different criteria
  – Use data from patents (Taciuk et al.) and published sources to estimate temp. for different retort chambers – allows recycle rate and energy balance calcs.
  – Retort could be run at lower temperature/slower to reduce carbonate decomposition
• Waste heat capture is possible, but uncertain how economics would play out
ICP Modeling

- Divide ICP process into stages
  - Preliminary ops./freeze wall const./dewatering
  - Heating
  - Production/upgrading
  - Restoration and remediation
  - SCO refining
- LCA again performed per tonne
- Processes reported in patents/reg. doc. are small-scale – **scaling required**
ICP plan – OST and modeled cases

Shell ICP-OST

Large-scale ICP project

Freeze wall continues around perimeter

Heated area extends +3 m on each side

Heater wells fill rest of area

Freeze wall continues around perimeter
ICP side-view

Heater wells continue

7.8 m

270 m

Overburden

320 m

Shale

Final radius of external conversion

$ r_{\text{converted}} = 3 \text{ m} $

Radius of area affected by heater
(at time of heater-well shut off)

$ r_{\text{affected}} = 15 \text{ m} $

Frozen radius

$ r_{\text{frozen}} = 1.6 \text{ m} $

Radius affected by freeze wall

$ r_{\text{affected}} = a_r r_{\text{frozen}} = 7.8 \text{ m} $
ICP difficulties and uncertainties

- Little empirical, publicly available work done at retorting temperatures, speeds, and pressures used in ICP
  - Work from LLNL is best source (Burnham, Braun, Singleton et al.)
- Operating pressures are uncertain, effect of pressure accounted for roughly in my model
- Difficult to reconstruct ICP from patents
- Inherent flexibility of ICP creates variability
4. Results – Energy inputs ATP

A conventional oil production process is compared to different stages of oil production:
- **Refining**
- **Upgrading**
- **Retort**
- **Crushing**
- **Transport**
- **Mining**
- **Preliminary operations**

The energy consumed per MJ of FFD (Final Feedstock Density) is shown for both low and high energy use scenarios.

- **Low energy use**:
  - Refining: 0.10 MJ
  - Upgrading: 0.05 MJ
  - Retort: 0.20 MJ
  - Crushing: 0.10 MJ
  - Transport: 0.10 MJ
  - Mining: 0.05 MJ
  - Preliminary operations: 0.05 MJ
  - Total: 0.50 MJ

- **High energy use**:
  - Refining: 0.15 MJ
  - Upgrading: 0.10 MJ
  - Retort: 0.25 MJ
  - Crushing: 0.15 MJ
  - Transport: 0.15 MJ
  - Mining: 0.10 MJ
  - Preliminary operations: 0.10 MJ
  - Total: 0.85 MJ
4. Results – Energy inputs ICP

The chart illustrates the MJ consumed per MJ of FFD for both the low and high case scenarios. The categories include refining, retorting, misc., freeze wall, pumping, drilling, and preliminary operation. The high case shows a significantly higher MJ consumption compared to the low case.
4. Results – Upstream GHGs ATP

- Conventional oil production

- Graph showing gCeq./MJ of FFD for Low case and High case.
  - Low case: Refining, Upgrading, Retort, Crushing, Transport, Mining, Preliminary operations.
  - High case: Refining, Upgrading, Retort, Crushing, Transport, Mining, Preliminary operations.

A. Brandt – ATP and ICP life-cycle analysis
4. Results – Upstream GHGs ICP

A. Brandt – ATP and ICP life-cycle analysis
4. Results – GHGs comp. to other fuels

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5. Conclusions and open questions

- Both processes very energy intensive
- GHG emissions comparable to or possibly higher than tar sands emissions
- ICP is more energy intensive than ATP, even given scale (e-use)
- Fuel flexibility gives ICP potential for lower carbon emissions
  - ICP could use renewable power to greatly reduce emissions
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