Energy Cost of Producing Energy – Why Thermodynamics Tell Us It Is Time for Unconventional Fuels from Oil Shale

27th Oil Shale Symposium
Colorado School of Mines
October 15-17, 2007

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Unconventional vs. Conventional Oil

• Conventional
  – Significant exploration risk
  – Shrinking availability
  – Subject to decline
  – Well-established markets
  – Variable quality

• Unconventional
  – Little exploration risk
  – Massive and rich resource base
  – High Capital Expenditure (CAPEX)
  – Assured production levels
  – Consistent quality
Energy balance* - BTU/ton-ore

Oil sands = 10.5 wt%
Oil shale = 30 gpt MFA

*preliminary
1st Law Efficiency Syncrude, Canada

Source - http://www.vcr-mvr.ca
“...estimates of the ultimate amounts of oil to be recovered [must take] into account the effect of the price of oil.”

David Nissen (Exxon) to M. King Hubbert (ca. early 80s) in response to Hubbert’s use of Ultimate Recovery as the area under the Hubbert Curve.
“Your statement that [price will govern] the fraction of the original oil-in-place that will be recovered is correct, but the [price] effect may easily be exaggerated. …So long as oil is used as a source of energy, when the energy cost of recovering a barrel of oil becomes greater than the energy content of the oil, production will cease no matter what the monetary price may be.”

M. King Hubbert (Shell) to Nissen
(as Referenced by Ivanhoe, 1982).
http://www.hubbertpeak.com/hubbert/to_nissen.htm
Minimum price of unsubsidized energy as a function of 1\textsuperscript{st} law efficiency where 1.0 = $30/bbl (2006 conditions)

1\textsuperscript{st} Law Efficiency = \frac{\text{output}}{\text{output} + \text{external input}}

Conditions today

feasible

not feasible
1st law energy efficiency vs. trillion bbl

petroleum today

end of conventional petroleum recovery

gushers
Energy efficiency vs. trillion bbl bitumen produced

bitumen
Cumulative US Oil Shale Resource vs 1st law Retort Efficiency

- 50 gpt
- 30 gpt
- 16 gpt
- 11 gpt

- Billions of barrels in-place: 0, 500, 1000, 1500, 2000, 2500
- Products/(products + heat consumed): 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1.0
Energy efficiency vs. trillion bbl produced

- Oil
- Oil shale
- Bitumen
- Grain alcohol
Implied Remaining reserves within 70% 1st law efficiency

(Remaining = Ultimate less economic and thermodynamic limitations)

- Petroleum = 1.5
- Bitumen = 1.6
- Oil shale = 1.1

Net Total (not including coal or NG) = 4.2 trillion bbl

Percentage in North and Latin America > 50%
Should be the target for proving reserves
Green River Formation Oil Shale

Richness vs Total Resource

gal/ton vs total bbls in-place greater than indicated richness (in billions)

- Typical richest
- Too thin
- Expected range for first-generation plant
- Base case
- Donnell 1964
- Athabasca richness
- Too lean
- Culbertson 1973
- Culbertson 1973
Goals

• Provide access to resource
• Demonstrate technologies for:
  – Surface recovery
  – Modified in-situ
  – True in-situ
• Achieve reclassification of resource to proven reserves of at least 400 billion bbls.
Thank You

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