Current Energy Crisis

- World’s main source of energy: Petroleum
- Demand exceeding supply
  - April 17, 2006: Oil reaches $70/barrel
- Opportunity to develop alternate energy sources
  - Large economic incentive
Why Shale Oil?

• Currently, United Arab Emirates hold 50% of world’s known oil reserves

<table>
<thead>
<tr>
<th>How much does the US hold?</th>
<th>How many reserves would be added from developing oil shale?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>2 TRILLION BARRELS</td>
</tr>
</tbody>
</table>

**Result:** US takes over as leader in the world in oil reserves.
Outline

• Introduction to Shale Oil
• Project Statement
• Subsurface Operations
  – Reservoir Temperature Profiles
  – Heating
  – Freeze Walls
  – Reservoir Composition Analysis
• Surface Facilities
  – Oil/Gas Processing
  – Power Plant
• Pipelines to Market
• Production Schedule
• Economics and Risk
Shale Oil: Definition

- Sedimentary rock with a high organic content
  - Organic matter is known as kerogen

- Kerogen:
  - $M_{\text{avg.}} = 3000$
  - Approximate formula $C_{200}H_{300}SN_5O_{11}$

Shale Oil: History in the US

- Office of Naval Petroleum and Shale Oil Reserves formed in 1912

- First Demonstration mine opened outside of Rifle, Colorado just after World War II
Shale Oil: History in the US

• TOSCO opened an experimental mine and production plant near Parachute, Colorado in 1960’s

• Exxon opens Colony II project outside of Parachute, Colorado in 1980
  – Colony Project is closed in May of 1982
  – Nearly 2,200 people unemployed
  – Loss of more than $900 million.
Project Statement

• Determine which method of production of shale oil is the most feasible.

• Analyze production process to determine
  – Subsurface designs
  – Reservoir characteristics
  – Surface processing facilities
  – Scheduling of project
  – Pipelines

• Perform an economic analysis on project.
Shale Oil Production Methods

Above Ground Retorting
- Mining of ore
- Well known technology
- Large environmental impact
  - Popcorn effect
  - Large open mines
  - Emissions

In-Situ Conversion
- Underground conversion
- Research in progress
- Lower environmental impact
- Not commercially proven
In-Situ Conversion

• Currently being explored by Shell Oil with the Mahogany Project.

• Entails the heating of kerogen in the ground and extracting the produced hydrocarbons for further processing.
In-Situ Process Overview

- **Step 1: Heating**
  - Conversion of kerogen to oil and gas
- **Step 2: Freeze Wall Construction and Water Removal**
  - Impermeable wall around production site
  - Prevents large environmental impact

1. Mut, Stephen. The Potential of Oil Shale. 8/20/05
In-Situ Process Overview

- Step 3: Production
  - Products from kerogen conversion

- Step 4: Processing and Transportation
  - Oil and gas separation
  - Pipelines to market
### Schedule Table

<table>
<thead>
<tr>
<th>Site</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>8 Months</td>
<td>36 Months</td>
<td></td>
<td>24 Months</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 2</td>
<td>13 Months</td>
<td>36 Months</td>
<td></td>
<td>24 Months</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 3</td>
<td>13 Months</td>
<td>36 Months</td>
<td></td>
<td>24 Months</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Site Preparation**: drilling wells, freeze wall formation, water removal
- **Heating Only**
- **Production**: refrigeration and heating continues
- **Water Injection**
- **Site Reclamation**
Reservoir Temperature Profile

- Unsteady state 1D temperature profile
- Profile created for
  - Heater to heater 60 feet apart (25 heaters/acre)\(^1\)
  - Heat given off by reaction accounted for
  - Initial Reservoir temperature 150\(\text{oF}\)

Reservoir Temperature Profile

- Heat balance on reservoir

\[ \rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} - q \]

- Concentration due to cracking

\[ \frac{dC_k}{dt} = -Ae^{\left(-\frac{E_a}{RT}\right)} C_k \]

Reservoir Temperature Profile

- Approximation Equation

\[
\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2} - \frac{q}{\rho C_p}
\]

\[
T_i \bigg|_{t+\Delta t} - T_i \bigg|_t = \frac{\alpha \Delta t}{\Delta x^2} \left( T_{i+1}\bigg|_t + T_{i-1}\bigg|_t \right) - \frac{2 \alpha \Delta t}{\Delta x^2} T_i \bigg|_t - \frac{Ate^{\frac{-E_a}{RT}} C_k (-\Delta H_{rx})}{\rho C_p}
\]

Temperature at certain time and distance between heaters

Accounts for heat spreading linearly away from each heater into the reservoir rock

Accounts for heat of reaction due to cracking of kerogen
Reservoir Temperature Profile Assumptions

• Thermal diffusivity assumed constant

• Models only include periods of time when no fluid flow is occurring in reservoir

• Heaters assumed to be in a hexagonal pattern in the earth

• Heat generation from reaction is calculated from average kinetic values of kerogen cracking

• Heat lost to overburden by heaters not considered
Reservoir Temperature Profile

Temperature vs. Reservoir Distance: Heat of Reaction Included

Takes 3.1 years to start production of the well in the center of the heaters.
Reservoir Temperature Profile: No Heat from Reaction

Takes 3.3 years to start production of the well in the center of the heaters.
Reservoir Temperature Profile: Heater to Freeze Wall

Temperature vs. Reservoir Distance: Heater to Freeze Wall

Distance (ft)

Temperature (F)

0 hrs 10 months 24 months 48 months 72 Months 130 months
2D Reservoir Temperature Profile

- Developed using ANSYS
- Initial reservoir temperature 150°F
- Freeze walls included as boundary condition.
NODAL SOLUTION
TIME=167.656
TEMP (AVG)
R_SYS=0
SMN =10
SMX =1500
Shale Oil: Subsurface Operations

- Drilling costs
- Refrigeration costs
- Pumping costs
- Heating costs
Drilling Costs

- Consists of wells for heaters and producers
  - 250 wells for heaters per 10 acre plot
  - 80 producer wells
- Total well costs of $26.4 million.
  - $80,000² per well.

2. Brown, Randy. Field Engineer XAE inc.
Freeze Wall Construction

- Constructed of double wall pipes placed 8 ft. apart
- Calcium chloride brine at -10 degrees F is circulated.
- Water in the soil freezes creating an impermeable barrier.

*Soil freeze technologies
Freeze Wall: Duty & Costs

During freezing:

\[ Q = M \times C_p \times (T_{\text{final}} - T_{\text{initial}}) + \Delta H_{\text{freezing}} \times M_{\text{water}} \]

\[ Q = 5.0 \times 10^6 \text{ kW} \]

During production:

\[ Q = -k \frac{dT}{dz} \]

\[ Q = 8.7 \text{ kW} \]

Purchase cost for 5.0*10^6 kW of refrigeration\(^1\): $12.5 million

Operating Cost\(^2\): $3.2 million per day

1. Peters et al p.894 fig. B-7
2. Peters et al p.898 table B-1
Pumping

- Ground water trapped within freeze wall
- Must be removed to prevent contamination
Pumping Costs

• A pump is needed to remove water from within the freeze wall.
  – 2 barrels of water for every barrel of oil\textsuperscript{6}
  – Pumps must handle 1.6 million gallons per hour to remove the water in 2 weeks.
    • Centrifugal pumps
    • 80 pumps, $23,000 per pump\textsuperscript{7}
    • $120,000 electricity needed per day

\textsuperscript{6} Bartis et. al. \textit{Oil Shale Development in the United States}. p. 50. Rand Santa Monica, California: 2005
Heating: Challenges

• Challenges
  – Regulated at a constant temperature
  – Must operate at high temperatures
  – Must have a large power output.
Heating: Solution

- Electric heaters lowered to the bottom of well hole
- Extends the entire length of the shale layer

Diagram:
- Supporting casing
- Overburden
- Shale
- Heaters

Dimensions:
- 2000 ft
- 500 ft
Heating Element

• Chromel AA* heating element
  • 68% nickel
  • 20% chromium
  • 8% iron
  • Self regulating: 1500 °F

*Trademark of Hoskins Manufacturing

2 Handbook of chemical engineers, p. 4-201 8th ed.
Heater Design

- Cylindrical design
- Electric heating element suspended in the center.
- Spaced from the casing by electrical insulators
Heater Design

- Heating Element
- Ceramic Insulator
- Steel Casing

Dimensions:
- 0.5”
- 6.625”
Heating Costs

**Electrical**
- 165 KW per heater
- Operating at 480 V AC and 350 amps
- Electrical costs heating:
  - $.08 per KW-hr $80,000 per day total

**Materials**
- Steel Casing
  - $10 per foot
- Heater element
  - $20 per foot
- Porcelain insulator
  - $14 each, 250 per heater
- Total material cost: $80,000 per heater
Reservoir Composition Study

- Heating process causes cracking of kerogen.
- Estimation of composition of products in reservoir needed.
- A temperature profile is necessary for composition computation.
- Ultimately, reservoir characteristics will allow design of processing facilities.
Reservoir Composition Model

- Cracking process under the earth
  - Kerogen:
    - $\text{MW}_{\text{avg.}} = 3000$
    - Approximate formula $C_{200}H_{300}SN_5O_{11}$
- Modeled using visbreaking model
- Using temperature profile, predicts concentrations of hydrocarbons in reservoir

Example of hydrocarbon cracking

\[
\frac{dC_{Si}}{dt} = \sum_{k=i+2}^{n} K_{k,i} C_{S_k} - C_{S_i} \ast \sum_{j=1}^{i-2} K_{i,j}
\]
Reservoir Composition

Weight Fractions of Hydrocarbons During Heating In Reservoir

- **C1-C5**: 0.2
- **C6-C10**: 0.4
- **C11-C15**: 0.6
- **C16-C20**: 0.8
- **C30-C40**: 1.0
- **C50-C60**: 0.8
- **C70-C280**: 0.6

Temperature:
- 700 F
- 800 F
- 900 F
- 1000 F
- 1100 F
Problems With Composition Model

- Averaged K-Values must be used due to the large amounts of data
- Parameters are fit to laboratory data that may not be similar to reservoir
- Does not account for coking in reservoir
- Results are not close to reported results from experimental site
Suggested Solution for Composition Model

• Use a tool with a larger capacity than excel

• Use a model specifically developed to calculate products from kerogen
  – Example: Braun and Burnham’s model of decomposition of kerogen
Oil Processing Design

Specifications

Oil composition
1. No significant sulfur content
2. Carbon solid from cracking is not produced
3. Heavy hydrocarbons are not produced
4. TBP curve of a sample light sweet crude oil is being used currently.
   - Update with compositional model results

Production
1. 20 acres produced from one facility
2. Water treatment will function ¼ of the time of the oil treatment

Oil Surface Facilities Considerations

- Elevation changes
- High temperature fluid
- Piping will be above ground
- Two different transportation routes for oil and gas
- Some gas will be used for running electricity plant

Experimental project site
Oil Processing Skeleton Model

Oil Processing

Water processing
Oil Processing Facilities

- Inlet temperature = 680°F
- Inlet pressure = 1000 psia

Separates C₁ - C₅ and from heavier products

Sent to Denver refinery for sale
Water Processing Facilities

- Inlet temperature = 680°F
- Inlet Pressure = 1000 psia

Pumps water back into well
To oil processing
Processing Facilities

• Future options for gas treatment
  – Create a gas plant on site
  – Use ethane to make ethylene on site
  – LPG to market with oil
  – Burn gas production for power generation
Power Plant Options

Nuclear Power Plant
- Bad public opinion
- Low emissions

Gas Powered Plant
- Methane is priced high
- Producing methane on sight

Coal Powered Plant
- High emissions
- Coal supply needed
Power Plant

- Combined Cycle
  - Capital Cost, $500M
  - Operating Cost, $60,000/day
  - Natural Gas Required, 110M ft³
  - Electricity Generated, 800 MW
  - Efficiency, 57%

R.H. Kehlhofer, et al., Combined-Cycle Gas & Steam Turbine Power Plants
Gathering Pipelines

• Well to Header
  – 4” Schedule 80, Carbon Steel
  – Oil & Gas

• Header to Main Gathering Pipe
  – 8” Schedule 80, Carbon Steel
  – Oil & Gas

• Main Gathering Pipe to Processing Facility
  – 20” Schedule 80, Carbon Steel
  – Oil & Gas
Sell Pipelines

- Gas to/from Market
  - 8” Schedule 80, Carbon Steel

- Oil to Market
  - 12” Schedule 80, Carbon Steel

- Gas to Power Plant
  - 16” Schedule 80, Carbon Steel
# Pipeline Costs

<table>
<thead>
<tr>
<th>Pipe Description</th>
<th>Contents</th>
<th>D (in)</th>
<th>Schedule</th>
<th>Length (ft)</th>
<th>$/foot</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. From Well</td>
<td>Oil &amp; Gas</td>
<td>4</td>
<td>80</td>
<td>400000</td>
<td>$10</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>2. From 1 Acre</td>
<td>Oil &amp; Gas</td>
<td>8</td>
<td>80</td>
<td>100000</td>
<td>$30</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>3. From 10 Acres</td>
<td>Oil &amp; Gas</td>
<td>20</td>
<td>80</td>
<td>1000</td>
<td>$100</td>
<td>$100,000</td>
</tr>
<tr>
<td>4. Crude Oil to Sell</td>
<td>Oil</td>
<td>24</td>
<td>80</td>
<td>1188000</td>
<td>$110</td>
<td>$130,680,000</td>
</tr>
<tr>
<td>5. Gas to sell</td>
<td>Gas</td>
<td>8</td>
<td>80</td>
<td>1188000</td>
<td>$30</td>
<td>$35,640,000</td>
</tr>
<tr>
<td>6. Gas to Power Plant</td>
<td>Gas</td>
<td>10</td>
<td>80</td>
<td>10500</td>
<td>$40</td>
<td>$420,000</td>
</tr>
</tbody>
</table>

**Total Piping Cost = $173,840,000**
Production Schedule

- Ten acre tracts
- 40,000 BPD per tract
- A new tract every year
## Schedule Table

<table>
<thead>
<tr>
<th>Site</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>8 Months</td>
<td>36 Months</td>
<td>24 Months</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 2</td>
<td>13 Months</td>
<td>36 Months</td>
<td>24 Months</td>
<td>6 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 3</td>
<td>13 Months</td>
<td>36 Months</td>
<td>24 Months</td>
<td>6 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Site preparation:** drilling wells, freeze wall formation, water removal
- **Heating only**
- **Production:** refrigeration and heating continues
- **Water injection**
- **Site reclamation**
Environmental Effects

• Location
  – Colorado Rocky Mountains
  – Lack of infrastructure
  – Low population
  – Natural habitats affected largely

• Ground Coverage
  – Drilling cannot occur on slope
  – Wells spaced 30-60 ft apart
  – Large land clearings necessary

• Emissions
  – Choice of power plant
  – Processing on site
Crude Oil Price Forecast

Crude Oil Forecasted Prices
(Price per Barrel, $US 2004)
Natural Gas Price Forecast

Natural Gas Forecasted Prices
(Price per Thousand Cubic Feet, $US 2004)
Pricing Estimations

• **Includes**
  - Equipment costs
  - Heating
  - Cooling
  - Power Plant
  - Drilling
  - Production taxes
  - Operating costs

• **Excludes**
  - Logistical costs
    - Extensive Road building
  - Transporting materials
  - Relocating employees
  - Research costs
  - Reclamation costs
# Processing Equipment Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Basis of Estimation</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Heat Exchangers</td>
<td>5 @ $15,867</td>
<td>$80,000</td>
</tr>
<tr>
<td>b. Distillation</td>
<td>D=3m, H=6m, 10 trays</td>
<td>$87,000</td>
</tr>
<tr>
<td>c. Mixer #2</td>
<td>D=.508</td>
<td>$16,000</td>
</tr>
<tr>
<td>d. Mixer #1</td>
<td>D=.4572m</td>
<td>$14,000</td>
</tr>
<tr>
<td>e. Flash #1</td>
<td>D=1m, H=10m</td>
<td>$15,000</td>
</tr>
<tr>
<td>f. Pump</td>
<td>.0544 m3/s, 6800 kPa</td>
<td>$40,000</td>
</tr>
<tr>
<td>g. Pumps (piping)</td>
<td>2 w/.151 m3/s, 1035 kPa</td>
<td>$32,000</td>
</tr>
<tr>
<td>h. Heat Exchangers</td>
<td>3 w/ SA= 100 ft2</td>
<td>$3,600</td>
</tr>
<tr>
<td>i. Expander</td>
<td>P=1932 kW</td>
<td>$235,000</td>
</tr>
<tr>
<td>j. Expander #2</td>
<td>P=552 kW</td>
<td>$105,000</td>
</tr>
<tr>
<td>k. Compressor</td>
<td>5800 kW, centrifugal-rotary</td>
<td>$1,100,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$1,727,600</strong></td>
</tr>
</tbody>
</table>
### Extraction Equipment Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Basis of Estimation</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Heaters</td>
<td>25/acre @ $100,000</td>
<td>$25,000,000.00</td>
</tr>
<tr>
<td>b. Refrigeration plant</td>
<td>800 KW capacity</td>
<td>$12,500,000.00</td>
</tr>
<tr>
<td>c. Pump</td>
<td>80, 1.6M gal/hr water, 2 weeks</td>
<td>$1,840,000.00</td>
</tr>
<tr>
<td>d. Power Plant</td>
<td>Combined Cycle, $400/kWh</td>
<td>$500,000,000.00</td>
</tr>
</tbody>
</table>

**Extraction Equipment Costs**: $541,067,000

**Total Capital Investment**: $867 million
## Annual Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Basis for Estimate</th>
<th>Cost Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Manufacturing Cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Direct Production Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Raw Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Cooling Water</td>
<td>178M lb/hr $0.08/1000kg</td>
<td><strong>$1,650,000</strong></td>
</tr>
<tr>
<td>2. Operating Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Drilling Costs (contract)</td>
<td></td>
<td><strong>$22,400,000</strong></td>
</tr>
<tr>
<td>b. Operating Labor</td>
<td>$2,000,000</td>
<td></td>
</tr>
<tr>
<td>c. Refrigeration</td>
<td>0.68 per KW</td>
<td>$196,000,000</td>
</tr>
<tr>
<td>3. Direct Supervision and Clerical</td>
<td>15% of Operating Labor</td>
<td>$300,000</td>
</tr>
<tr>
<td>4. Utilities (Power Plant)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Variable Operating Costs</td>
<td>$86,500/day</td>
<td>$31,572,500</td>
</tr>
<tr>
<td>b. Fixed Operating Costs</td>
<td>$3.6M/year</td>
<td>$3,600,000</td>
</tr>
<tr>
<td>5. Maintenance and Repair</td>
<td>7% of FCI</td>
<td>$57,798,000</td>
</tr>
<tr>
<td>6. Operating Supplies</td>
<td>15% of Maintenance and Repair</td>
<td>$8,670,000</td>
</tr>
<tr>
<td>7. Laboratory Charges</td>
<td>5% of Operating Labor</td>
<td>$100,000</td>
</tr>
<tr>
<td>8. Patents not applicable</td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td>B. Fixed Charges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Capital Costs</td>
<td>Straight Line Depreciation, 25 years</td>
<td><strong>$33,027,000</strong></td>
</tr>
<tr>
<td>a. BLM Production Tax</td>
<td>12.5% of Gross</td>
<td><strong>$228,617,750</strong></td>
</tr>
<tr>
<td>b. Insurance</td>
<td>.7% of FCI</td>
<td><strong>$5,780,000</strong></td>
</tr>
<tr>
<td>c. State Production Tax</td>
<td>1% of Gross</td>
<td><strong>$18,289,420</strong></td>
</tr>
<tr>
<td>C. Overhead Costs</td>
<td>10% of the Total Product Cost</td>
<td><strong>$56,000,000</strong></td>
</tr>
<tr>
<td><strong>II. General Expenses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Administration Costs</td>
<td>20% of Operating labor and maintenance</td>
<td><strong>$11,960,000</strong></td>
</tr>
</tbody>
</table>

### Total Annual Cost
- **$677,800,000**

**Cost per barrel:** **$23.21**
Profit Estimates

Payback period: 9.7 years

Cash Flow at 25 years: $9.7 billion

NPV at 8%: $1.5 billion

Return on Investment: 162%
Risk Assessment

Distribution for NPV / Net Income/G30

Mean=1.485529E+09

Values in Billions

-6  -4  -2  0  2  4  6  8  10

Values in 10^-10

-6  -4  -2  0  2  4  6  8  10

5%  90%  5%

-1.4391  4.3723
Risk Assessment

Distribution for Total / ROI/F29

Mean = 0.9269187

5% at -0.1468
90% between 0 and 1.9868
5% at 1.9868
Future Work

• Logistics
  – Transportation of materials
  – Drilling complications
  – Reclamation Process
  – Work Force

• Optimizations
  – Heater to heater distances
  – Heater temperature
  – Heater material
  – Composition of reservoir

• 3D temperature profile
• Detailed project risk assessment
Questions?
## Net Present Values: Varied Rates

<table>
<thead>
<tr>
<th>Rate</th>
<th>NPV (25 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>$1.5 billion</td>
</tr>
<tr>
<td>0.10</td>
<td>$0.8 billion</td>
</tr>
<tr>
<td>0.12</td>
<td>$0.4 billion</td>
</tr>
<tr>
<td>0.15</td>
<td>$-0.1 billion</td>
</tr>
</tbody>
</table>
Risk Assessment:
NPV with Rate=10%

Distribution for NPV / Net Income/G30

Values in Billions

Mean=8.349873E+08
Risk Assessment: NPV with Rate=12%

Distribution for NPV / Net Income/G30

Values in Billions

Mean=3.687469E+08

-1.3767 90% 2.1075
Risk Assessment: NPV with Rate=15%

Distribution for NPV / Net Income/G30

Values in Billions

Mean=-1.012595E+08

5% -1.3296 90% 0.000 90% 1.1296 5%
Temperature Profile: Affect of Thermal Diffusivity

Thermal Diffusivity vs. Time

Time (hrs)

Thermal Diffusivity (ft^2/hr)

- 40 ft
- 50 ft
- 60 ft
- 30 ft
- 70 ft
Temperature Profile: Affect of Heater Distance

Heater Distance vs. Time

Heater Distance (ft) vs. Time (hrs)

- .004 ft^2/hr
- .008 ft^2/hr
- .016 ft^2/hr
Reservoir Production: Fracturing

Water and Sand

Heater

Heater

Reservoir