Maximization of the Net Present Value of In Situ Oil Sands Projects

SPE Calgary Petroleum Economics Special Interest Group

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Disclaimer

• This presentation is based on workflows created for an SPE paper\(^1\), and does not necessarily reflect the views and planning processes of Cenovus Energy Inc. or Penn West Petroleum Ltd.
Introduction

- Background
- Development of Integrated Model
Overview

• Maximization of Net Present Value
• Integrated Production Models
  • Definition
  • Sub-Surface Model
  • Surface Model
  • Economic Model
• Case Study
• Summary
Maximization of NPV
Maximization of NPV

• Development of a resource should be planned to maximize NPV

• Relatively simple to maximize the NPV of a single well under primary production:

\[
Net\ Present\ Value = \sum_{t=1}^{n} \frac{C_t}{(1 + r)^t}
\]

\[
C_t = (Product\ Volume \times Received\ Product\ Price)_t - Royalties_t - Operating\ Costs_t - Capital\ Investment_t - Abandonment\ /\ Reclamation\ Costs_t
\]

• Thermal heavy oil projects not as simple...
Maximization of NPV of Thermal Project

• Maximization of NPV is complicated:
  • Capital intensive CPF sets project level constraints on steam injection as well as oil, water, gas production rates
  • Surface network provides additional constraints
  • Wells with high production rates that rapidly decline (in the case of CSS) and need be scheduled along with others to receive steam
  • Varying well production performance
  • Operational performance
Maximization of NPV of Thermal Project

• “What is the optimal CPF size?”
• “How many phases should the CPF have?”
• “What is the optimal pad and well development schedule?”
• Construction of an Integrated Production Model (IPM) or Fully Integrated Stochastic Asset Model (FISAM) is required to solve these problems
Integrated Production Models
IPM

Sub-Surface Model
- Numerical or analytical reservoir model
- Well configuration and operating conditions
- Generation of injection and production forecasts for type wells

Surface Model
- CPF capacity
- Schedule of pads and wells
- Creation of a field level production forecast

Economic Model
- Price forecasts
- CPF and well capital costs
- Operating costs
- Royalty parameters
- Other economic assumptions

Start → Output Results

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IPM with Optimization

Sub-Surface Model
- Numerical or analytical reservoir model
- Selection of well configuration and operating conditions
- Generation of injection and production forecasts for type wells
- Adjust sub-surface model parameters
- Adjust surface model parameters

Surface Model
- Selection of CPF capacity
- Scheduling of pads and wells
- Creation of a field level production forecast

Economic Model
- Generation of a capital profile based on CPF size and pad/well schedule
- Calculation of project royalties, operating costs, prices, and cash flows
- Calculation of NPV and other economic metrics

Start

Current NPV greater than previous iteration?
- Yes
  - Output Results
- No

Maximum iterations reached?
- Yes
  - Stop
- No

Stop
FISAM with Optimization
Reserves Aggregation

- Another benefit to a FISAM approach is that it can be used to aggregate the results of individual well probabilistic forecasts into a field level probabilistic forecast.

- This statistical aggregation may produce a more accurate estimate of a P90/P10 field level production forecast compared with arithmetic aggregation.
  - However, dependency (correlation) among parameters must be considered for this method to have a valid basis.
  - Ex: If one well in a field produces at a P90 rate, do all the wells produce at a P90 rate? How about year over year?
Sub-Surface Model
Sub-Surface Model

• **CSS**
  • Widely used thermal recovery method of heavy oil
  • Three phases
    • Steam Injection: 10-60 days
    • Soaking: 3-30 days
    • Production: 90-730 days

Typical CSS Process\(^{(2)}\)
Sub-Surface Model

- Two models were constructed
- One model uses Arps’ decline equations:

Table 1 - Summary of Decline Model Parameters

<table>
<thead>
<tr>
<th>Decline Model Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Steam Slug Size</td>
<td>12,000 m²</td>
</tr>
<tr>
<td>Steam Rate</td>
<td>240 m³/d</td>
</tr>
<tr>
<td>Steam Slug Increase per Cycle</td>
<td>22%</td>
</tr>
<tr>
<td>First Cycle Peak Rate</td>
<td>119 m³/d (750 BBL/D)</td>
</tr>
<tr>
<td>Peak Rate Decline per Cycle</td>
<td>9%</td>
</tr>
<tr>
<td>Cycle Decline Rate</td>
<td>96%</td>
</tr>
<tr>
<td>Cycle b-value</td>
<td>0.5</td>
</tr>
<tr>
<td>Cumulative Oil Production</td>
<td>97.8 e³m³ (615 MBBL)</td>
</tr>
<tr>
<td>Water-to-Steam Ratio</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Graphs:**
- Oil Rate
- Steam Rate
- Cumulative Steam-to-Oil Ratio (CSOR)
- Recovery Factor (RF) vs. Pore Volume Injected (PVI)
Sub-Surface Model

- Other model uses an analytical HCSS model (Saripalli, 2013)
  - Radial heat transfer model + Joshi’s horizontal well inflow model
Surface Model
Surface Model

- Surface model is used to adjust the size of the CPF (oil, steam, and water capacity) as well as the development schedule of the pads/wells at the same time to determine an economic optimal combination.

- In this example we used a single phase approach to development, but the model also works with multiple phases of plant development.
Surface Model

• CSS monthly production profile is volatile:
CPF Constraints

• Two approaches considered:
  • Adjust the sub-surface model at every time step to maximize CPF usage via adjusting steam rate, duration, etc.
  • Relax the CPF constraints either by allowing > 100% of capacity or changing the constraint itself.

• Approach used in the paper was to change the CPF constraint itself by ignoring a percentile of upper data points:

  Central Processing Facility Oil Capacity – $P_{85}$ of Plateau Oil Rate

• The percentile of data to ignore needs to be tuned to the model
Economic Model
Economic Model

• Price Deck
• Royalty Calculations
• Capital Costs
• Operating Costs
• Calculation of NPV
Price Deck

• Bitumen field price is used for economic calculations

• Bitumen field price = Blend Price (WCS) – Diluent Price (Condensate)
  • Adjusted for density of produced bitumen, blend, and diluent
  • Offsets for FX, marketing and transportation, quality, etc.

• Natural gas price is based off AECO with transportation fees added
Royalty Calculations

- Alberta Oil Sands Royalty regime modelled
- Sliding scale based on WTI in $CAD/BBL
- Gross revenue rate is in affect prior to project payout
- Net revenue rate is in affect after project payout
  - Net Revenue = Gross Revenue – Opex – Capex – Other Allowances

<table>
<thead>
<tr>
<th>Price WTI C$/bbl</th>
<th>Royalty Rate on Gross Revenue</th>
<th>Royalty Rate on Net Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below C$55</td>
<td>1.00%</td>
<td>25.00%</td>
</tr>
<tr>
<td>C$55</td>
<td>1.00%</td>
<td>25.00%</td>
</tr>
<tr>
<td>C$60</td>
<td>1.62%</td>
<td>26.15%</td>
</tr>
<tr>
<td>C$65</td>
<td>2.23%</td>
<td>27.31%</td>
</tr>
<tr>
<td>C$70</td>
<td>2.85%</td>
<td>28.46%</td>
</tr>
<tr>
<td>C$75</td>
<td>3.46%</td>
<td>29.62%</td>
</tr>
<tr>
<td>C$80</td>
<td>4.08%</td>
<td>30.77%</td>
</tr>
<tr>
<td>C$85</td>
<td>4.69%</td>
<td>31.92%</td>
</tr>
<tr>
<td>C$90</td>
<td>5.31%</td>
<td>33.08%</td>
</tr>
<tr>
<td>C$95</td>
<td>5.92%</td>
<td>34.23%</td>
</tr>
<tr>
<td>C$100</td>
<td>6.54%</td>
<td>35.38%</td>
</tr>
<tr>
<td>C$105</td>
<td>7.15%</td>
<td>36.54%</td>
</tr>
<tr>
<td>C$110</td>
<td>7.77%</td>
<td>37.69%</td>
</tr>
<tr>
<td>C$115</td>
<td>8.38%</td>
<td>38.85%</td>
</tr>
<tr>
<td>C$120</td>
<td>9.00%</td>
<td>40.00%</td>
</tr>
<tr>
<td>Above C$125</td>
<td>9.00%</td>
<td>40.00%</td>
</tr>
</tbody>
</table>

Alberta Oil Sands Royalty Rates\(^{(8)}\)
Capital Costs

• Along with price, and production rate (SOR), capital costs are one of the primary influences of thermal project NPV
  • Particularly important to the calculation as substantial capital is spent upfront, prior to revenue commencing

• Initial (growth) plant capital is modelled with a capital intensity ($/BBL/D) value

• Well and pad capital (growth and sustaining) is scheduled based off of first steam date

• Abandonment and reclamation capital is also estimated and scheduled
Operating Costs

- Modelled using both a fixed (cost per month) and variable (cost per barrel of oil, water, or steam) component

- Fuel gas cost is calculated using a gas-to-steam ratio (function of steam generator efficiency, steam quality, etc.)
  - Alberta CO$_2$ taxes are also modelled off of fuel gas consumption
Calculation of NPV

- Straightforward calculation at this point as all inputs have been defined:

\[
Net \, Present \, Value = \sum_{t=1}^{n} \frac{C_t}{(1 + r)^t}
\]

\[C_t = (Product \, Volume \times Received \, Product \, Price)_t - Royalties_t - Operating \, Costs_t - Capital \, Investment_t - Abandonment / Reclamation \, Costs_t\]

- Taxes were not incorporated into the model at this point but is a planned future addition

- Other metrics: IRR, PIR, payout period, supply cost, etc.
Case Study – Peace River CSS Project

• 75 HCSS wells with lengths between 1,200 m to 1,400 m and 75 m inter-well spacing:

<table>
<thead>
<tr>
<th>Reservoir Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Pay (m)</td>
<td>14.4</td>
</tr>
<tr>
<td>Average Depth to Top of Bluesky (m)</td>
<td>673</td>
</tr>
<tr>
<td>Formation temperature, °C</td>
<td>23</td>
</tr>
<tr>
<td>Initial reservoir pressure (kPa)</td>
<td>4570</td>
</tr>
<tr>
<td>Estimated reservoir pressure at beginning of steam injection (kPa)</td>
<td>3,000</td>
</tr>
<tr>
<td>Average permeability (mD)</td>
<td>50-5,000</td>
</tr>
<tr>
<td>Average porosity (fraction)</td>
<td>0.27</td>
</tr>
<tr>
<td>Average bitumen saturation (fraction)</td>
<td>0.78</td>
</tr>
<tr>
<td>Dead oil viscosity (cSt)</td>
<td>~10,000</td>
</tr>
<tr>
<td>Live oil viscosity (cP)</td>
<td>~4,000</td>
</tr>
<tr>
<td>Solution GOR(m³/m³)</td>
<td>12</td>
</tr>
</tbody>
</table>
Case Study – Peace River CSS Project

- 500 NPV optimization iterations
- CPF capacity decreased from 11,000 BBL/D oil to 9,000 BBL/D oil
- Well/pad development schedule adjusted for 5 years at CPF peak production
Case Study – Peace River CSS Project

Before NPV Optimization

After NPV Optimization
Case Study – Peace River CSS Project

- Stochastic simulation (1,000 trials) on decline model:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Distribution Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCS-WTI Discount</td>
<td>20%</td>
<td>2%</td>
<td>Lognormal</td>
</tr>
<tr>
<td>CSS Decline Model Initial Rate</td>
<td>119 m³/d (750 BBL/D)</td>
<td>11.9 m³/d (75 BBL/D)</td>
<td>Lognormal</td>
</tr>
<tr>
<td>CPF Capital Intensity</td>
<td>$220,150/m³/d ($35,000/BBL/D)</td>
<td>$22,015/m³/d ($3,500/BBL/D)</td>
<td>Lognormal</td>
</tr>
</tbody>
</table>

Table 3 - Input Variable Distribution Data Used – Decline Model
Case Study – Peace River CSS Project

- Stochastic simulation (500 trials) on analytical model:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Distribution Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Temperature</td>
<td>22 °C</td>
<td>2.2 °C</td>
<td>Lognormal</td>
</tr>
<tr>
<td>Viscosity Constant, A (Andrade, 1930)</td>
<td>2.97e-5</td>
<td>2.97e-6</td>
<td>Lognormal</td>
</tr>
<tr>
<td>USD/CAD Exchange Rate</td>
<td>0.95</td>
<td>0.1</td>
<td>Lognormal</td>
</tr>
</tbody>
</table>

Table 4 - Input Variable Distribution Data Used – Analytical Model
Summary
Summary

• We have developed a FISAM with optimization for thermal heavy oil projects

• Optimization (deterministic or stochastic) features are useful for early scoping of projects and competitor evaluations

• Stochastic simulation is useful for generating a range of NPV, oil rates, and other results for project/business planning

• Business decisions can incorporate a range of results rather than only a base case plan with a few sensitivities
Summary

- Working with distributions from Geology through to Business Planning may reduce errors in aggregation of values

- Plots of NPV vs. Standard Deviation of NPV of various projects would allow for efficient frontier to be constructed for corporate portfolio management

- Model workflow can be used for other processes, such as SAGD
References


