Lockhart Crossing: Economically Efficient Reservoir Operations

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*Denbury Resources Inc.*

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Economically Efficient Reservoir Operations Agenda

- Lockhart Crossing Introduction and Background
- Asset Development Principles / Business Plan
- Reservoir Surveillance Metric Creation
- Economically Efficient Process Evolution
  - Asset Observations
  - Optimization Process Design
  - Implementation
  - Results
Phase 1
86 MMBbls

Phase 2
77 MMBbls

Phase 3
44 MMBbls

Phase 4
31 MMBbls

Phase 5
33 MMBbls

Phase 6
26 MMBbls

Phase 7
Hastings Area
60 - 100 MMBbls \(^{(1)}\)

Phase 8
Seabreeze Complex
25 - 35 MMBbls \(^{(1)}\)

(1) Proved plus probable tertiary oil reserves as of 12/31/08, including past production, based on a range of recovery factors. Hastings Field was purchased 2/2/09.
Lockhart Crossing 1st Wilcox Structure

**OOIP**: 56.1 MMBBLS
**Production**: 18.2 MMBBLS (32%)

**Discovery**: July 1982 Callon Petroleum
**Acres**: 3,500 Acres
**Unitized**: 1985
1st Wilcox Bar Isopach

OOIP: 41.8 MMBBLs

Phi: 15 - 24%, avg. 20%
K: 1 - 100 md, avg. 80 md
1st Wilcox Channel Isopach

OOIP: 14.3 MMBBLS

Phi: 10 - 27%, avg. 21%
K: 0.1 – 4,400 md, avg. 500 md
# Lockhart 1st Wilcox Review (Pre CO2)

## Lockhart Field Wilcox 1

<table>
<thead>
<tr>
<th>Field Found</th>
<th>1982</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Operator</td>
<td>Callon</td>
</tr>
<tr>
<td>Formation</td>
<td>Wilcox</td>
</tr>
<tr>
<td>Depth</td>
<td>~10,100'</td>
</tr>
<tr>
<td>OWC</td>
<td>-10,159'</td>
</tr>
<tr>
<td>DRIVE</td>
<td>Solution Gas - Moderate Water</td>
</tr>
<tr>
<td>TTL Field Area (acre)</td>
<td>3,500</td>
</tr>
</tbody>
</table>

## Production History

<table>
<thead>
<tr>
<th>Black Oil produced (stb)</th>
<th>18,200,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Gas Produced (stb)</td>
<td>17,300,000,000</td>
</tr>
<tr>
<td>Water Produced (stb)</td>
<td>21,200,000</td>
</tr>
<tr>
<td>Water Injected (stb)</td>
<td>38,988,000</td>
</tr>
<tr>
<td>Recovery Primary (stb)</td>
<td>6,808,038</td>
</tr>
<tr>
<td>Recovery Secondary (stb)</td>
<td>11,391,962</td>
</tr>
<tr>
<td>Rf Primary</td>
<td>12%</td>
</tr>
<tr>
<td>Rf Secondary</td>
<td>20%</td>
</tr>
</tbody>
</table>

## Reservoir Description

<table>
<thead>
<tr>
<th>Original Pressure (psi)</th>
<th>4,600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest Pressure (psi)</td>
<td>2,500</td>
</tr>
<tr>
<td>Original Bubble Point (psi)</td>
<td>3,550</td>
</tr>
<tr>
<td>Porosity</td>
<td>20%</td>
</tr>
<tr>
<td>Permeability (bar / channel) (md)</td>
<td>80 / 500</td>
</tr>
<tr>
<td>Sw Original (bar / channel) (%)</td>
<td>43 / 28</td>
</tr>
<tr>
<td>Avg H Koil (ft)</td>
<td>42</td>
</tr>
<tr>
<td>Bo Original (rb/stb)</td>
<td>1.53</td>
</tr>
<tr>
<td>Gravity (API)</td>
<td>42</td>
</tr>
<tr>
<td>Temp (f)</td>
<td>212</td>
</tr>
<tr>
<td>OOIP (stb)</td>
<td>56,000,000</td>
</tr>
<tr>
<td>OGIP (Solution) (scf)</td>
<td>53,000,000,000</td>
</tr>
<tr>
<td>Solution GOR (scf/stb)</td>
<td>951</td>
</tr>
</tbody>
</table>

## Well Count during Primary and Secondary

<table>
<thead>
<tr>
<th>Primary Total</th>
<th>37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Total</td>
<td>49</td>
</tr>
<tr>
<td>Secondary Producers</td>
<td>27</td>
</tr>
<tr>
<td>Secondary Injection</td>
<td>22</td>
</tr>
</tbody>
</table>
Lockhart’s Business Plan / Development Principles

- Lockhart provides a relatively small tertiary target that requires efficiencies in design, development, and operation to be strong economically

- Utilize known analogues for technical guidance to reduce cost and accelerate timing

- Utilize old wellbores to develop asset at low cost

- Small facilities in design and footprint to minimize CAPEX and LOE

  - Asset Design Capacities
    - 3,500 BOPD
    - 11,000 BWPD
    - 60 MMSCFPD recycle
    - 60 MMSCFPD purchase
Lockhart Crossing Field CO$_2$ Flood - Milestones

- Well work commenced in January 2007
- Drilling commenced April 2007
- Denbury commenced construction of CO$_2$ Recycling Facility in May 2007
- After receiving COE permit, pipeline construction commenced September 2007
- Construction of six-mile 8” CO$_2$ supply pipeline completed 3$^{rd}$ quarter 2007
- Injection of CO$_2$ began in December 2007
- First CO$_2$ production occurred in June 2008 – first sales July 2008
- Test Site 1 operational June 2008, Test Site 2 operational January 2009
- Lockhart has produced ~2,000,000 BBL of CO2 Oil!
Lockhart Original Pattern Design
Lockhart Crossing Field Life

Lockhart Crossing Fluid Rates

- Date
- BPD
- MSCFPD

Oil (bpd) Water (bpd) Water Inject (bpd) CO2 Injection (mscfpd) CO2 Production (mscfpd)
## Lockhart Crossing Reservoir Surveillance

### Life Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Date</td>
<td>6/1/2008</td>
</tr>
<tr>
<td>Current date</td>
<td>7/6/2011</td>
</tr>
<tr>
<td>Life to date</td>
<td>3.09 years</td>
</tr>
<tr>
<td>Life to date (as %)</td>
<td>8.8%</td>
</tr>
<tr>
<td>Expected Life (years)</td>
<td>35</td>
</tr>
</tbody>
</table>

### Cumulative Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cum CO2 injected</td>
<td>69,000,000 MCF</td>
</tr>
<tr>
<td>Cum Recycle</td>
<td>30,000,000 MCF</td>
</tr>
<tr>
<td>Cum Purchase</td>
<td>39,000,000 MCF</td>
</tr>
<tr>
<td>Cum Water</td>
<td>7,500,000 BBLS</td>
</tr>
<tr>
<td>Cum Oil</td>
<td>2,000,000 STB</td>
</tr>
<tr>
<td>Current Pattern Total HCPVI</td>
<td>59.48%</td>
</tr>
<tr>
<td>Current Pattern Oil Rec</td>
<td>5.61%</td>
</tr>
<tr>
<td>Oil Rec to HCPVI</td>
<td>0.094 &lt; 0.10</td>
</tr>
<tr>
<td>Field Total HCPVI</td>
<td>38%</td>
</tr>
<tr>
<td>Field Oil Rec</td>
<td>3.6%</td>
</tr>
<tr>
<td>Total HCPVI to Oil Rec</td>
<td>0.09 dmsless</td>
</tr>
<tr>
<td>Gross Utilization</td>
<td>35 mcf/stb</td>
</tr>
<tr>
<td>Net Utilization</td>
<td>20 mcf/stb</td>
</tr>
</tbody>
</table>

### Rate Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Oil Rate</td>
<td>2,600 STBPD</td>
</tr>
<tr>
<td>Daily Purchase</td>
<td>25 mmscfpd</td>
</tr>
<tr>
<td>Daily Recycle</td>
<td>55 mmscfpd</td>
</tr>
<tr>
<td>Current Pattern HCPVI/day</td>
<td>0.07%</td>
</tr>
<tr>
<td>HCPV oil recovered/day</td>
<td>0.007%</td>
</tr>
<tr>
<td>HCPV rec/inj/day</td>
<td>0.11 &gt; 0.083</td>
</tr>
</tbody>
</table>
Dimensionless Top Performer

Dimensionless Comparison LCU Phase 3 vs. LCKT

- CO2 Injected (% of HCPV)
- Oil Recovery (% of HCPV)

LCU Phase #3 vs. LCKT Field
DRI's Tertiary Fields Relative Capital Hurdles

- Brookhaven
- Eucutta
- Little Creek
- Mccomb Field
- Tinsley
- West Mallalieu
- Lockhart Crossing

Relative Capital Cost per OOIP

Challenge Comes with Smaller Scale
**Reservoir Pressure Surveillance**

**IWR**

- IWR = CO2 (RB) ÷ (Gas (RB) + Oil (RB) + Water (RB))
- IWR (instantaneous) delivers direction your reservoir pressure is going at a given instant.
- IWR (cumulative) delivers the relative reservoir pressure from the point in time the accumulation began.

**Net Cum Fluid**

- Net Cum Fluid = Cum CO2 RB – Cum (Gas (RB) + Oil (RB) + Water (RB))
- Delivers direction the reservoir pressure is going at a given instant by the slope of the curve.
- Delivers the relative reservoir pressure from the point in time the accumulation began.
- Delivers magnitude of fluid thus the magnitude of relative pressure change based on reservoir size.
Fluid to Pattern Allocation

- Fluid dynamics within a reservoir are difficult to calculate

- Pattern allocation is a simple method used to account / estimate source of fluid flow
  - Used for Net Cum Fluid calculation
  - Serves as guides to remaining saturations within patterns

- There are many methods for allocation

**Geometric allocation**

>Splits Pattern 1 and 2 production of fluid evenly

\[
\text{Producing Well C allocation to Pattern 1} = \frac{\text{# of wells}}{\text{# of patterns sharing the well}} = \frac{1}{2} = 50\% 
\]

**HCPV & I allocation**

>Splits Pattern 1 and 2 production based on injection rate and magnitude of HCPV

\[
\text{Producing Well C allocation to pattern 1} = \frac{\text{HCPV1} \cdot \text{Injection rate1}}{\text{HCPV1} \cdot \text{Injection rate1} + \text{HCPV2} \cdot \text{Injection rate2}} = \frac{10 \cdot 150}{10 \cdot 150 + 5 \cdot 100} = 75\% 
\]
Net Cumulative Fluid Comparing Allocation Methods

Date


Net Cum Fluid (RB)

0 200,000 400,000 600,000 800,000 1,000,000 1,200,000 1,400,000 1,600,000 1,800,000 2,000,000

Thom 1 I&HCPV

Thom 1 Geo

5,847 psi 1,050 MRB

5,506 psi 1,016 MRB

1,400 MRB

1,600 MRB

5,847 psi 1,050 MRB

5,506 psi 1,016 MRB
Asset Optimization

- Maximize oil recovery magnitude

- *Minimize recovery time (acceleration)*

- *Minimize cost*

- Maximize delay in capital outlays
Optimize recovery time and cost

Maximize Pressure Drop and Conductivity

Facility
Minimize cost of attaining pressure drop and conductivity

Constrained by: coning, MMP, and sand production
Net Cumulative Fluid Thom #1 Pattern

- **Date:**
  - 12/7/07
  - 1/7/08
  - 2/7/08
  - 3/7/08
  - 4/7/08
  - 5/7/08
  - 6/7/08
  - 7/7/08
  - 8/7/08
  - 9/7/08
  - 10/7/08
  - 11/7/08
  - 12/7/08
  - 1/7/09
  - 2/7/09
  - 3/7/09
  - 4/7/09
  - 5/7/09
  - 6/7/09
  - 7/7/09
  - 8/7/09
  - 9/7/09
  - 10/7/09
  - 11/7/09
  - 12/7/09
  - 1/7/10
  - 2/7/10

- **Net Cum Fluid (RB):**
  - 0
  - 200,000
  - 400,000
  - 600,000
  - 800,000
  - 1,000,000
  - 1,200,000

- **Open Wells:**
  - 5,200 psi

- **Optimum reservoir Management?**

- **Open chokes**

- **Fill Up**

- **1,050 MRB**
  - 5,847 psi

Denbury Resources Inc. 22
Lockhart Crossing CO2 EOR

Lockhart Crossing Fluid Rates

Induced Acceleration

- Oil (bpd)
- CO2 Injection (mscfpd)
- CO2 Production (mscfpd)
- CO2 Purchase (mscfpd)
Opening of Chokes

Cum Net Fluid Injected

Thom #1

Net Cum Fluid

Injection Rate
Results of choke changes

**Lockhart Choke Size Increase**

<table>
<thead>
<tr>
<th>% increase</th>
<th>Choke Size</th>
<th>Oil Rate</th>
<th>CO2 Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>310</td>
<td>1441 bopd</td>
<td>50 mmscfpd</td>
</tr>
<tr>
<td></td>
<td>374</td>
<td>2284 bopd</td>
<td>65 mmscfpd</td>
</tr>
</tbody>
</table>

- **Choke Size**: 310 vs. 374 mmscfpd
- **Oil Rate**: 1441 bopd vs. 2284 bopd
- **CO2 Injection**: 50 mmscfpd vs. 65 mmscfpd

Lockhart’s Bar Injection Hurdle

- Bar Injection wells injecting at ~5 mmscfpd

- Channel wells maximum injection rate ~17 mmscfpd down 2-7/8” tubing

- For the Bar Injection Wells the formation is the bottle neck
  - (not the 2-7/8” tubing)

- Remaining Lockhart development is in the Bar Formation

- NPV is hindered due to a choke at the formation
  - Stimulation is not currently an option
### Horizontal vs. Vertical

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Formation Contact</td>
<td>200’</td>
<td>40’</td>
</tr>
<tr>
<td>Injection Rate</td>
<td>5X</td>
<td>1X</td>
</tr>
<tr>
<td>Production Rate</td>
<td>5X</td>
<td>1X</td>
</tr>
</tbody>
</table>

\[
\frac{K \cdot H \cdot dp}{u \cdot \ln \left( \frac{re}{rw} \right)}
\]

Lateral Length = 1000’
Horizontal Well / Asset Optimization

Well Count → Cost

Oil Rate Rate → Revenue Acceleration → NPV

Fluid Rate → Facilities → Cost

Asset Harmony (where NPV is maximum)
Horizontal Well Asset Optimization

Lockhart Future Development Economic Comparison

Lockhart Incremental Future Development PV10 with vertical well development

Total Future Horizontal Well Count

PV10 (M$)

Injection rate per horizontal (mmscfpd)
Economically Efficient Reservoir Operations Results

**Lockhart Crossing Fluid Rates**

- Induced Acceleration

**Value Realized through Induced Acceleration**

- Incremental Value Associated with Acceleration
- Base Value

**Legend**
- Oil (bpd)
- CO2 Injection (mscfpd)
- CO2 Production (mscfpd)
- CO2 Purchase (mscfpd)
Today’s presentation covered some of the topics in the circled area.

There’s significantly more value to be added to the asset outside (and inside) that circle.

Surveillance, data analysis, and system optimization to maximize asset value.
Questions