BOLD IDEAS FOR ENERGY

Panny LEAD Pilot
Experimental Scheme Approval No. 12283C

Dec 10, 2018 CONFIDENTIAL
Agenda

Subsurface
1. Background
2. Geoscience
3. Drilling & Completions
4. Artificial Lift
5. Instrumentation
6. 4-D Seismic
7. Scheme Performance
8. Future Plans

Surface
1. Facilities
2. Measurement & Reporting
3. Water
4. Environmental
5. Compliance
6. Future Plans
Subsurface
Background
Background

The Panny LEAD (Low-Pressure Electro-Thermally Assisted Drive) Pilot project was conducted in the W½-34-094-07W5 Panny area within the Peace River Oil Sands Area. The pilot surface location was at 13-34-94-7W5. This pilot project evaluated the potential of a low-pressure process that utilizes downhole electric heaters combined with water and/or solvent injection to recover bitumen from the Bluesky formation. This Bluesky formation has an overlying gas cap that had been produced, and so exhibits depleted pressure. This technology has the potential to be commercialized in both the Panny area as well as many other bitumen/heavy oil reservoirs in Alberta.
Panny CHS Test project site is 77 km north of Red Earth Creek, AB
Off of Highway 88 (fully paved), 7 km of high grade gravel road to site
In the Peace River Oil Sands Area
Panny Map
LEAD Pilot Stage 1 CHS – Objectives / Scope

– Primary Objective:
  • Collect significant pressure, temperature, and oil production data in response to conductive heating to tune simulator assumptions and geological understanding

– Secondary Objective:
  • Obtain experience operating electrical resistance heaters

– Scope:
  • Install heater in existing 4-34 Hz well
  • Drill 2 observation wells and install pressure & temperature instrumentations
  • Install onsite electrical generator
  • Use all existing production equipment currently on-site
  • Conduct minimum 3 heating & production cycles as required to obtain necessary data
  • Reduce bitumen viscosity using electric cables and possibly injection of water/solvent
  • Have concurrent production of bitumen and associated gas cap
  • Understand lateral and vertical heat conduction and convection
  • Demonstrate commercial production and ultimate recovery factor
  • Gather data for accurate numerical simulation to optimize commercial process
Regulatory Work

• Experimental Recovery Scheme Approval
  – July 24, 2014: Obtained Experimental Scheme Approval No. 12283
    • Full LEAD Pilot design
  – November 13, 2014: Experimental Scheme Amendment Submitted for LEAD Pilot Stage 1
    • Updated to include Stage 1 and Stage 2 LEAD Pilot designs
  – September 28, 2016: Experimental Scheme Approval 12283B
    • Approval to inject C5+ solvent
  – May 26, 20117: Experimental Scheme Approval 12283C
    • Extended confidentiality and validity to July 24, 2019

• EPEA
  – June 2, 2014: Obtained AER EPEA Approval No. 299681-00-00
  – September 29, 2014: Received a ‘No Objection Letter’ from the AER for LEAD Pilot Stage 1 design
  – February 2, 2015: Groundwater Monitoring Program Proposal approved by AER

• Facility Licence
  – Facility considered a Single Well Bitumen Battery, and therefore required no facility licence

• Injection Well Approval
  – August 5, 2015: Obtained D51 Class IV Injection Well Approval for 100/04-34-094-07W5 horizontal well (a condition of the Experimental Scheme Approval for heater operation) Approval No. 12283
  – September 21, 2016: Obtained D51 Class III & IV Injection Well Approval for 100/04-34-094-07W5 horizontal well (a condition of the Experimental Scheme Approval for heater operation) Approval No. 12283B (as amended)
Geoscience
McDaniel & Associates conducted an independent resource assessment as of December 31, 2011.

Resources assigned based on CSS recovery process.

<table>
<thead>
<tr>
<th>Category / Level of Certainty</th>
<th>Discovered Bitumen Initially In-Place (MMbbl)</th>
<th>Assigned Recovery Factor</th>
<th>Contingent Resource (MMbbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Estimate</td>
<td>509.2</td>
<td>10.0%</td>
<td>50.9</td>
</tr>
<tr>
<td>Best Estimate</td>
<td>755.0</td>
<td>17.5%</td>
<td>132.1</td>
</tr>
<tr>
<td>High Estimate</td>
<td>983.0</td>
<td>25.0%</td>
<td>245.8</td>
</tr>
</tbody>
</table>
Net Bitumen Pay Map

Net Bitumen Pay
CI 2m

Minimum thickness
Logs NDE

0.4 m
Bitumen Structure Map

Bitumen Structure
CI 0.5m

Minimum thickness
Logs NDE
Wilrich Isopach – Top of Bluesky
100/13-34-094-07W5/00 - Type Well

Top Bluesky

Base Bluesky

Gething

Paleozoic

Gas Cap

Bitumen Leg
Overall rare to moderate low angle, planar to wavy mud laminations.
Panny Bluesky Reservoir Overview

Depth = 315 mTVD
Porosity = 27%
Oil saturation = 67%
Temperature = 11°C
Density = 11° API
Viscosity = 50,000 cP at 11°C average
Horizontal permeability = 1,400 mD
Vertical permeability = 900 mD
Gas cap = Avg 3m, up to 6m
Bitumen pay = Avg 12m, up to 16m
Gas cap pressure = 500 kPaa
Bitumen pressure = ~1,200 kPaa (gradient exists)
Bitumen leg divided into 2 gross reservoir quality facies: F1 and F3 (F3U and F3L).
Core Analysis Summary – Reservoir Facies

**Bluesky Oil F-3 Facies (primary bitumen target)**

- **Porosity** = 27%
- **Horizontal permeability** = 1,400 mD
- **Vertical permeability** = 900 mD
- **Oil saturation** = 67%

- **Bluesky facies based on petrographic and core data**
- **Chert Arenite Lithology** – excellent reservoir rock. Minor, localized, non extensive shale partings and laminae seen near base of Bluesky sand. Localized minor shale clast blebs.
- **Slight coarsening upward sequence observed.** Grain size range: V Fine - Fine at base (facies F1) Fine- Lower Medium (facies F3, targeted bitumen leg)
- **Best reservoir permeability / porosity relationship in facies F3.**
Core Analysis Summary – Porosity vs Permeability

Horizontal Permeability vs Porosity

Data Circles:
- Series 1
- Facies F3 U
- Facies F3 L
- Facies F1
- Gas Cap

Data Squares:
- 2/12-34-94-7w5

Scale:
- X-axis: 0.2 to 0.4
- Y-axis: 10 to 10000
Porosity Relationships

Porosity Sandstone Classification Diagram
Bluesky Formation; Panny Field
- 100/06-34-094-07W5
- 102/12-34-094-07W5

Intergranular Porosity
- GR-001
- GR-002
- GR-003
- GR-004
- GR-005
- GR-006
- GR-007
- GR-008
- GR-009
- GR-010

Grain Moldic Porosity
- GR-004
- GR-005
- GR-006
- GR-007
- GR-008
- GR-009
- GR-010

Microporosity

Log and core porosity increases
H2O saturation decreases
K increases
H2O production decreases
Reservoir quality increases

Log and core porosity decreases
H2O saturation increases
K decreases
H2O production increases
Reservoir quality decreases

Porosity Relationships

Intergranular/Intercrystalline
Macro Porosity

Grain/Feossil Moldic
Porosity

Microporosity

GR 24099 2015
\( \phi_{ca} \): Total Core Analysis Porosity
\( K_{ca} \): Core Analysis Permeability

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Log and core porosity decreases
H2O saturation increases
K decreases
H2O production increases
Reservoir quality decreases
Mineralogy

**COMPANY:** Perpetual Energy Inc.  
**WELLS:** 100/06-34-094-07W4 & 102/12-34-094-07W5M  
**FILE:** GR 24899 2015  
**FORMATION:** Bluesky  
**FIELD:** Panny

### TABLE 4
Mineralogy Calculated from Thin Section Modal Analysis

<table>
<thead>
<tr>
<th>GR Sample #</th>
<th>Quartz (%)</th>
<th>Feldspar (%)</th>
<th>Dolomite (%)</th>
<th>Calcite (%)</th>
<th>Siderite (%)</th>
<th>Pyrite (%)</th>
<th>Clay (%)</th>
<th>Glauc (%)</th>
<th>Phos (%)</th>
<th>CD (%)</th>
<th>HM (%)</th>
<th>Grain Density Calculated (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR-001</td>
<td>71.6</td>
<td>4.4</td>
<td>2.3</td>
<td>0.3</td>
<td>1.3</td>
<td>0.3</td>
<td>15.6</td>
<td>3.3</td>
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<td>GR-002</td>
<td>64.0</td>
<td>5.5</td>
<td>3.7</td>
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<td>-</td>
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<tr>
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<td>7.0</td>
<td>0.7</td>
<td>-</td>
<td>-</td>
<td>16.4</td>
<td>1.0</td>
<td>0.3</td>
<td>0.3</td>
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<td>GR-007</td>
<td>67.4</td>
<td>6.2</td>
<td>1.3</td>
<td>0.7</td>
<td>0.3</td>
<td>tr</td>
<td>20.8</td>
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<td>2682</td>
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<td>GR-008</td>
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<td>0.0</td>
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<td>21.7</td>
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<td>GR-010</td>
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<td>0.3</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>2686</td>
</tr>
</tbody>
</table>

Glauc (%) - Glaucite  
Phos (%) - Phosphate  
CD (%) - Carbonaceous Detritus  
HM (%) - Heavy Minerals  
tr - trace
Reservoir Sensitivity

- High sensitivity and incompatibility with HCL, HF acid systems.
- Slight to moderate sensitivity to water based fluids – clay sloughing and fines migration.
- Slight to moderate potential for permeability reduction related to fines migration.
- Moderate potential for scale formation with water production.
- Moderate potential for clay expansion.
- Potential for sand migration and production.
Viscosity gradation observed.
Drilling and Completions
Stage 1 CHS Test Layout

- **CHS Test:**
  - Used existing Hz 4-34
  - Drilled 2 Obs wells
    - Drilled, cored, logged, cased with instrumentation
      - ~7 pressure sensors
      - ~19 temp sensors

- **Obs#1:** 12-34
- **Obs#2:** 6-34

- **Hz Well**
  - 100/04-34-094-07W5/00

- **Gas Pipeline**
  - 8-33 to 13-34

**Pressure Sensors**

**Temp Sensors every ~2m**
Horizontal Well Completion

**Electrical Heaters**

- 2 x MI (Mineral Insulated) Electric Downhole Heater Systems
- A/C 3 phase (3 cables each), wye-spliced at ends
- ~600 W/m total nominal output (~300 W/m each x 2)
- Configuration:
  - ESP cables, spliced to
  - Cold Lead MI cables, spliced to
  - Hot Lead MI cables
  - Splices offset from each other
- Control: Temperature or kW set points
PEOC Panny 12-34-94-7W5

- Spudded Feb 18, 2015; Rig released Feb 24, 2015.
- Drilled surface, ran 219.1mm (9 5/8") J-55 ST&C surface casing set at 118m.
- Drilled out with directional tools, KOP at 213m, build hole angle to 7° to core point at 301.4m
- Cored from 301.4m to 342m and had 99.6% core recovery:
  - Cut core #1 and then RIH with survey tools to take ranging shot
  - Cut core #2 and then RIH with survey tools to take ranging shot
  - Cut cores #3-6, RIH with directional drilling BHA and Range to 4-34
- Drilled to 348.5m (0.5m from TD) when well lost mud circulation, cured losses:
  - Bit was 8.5m into the Paleozoic, 0.5m away from planned TD
- Open hole logged.
- Ran 114.3mm (4.5") L-80 SLHT casing with sensors, cemented with Thermal-40 cement with 4.0 m³ returns.
- Final ranging shows 3.58m separation.
PEOC Panny 6-34-94-7W5

- Originally licenced as 5-34-94-7W5.
- Drilled surface hole and kicked-off directional at 100mMD; landed surface casing at 165mMD.
- Drilled out with directional tools and build hole angle to 9° by core point at 299.7m
- Cored from 299.7m to 341.2m and had 99.4% core recovery:
  - Cut core #1 and then RIH with survey tools to take ranging shot
  - Cut core #2 and then RIH with survey tools to take ranging shot
  - Cut cores #3-6, RIH with directional drilling BHA and Range to 4-34
- Lost mud circulation in Paleozoic, cured losses.
- Open hole logged.
- Ran 114.3mm (4.5”) L-80 SLHT casing with sensors, cemented with Thermal-40 cement.
- Cement briefly lost circulation, top filled cement ~50m
- Ran cement bond long – good cement.
- TD crossed into LSD 6-34; well license amended.
- Final ranging shows 3.01m separation.
Artificial Lift
**Artificial Lift**

- Pump Seating Nipple for Insert Rod Pump
  - 30-250-RWAFR-20-3
  - Sucker rods w/ sinker bars
  - Landed at 60° inclination in intermediate casing tangent section
- Wellhead mounted hydraulic stroking unit
Reciprocating pump utilized.
No issues experienced with artificial lift system.
38 m3/d peak rates @ 350 kPaa sandface pressure.
Instrumentation
Instrumentation

- 1 Fiber Optic Distributed Temperature Sensing (DTS) String
  - 1m resolution from wellhead to end of heater
  - Max operating temperature 300°C
  - Scanned every 5 min
  - Heaters operate with feedback from DTS
- 4 Thermocouples (redundancy for DTS)
- 2 Bubble Tubes using N₂ gas
Observation Wells

- 9 5/8” surface, 4 1/2” production casing
- Ranged wells to land close to horizontal well
  - Obs 6-34: 3.01m separation
  - Obs 12-34: 3.58m separation
- Cored entire Bluesky/Gething formation
  - Avg 100 core sample points per well
  - Petrology lab work
- Log with typical log suite plus CMI log on one well
- All instrumentation clamped to outside of production casing and cemented-in-place
- 7 pressure and 19 temperature points per well
- Solar powered RTU for data recording, download with USB stick weekly
4-D Seismic
No seismic / microseismic utilized directly for this project.
Scheme Performance
• LEAD Pilot Stage 1: Cyclic Heating Stimulation (CHS) Test -
  – First heat on Oct 14, 2015
  – First production on Mar 1, 2016
  – Cycle 1 - Produced for 6 weeks, followed by 2 week temperature falloff
  – Cycle 2 - Heated for 6 weeks, then produced
  – Cycle 2 - Produced while heating.
  – Cycle 3 - Solvent injection; aborted due to asphaltene deposition.
  – Toluene soak and clean out
  – Cycle 4- Produced while heating
  – Heater off May 06, 2017
  – Excellent data collected during heating phase, production phase and shut-in
  – Positive production results
  – Incorporate data into refined reservoir model to evaluate additional pilot work and commercial designs
Operations Overview – Observation Wells

- Observation wells
  - Drilled March 2015
  - 100% of sensors are working (52 total)
  - Measurements recorded hourly
  - Thermocouples have allowed accurate reservoir thermal conductivity tuning in the model
  - Reservoir thermal conductivity higher than previously assumed
  - Pressure gauges have provided important insight into vertical and horizontal permeabilities
  - Reservoir pressures took ~3 months post-drilling to equalize
Lessons Learned

- Reservoir
  - Seven pressure sensors per observation well have provided necessary insight into the non-linear bitumen pressure gradient
  - Pressure response during heating has been less than expected, and pressure depletion during production has also been less than expected
    - significant upside which has contributed to production outperforming expectations
  - Observation well thermocouples have allowed improved thermal conductivity estimates
  - Heater operation during production (“flow assurance”) appears to increase production rates significantly, and enables continued heating of the reservoir during production cycle
    - shortens heating cycle since continue to heat the reservoir during production
Pilot was terminated May 06, 2017 after failure of the second heater. Perpetual continuing to gather pressure and temperature data at the observation wells. No further production is anticipated.

This is the final presentation for this pilot.
Surface
Facility
13-34-094-07W5
- Emulsion goes directly to 750 bbl production and sales tanks
- Treating of oil to pipeline spec (<0.5% BS&W) is achieved through demulsifier injection near the wellhead and tank heating to temperatures of 60-80°C
Facility Photos

- Communications Tower with Cell Booster Antenna
- 50 kW Generator Package (5 x 200kW Turbines)
- Piping Utilidor
- Tank Farm including Production and Sales Tanks
- 95 HP Booster Compressor
- 1 MW Generator Package (5 x 200kW Turbines)
- 13-34-94-7W5 Vertical Wellhead
- 4-34-94-7W5 Horizontal Wellhead
- 65kW Backup Generator
- Nitrogen Packs for Bubble Tubes
- MCC with 2 x Heater Transformers & Controllers, and Data Capture Computers
- Hydraulic Pumping Skid

**Site Features:**
- Communications Tower
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- Tank Farm including Production and Sales Tanks
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Measurement and Reporting
Measurements

-8.3 kPa

-1375.0 kPa

Rate: 0.06

Rate: 0.84

From 08-33

EG-9000 Generator

KP-8000 Compressor

V-1200

P-400 Hydraulics Skid

ST-7100

ST-7200

V-1100
**Measured Data – Production and Observation wells**

<table>
<thead>
<tr>
<th>100/04-34-094-7W5</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Casing pressure</td>
<td>kPaa</td>
</tr>
<tr>
<td>Tubing pressure</td>
<td>kPaa</td>
</tr>
<tr>
<td>Sandface pressure</td>
<td>kPaa, bubble tube</td>
</tr>
<tr>
<td>Liquid rate</td>
<td>Tank height, m</td>
</tr>
<tr>
<td>Oil Rate</td>
<td>Prorated from spin cut</td>
</tr>
<tr>
<td>Produced gas rates</td>
<td>Meter, m3/d</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>Thermocouples, DTS – Deg C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>100/13-34-094-7W5 - Surface Location</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel gas rate</td>
<td>Meter, m3/d</td>
</tr>
<tr>
<td>Three Phase Currents</td>
<td>Meter, A</td>
</tr>
<tr>
<td>Three Phase Voltages</td>
<td>Meter, V</td>
</tr>
<tr>
<td>Power</td>
<td>Calculated, W</td>
</tr>
<tr>
<td>Generator data</td>
<td>Measured</td>
</tr>
</tbody>
</table>

All acquired data were stored in the ClearScada

<table>
<thead>
<tr>
<th>100/12-34-094-07W5 &amp; 100/06-34-094-07W5 – Observation Wells</th>
<th></th>
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<tbody>
<tr>
<td>Reservoir Pressure</td>
<td>ERE, kPaa</td>
</tr>
<tr>
<td>Reservoir Temperatures</td>
<td>ERE and Thermocouples – Deg C</td>
</tr>
</tbody>
</table>
The primary operating constraint was the fiber optic DTS temperature limitation – 300°C maximum.
Secondary operating constraint was intermediate casing temperature - 140°C maximum during production.
Even with active hot spots, average temperatures increased slowly over time.
The DTS measured heater temperature with heaters on, and sandface temperature with heaters off. Simulation assumes sandface temp; difference between the two is primarily the fluid in the wellbore acting as an insulator.
Water cuts obtained from spin cut averaged ~5% BS&W with only trace sand
Running the heaters at maximum power within constraints during production contributed to increased performance
The majority of the trucked-out oil met pipeline specifications without the need for diluent
- P4 sensors horizontally across from the 4-34 Hz well showed good response to heating and production but higher than modelled pressures after the first cycle of heating.
- Sensors above and below showed pressure responses that suggest baffling or compartmentalization.
- Slow pressure decline deemed related to stronger production performance than originally expected.
Bitumen Treatment
Successfully produced sales spec oil with existing facility process

Water Treatment
No water injection or water treatment required for CHS test Phase 1

Gas Conservation
Power generation utilized natural gas from the Panny gas field
Measurement and Reporting

Production Volume:
Fluid rate measured daily based on tank levels.
Oil and Water prorated from spin cut of well sample.

Injected volume:
Volume of injected fluid measured using supply tank meter.
Environmental
Obtained and complied with EPEA approvals.
Compliance
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