Weyburn Unit
Extending The Horizon

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Weyburn Unit General Overview

- Significant and predictable base production
  - 24,000 bbls/d liquids (including NGLs) with <5% decline

- Large High Quality Resource on continuous land base
  - 1.4 B bbls OOIP in Midale
  - Weyburn Unit unitized lands total 22,000 ha
  - 30 API Oil (2-5% sulphur content)

- 18 years CO2 EOR Development
  - More than 80 CO2 EOR patterns rolled out to date
  - Over 400 horizontal wells drilled since 2000
  - Secure CO2 supply (2 suppliers)
  - Continuous improvement in CO2 EOR implementation and flood optimization are significantly extending the life of the field

- Whitecap Resources began operating the Weyburn Unit in 2018
  - Strong commitment to new EOR investment within Unit
    - New EOR Rollouts
    - Flood Optimization
    - Expanded NGL capture
  - Continue to investigate new CO2 EOR opportunities outside of the Unit to leverage existing CO2 supply, new carbon taxes, and our technical expertise
Geological Overview

- Capped by Midale Evaporite and regional Jurassic Red Beds
- Frobisher Marly + Evaporite form base seal

<table>
<thead>
<tr>
<th>Midale Reservoir</th>
<th>Marly</th>
<th>Vuggy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Net Pay</td>
<td>(m)</td>
<td>4</td>
</tr>
<tr>
<td>Porosity</td>
<td>(%)</td>
<td>25</td>
</tr>
<tr>
<td>Permeability</td>
<td>(mD)</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Net values, stressed Perm
Reservoir Characteristics

- Stacked, shallowing-upward cycles (subtidal to supratidal in origin) were deposited on a regionally extensive, gently dipping carbonate ramp.
- Original drilling target = permeable Vuggy Shoal beds; today’s CO₂ flood largely targets the relatively unswept Marly dolomite beds.
- Local baffles and quality of reservoir rock controls sweep efficiency: strong focus on flood management and well configurations that promote good conformance in all Midale zones.
- Effective sweep of tighter Marly zones achieved without overcapitalizing through use of multi-leg wells, Hz re-entries, and select vertical development.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Marly</th>
<th>Vuggy Intershool</th>
<th>Vuggy Shoal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone</td>
<td>M1, M3</td>
<td>V1</td>
<td>V2-V6</td>
</tr>
<tr>
<td>Porosity</td>
<td>15-37% (26% avg.)</td>
<td>2-15% (10% avg.)</td>
<td>5-20% (10% avg.)</td>
</tr>
<tr>
<td>Permeability</td>
<td>1-100 (10 avg.)</td>
<td>0.1-20 (1 avg.)</td>
<td>1-500 (20 avg.)</td>
</tr>
<tr>
<td>Fracture Density</td>
<td>Low (2-10)</td>
<td>High (&lt;1)</td>
<td>Moderate (1-3)</td>
</tr>
</tbody>
</table>
Fracture style and intensity is dictated by timing & origin of stresses, bed properties & thickness (mechanical stratigraphy)

Multiple sets of fracture scales and styles contribute to reservoir permeability and communication

- Natural, injection induced, abandonment

Natural and induced sets contribute to a dominant NE-SW anisotropy

Most natural fractures are subvertical and terminate at bed boundaries

- Contributes to both heterogeneity and homogenization of reservoir

End product is a complex triple porosity system
Weyburn Carbon Capture, Utilization & Storage (CCUS)

- Initiated carbon dioxide (CO₂) flood to enhance oil recovery (EOR) in Oct 2000
- Have safely stored more than 30 million tonnes of CO₂
- Store an additional two million tonnes of CO₂ each year
- Site of an international research project, IEA GHG Weyburn-Midale CO₂ Monitoring & Storage Project; led by the Petroleum Technology Research Centre (PTRC) in Regina
- Estimate 55 million tonnes of potential CO₂ storage capacity
- The Weyburn Unit has hosted over 250 groups from 20 countries
CO₂ from SaskPower’s (SPC) Boundary Dam Power Station

Rafferty CO₂ pipeline owned & operated by the Weyburn Unit

CO₂ from the Great Plains Synfuels Plant in Beulah, North Dakota

Pipeline and plant owned & operated by the Dakota Gasification Company (DGC)

Central Receiving Terminal

Both DGC & Rafferty CO₂ pipelines terminate at 06-34-06-13

CO₂ delivers directly into the CO₂ injection system at full pressure, blends with recycled CO₂ from Weyburn Plant
Development and Production History and Recovery

- **Primary & Waterflood (~20% Current)**
- **Pre-CO₂ Vertical & Hz Infills (~8% Current)**
- **CO₂ EOR + NGL (~6% Current)**
Weyburn Flood Evolution

- **Waterflood**
  - Inverted 9 spot
  - Line drive
  - Vertical/Horizontal infill drilling

- **CO₂ Separate/Simultaneous Injection (“SSWG”)**
  - Separate and simultaneous injection of water and CO₂
  - Central CO₂ injection into Marly with vertical injection in Vuggy to control mobility
  - Only used Phase 1A & 1B (shoal)

- **CO₂ Water Alternating Gas (“WAG”)**
  - Alternating the CO₂ with the water injection
  - Initially central vertical injectors with horizontal Marly and vertical Marly/Vuggy producers
  - CO₂ Placement Enhancement (“COPE”) program converts central injection to horizontal
  - Edge ½ pattern injectors in new rollouts now horizontal
  - Wide leg injectors

Horizontal wells have improved injectivity and sweep in lower kH Marly in a cost effective manner.
Mature rollouts are performing better than expected and new rollouts have been successful in more challenging reservoir
### Weyburn Unit Infrastructure Overview

<table>
<thead>
<tr>
<th></th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Producing Formation:</strong></td>
<td>Mississippian, Midale</td>
</tr>
<tr>
<td><strong>Depth:</strong></td>
<td>1,450 m</td>
</tr>
<tr>
<td><strong>Discovered:</strong></td>
<td>1954</td>
</tr>
<tr>
<td><strong>Oil Quality:</strong></td>
<td>25-35 °API</td>
</tr>
<tr>
<td><strong>Area:</strong></td>
<td>22,000 hectares (85 sq mi.)</td>
</tr>
<tr>
<td><strong># Production Wells:</strong></td>
<td>727 (435 Hz)</td>
</tr>
<tr>
<td><strong># Injection Wells:</strong></td>
<td>309 (100 Hz)</td>
</tr>
<tr>
<td><strong>Pipeline:</strong></td>
<td>1,625 km</td>
</tr>
<tr>
<td><strong>Oil Rate:</strong></td>
<td>23,000 bbl/d</td>
</tr>
<tr>
<td><strong>NGL Rate:</strong></td>
<td>700 bbl/d</td>
</tr>
<tr>
<td><strong>Water Injection:</strong></td>
<td>175,000 bbl/d</td>
</tr>
<tr>
<td><strong>CO₂ Injection:</strong></td>
<td>350 mmcf/d</td>
</tr>
</tbody>
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**Map Image:** Weyburn Unit Central Battery 5-16-6-13W2

**Map Legend:**
- Weyburn Unit
- Oil Effluent Pipeline
- Market Oil Pipeline
- CO₂ Injection Pipeline
- Supply CO₂ Pipeline
- Water Pipeline
- Central Battery

**Map Details:**
- Regina
- Saskatchewan
- Canada
- Manitoba
- Montana
- North Dakota
- USA
- CO₂
- Beulah
Weyburn Plant Facilities

- 2 free water knock out vessels, 4 treaters
- 20,000 bbl oil storage, 50,000 bbl H₂O storage
- 50,000 hp sour CO₂ gas compression
  - 2 x 100 mmcf centrifugal (2 section, 7 stage)
  - 2 x 25 mmcf recips, 3 stage machines
  - 2 x 12 mmcf recips, battery gas compressors
- 2 x 100 mmcf/d CO₂ dehydrators
- 14,000 hp water injection pumps (5 - 7 stage centrifugal pumps)
- 2 - 138kV to 4160V, 1 – 138 kV to 13.8 kV transformers
- NGL plant (~600 bbl/d C4, 200 bbl/d C3)
- Auxiliary systems: heat medium systems, instrument air, back up utility generators, N₂ generators, seal gas, lube oil, SaskEnergy fueled flare systems, etc,
- 100% electric drivers, no gas drivers
- Delta V DCS plant operation installed 2008 – 2010, independent SIS SIL level 3 designed system, separate F&G system (PLC)
- 24 hour control room monitors & operates plant equipment plus field production & injection wells and facilities
Weyburn Field Facilities

- Approximately 530 pumpjacks, 100 ESPs, some flowing wells, 100% electric drivers
- 80 production and 54 injection satellites
- 24hr surveillance via SCADA
  - 99% of production
  - 100% of Water & CO$_2$ injection
- EOR production satellites are fully automated & able to do short duration statistical well testing & significantly more wells per test separator (up to 50 wells)
- 3250 km of flowlines in 85 sq miles (~50/50 active & abandoned)
  - Water injection – polylined steel & fibrespar
  - CO$_2$ Injection – bare steel
  - Emulsion gathering – fibrespar, fibreglass, polylined steel, bare steel
  - EOR Gas Gathering – polylined steel
- 68 km high pressure Rafferty CO$_2$ pipeline from Estevan
Well Servicing

- Well control is critical
- Specialized well control techniques to deal with high reservoir pressures and liquid CO$_2$ present at production wellbore conditions
  - Access to variety of kill fluid densities is critical
  - Well Servicing activities require engineering support to manage reservoir pressures in order to minimize kill fluid costs
  - Routinely modify injection prior to downhole repairs or utilize coiled tubing or snubbing services.
  - Experienced consultants and rig crews are able to recognize potential well control issues before they become a problem
- Full time flushby unit deals with pumping/plugging issues by circulating with oil, flowing back to testers and or treating with chemical
- Wax/asphaltene deposits on rods and in tubing may require chemical treatment and occasionally removal by hand
- Wax and asphaltenes sometimes require specialized equipment (rod snubbers)

EOR service jobs require a line heater, portable separator and fuel supply ($C_3$) to enrich flared gas.
Operational Challenges - Problems

- **Asphaltene/Wax (60%/20%)**
  - Asphaltene more typical than Wax
  - Pump fouling/plugging
  - Rod hang-ups
  - Tubing/annular plugging

- **Solids (20%)**
  - Inorganic solids and scale
  - Formation fines up to large diameter rocks mobilized by gas and fluid
  - Inorganic fines combine with asphaltene and wax to form composite deposits
  - Hz section, tubing, and flowline plugging
  - Pump system wear/destructive failure

Above - just thought I would share, This Photo is from the previous ESP and is the bottom of the handling pup. We didn’t see any build up on this ESP.
Operational Challenges - Solutions

- Engineering
  - Artificial lift design improvements
  - Failure tracking and analysis & design revisions
  - Monitoring and verification, MTTF, pump tear-down findings

- Drillout program

- Chemical treatment
  - Pre 2014, wax dispersant from a single supplier was used in production wells
  - Since 2014, asphaltene inhibitors from multiple suppliers have been used, and oil samples are collected to monitor asphaltene stability and adjust dosages
  - Sample monitoring data are cross referenced with plugging events
  - Improved inhibitor formulations have been developed, such as dual asphaltene inhibitor/demulsifier
  - Reduced frequency of capillary line plugging through design & operation changes
  - Asphaltene inhibitor squeeze treatments appear to be effective, but more expensive than continuous treatment
In spite of a challenging commodity price environment and a technically complex asset, the Weyburn Unit has been able to demonstrate continuous improvement in many areas of the operations.
Reservoir Simulation and Forecasting

- Importance of accurate forecasting
  - Base CO2 EOR predictions
  - CO2 EOR rollout Planning
  - Flood Optimization
  - Capital CO2 budget
  - CO2 recycle requirements

- Forecasting Tools
  - Historical Simulation Models
    - Older models 1976-2009
    - 2009 “Fine” Grid 2009 model
  - Course Grid Model
  - Streamline Model (3DSL)
  - Current Eclipse/IX Model
    - Fast and easy to use
    - Build close to geological grid
  - Analytical Forecasting Tools

Simulation and analytical tools used in conjunction to make development planning and reservoir management decisions
“LRP Tool” provides a range of future field performance by combining history of both performance trends and operations with reservoir simulation driven scenarios

- Uses fractional flow methods for forecasts, with future pattern processing rates and VRR as key inputs
- Geological variability and miscibility differences handled through the results of simulation sector models
- Forecasts generated for waterflood and EOR scenarios, allowing both short term (e.g. budget) and long term (reserves) objectives to be met and integrated
- Easy to use, flexible, quantitative

Other Excel based analytical tools

- Other similar tools have been developed in recent years to create incremental oil and CO2 purchase/recycle forecasts based on analog pattern behavior
- Main purpose is to allow exploitation engineers to make quick, high level initial forecasts that can later be verified and refined by simulation
Weyburn Streamline Model

- Streamline Model (3DSL)
  - Based on 2009 fine grid Eclipse model
  - Key pattern review tool
    - Easily integrated into Tableau surveillance tool
    - Helps to understand well level interactions
  - Reality check for simulation

Time 21703.0 days (2016/10/01 - 2016/11/01) - ff_omega.dat

Delta Time 22462.0 days (1953/01/01 - 2016/07/03) - 2016_Summer, FULLHIST_400, 2.dat

CO2

Water and CO2

Water
Eclipse Simulation Models

- **Current Eclipse/IX Model**
  - Fast and easy to use
  - Integration with Petrel
  - Build close to geological grid

- **Historical Simulation Models**
  - Older models 1976-2009
    - Intercomp ’76 (2 small areas)
    - 4 Area Models (’93-’97)
    - 2002 EOS Models
    - 2003-2005 New EOS larger area

- **2009 “Fine” Grid model**
  - 60x60m, 8 layer model
  - 1 million grid blocks
  - Single and dual porosity
  - 6 component EOS
  - Cut-outs from full field model used for rollout simulation

- **2011 Course Grid Model**
  - 400x400m, 2 layers
  - 3 pseudo wells/pattern
  - Dual porosity & dual perm
  - Upscaled to be flexible and fast
CO2 EOR Conformance

- **Conformance Challenges**
  - Natural and induced fractures, most prominent in NE-SW direction
  - High CO\(_2\) mobility → preferential perm to gas
  - Old vintage wells affect vertical containment
  - Tight well spacing leads to “short-circuiting” of CO\(_2\) between injectors and producers
  - CO\(_2\) in water affects carbonate composure over time, increasing permeability in limestone and leading to preferential Vuggy injection

**Simplified Example of Poor Conformance**

Ideal reservoir conformance: uniform distribution of CO\(_2\) sweeping oil towards producers at optimal rates under miscible pressure
Reservoir Surveillance

Phase Level Monitoring (groups of 4-8 patterns)

- Performance of EOR Rollout Phases reviewed monthly to determine if expectations are being met and to share new ideas and learnings from detailed pattern reviews
- Strong focus on phase level cash flow to ensure that CO2 usage is optimized and profit maximized across the field

Above CO2 rollout shows transition to positive cash flow with CO2 oil response
Reservoir Surveillance – Pattern Reviews

Pattern Reviews

- Multidisciplinary teams meet weekly to review pattern and well performance
- Production and injection data are reviewed in conjunction with simulation, 4D seismic, spinner and DTS survey data to understand well interactions and identify optimization opportunities
Surveillance to Verify CO2 Containment

- Mud Gas Logging
  - Pason gas concentration sampling in Vertical and Horizontal sections while drilling

- Pressure Observation Wells

- Shallow Aquifer Regional Fluid Characterization
  - Isotope and chemical water tests to confirm that Injected CO2 is not appearing in surface water

- Mobile Gas Detection
  - Equipment measured CO2, CH4, H2S and SO2 associated with wells and facilities and well service events
  - Surveyed fugitive emissions from 200 wells and compared to SCVF results

- 4D Seismic
  - Seismic used to evaluate CO2 in-zone conformance but also to verify that vertical migration is not occurring

Figure 1. Plot of SO values versus $^8$O values. Included data: surface water; groundwater (2014 and 2017), the Viking Formation, the Mannville Group, the Middle, and 19 SCVF samples. The solid line represents the "Saskatchewan" Meteor; Water Line (SK-WL) modified from Mclennan 1987.
Flood Optimization

Key Success Drivers: Injection Strategy and Efficiency ➔ Reservoir Conformance
General WAG Management Case Study

Monitor phase performance

- Turned central injector 92/10-32 over to CO₂ after long water cycle
- Improves CO₂ conformance and utilization
- Allows CO₂ and recycle capacity to be utilized in other areas (reducing total demand)
- CO₂ injection reduced over time by extending water cycles and suspending wells

Water injection cycles used to enhance conformance and manage CO₂ purchase and recycle
Complex Conformance Treatment Case Study

**Pre-conformance intervention:**
- Central horizontal drilled in 2011 with poorer EOR response than expected
- Low injection pressure and increasing rates at central injector (below miscible)

More advanced conformance treatments can provide very strong results but are very expensive
**Complex Conformance Treatment Case Study**

**93/07-12-006-14W2/0**
- Mechanical shut-off of Wtr Prd
- Current Prd = 58 bbls/d (Gross)

**DTS shows water influx at heel**

- **Well watered Out**
- **Wtr influx from M3 heel (above good Vuggy shoal)**

**Increasing investments Mechanical Conformance**
Future of the Weyburn Unit

- Strong base cash flow to internally fund new opportunities
  - 24,000 bbls/d liquids with <5% decline
    - 30 API Oil (2-5% sulphur content)
    - High field gate price for Canadian crude
- Whitecap Resources acquired operatorship of the Weyburn Unit in 2018
  - Strong commitment to new Unit EOR investment
    - New EOR Rollouts
    - Flood Optimization
    - Expanded NGL capture
  - Continue to investigate new CO2 EOR opportunities in Western Canada and the US, leveraging
    - 18 years of CO2 EOR experience
    - Significant existing infrastructure investment
    - Excess CO2 supply
    - New carbon tax legislation