Program to Determine the Uniqueness of Three Forks Bench Reserves, Determine Optimal Well Density in the Bakken Pool, and Optimize Bakken Production

Participant Kickoff Meeting
Dickinson, North Dakota
August 15, 2013

John Harju
Associate Director for Research
Energy & Environmental Research Center

Stan Wilson
Manager, Resource Development, Northern Region
Continental Resources, Inc.
Introduction to the EERC
More than 254,000 square feet of state-of-the art laboratory, demonstration, and office space.
The EERC possesses specialized facilities supporting engineering development of oilfield technology:

- Chemistry/geology/emission laboratories
- Mobile groundwater-sampling and remediation trailers
- Liquid fuels production pilot-scale units
- Multiple flexible-configuration furnaces to simulate process unit operations
- Rich-gas mixture generator and delivery system
EERC
Oil- and Gas-Related Capabilities
Oil- and gas-related research programs at the EERC address a broad range of topics relevant to the industry.

- Three decades of practical laboratory, pilot-scale, and field experience
- Petroleum engineering expertise
- Reservoir simulation capabilities
- Geological characterization and resource assessment
- Process and mechanical engineering
  - Design, fabrication, and operation
- Combustion science and emission control
- Coalbed methane and other unconventional resource-related services
- Soil and groundwater remediation
- Water management
The EERC has dedicated staff to carry mechanical and chemical process designs from conception through fabrication and installation.

- Multiskilled, matrixed engineering and science staff
- Instrumentation and automation specialists
- Process design group
- Mechanical design group
- Fabrication shop
- Quality assurance/quality control personnel
- Skilled technician/operator staff
EERC Laboratory Capabilities

• The EERC has a long history of laboratory testing and providing quality data in a timely manner.
  – Analytical Research Laboratory (ARL)
  – Applied Geology Laboratory (AGL)
  – Gas Chromatography–Mass Spectroscopy Laboratory (GC–MS)
  – Natural Materials Analytical Research Laboratory (NMARL)
  – Computer modeling

• Specialized staff in each area.
• Ever-expanding laboratory capabilities.
Project Experience
Gas/Diesel-Powered Drilling Rig

Project Overview

- Tested dual-fuel operation of a Caterpillar 3512 engine at the EERC using simulated rich gas.
  - Simulated rich-gas mixture produced using bottled/tank-delivered industrial gases and EERC-fabricated gas-metering system.
  - Monitored engine performance and emissions over a range of operating conditions and fuel mixtures.
- Field demonstration of gas-powered drilling operations using rich Bakken gas.
  - Two wells drilled using GTI Bi-Fuel system and rich wellhead gas from nearby well.
  - Monitored engine performance, gaseous and diesel fuel use, and emissions.
Benchmarking Proppants, Stimulation Methods, and Fracture Fluids

Proppants
(ceramic vs. sand)

Stimulation Methods
(sliding sleeves vs. plug and perf. vs. combo)

Fracture Fluid Types
(diesel-based vs. water-based)
The EERC is using a phased approach to:

- Assess, develop, and demonstrate technologies and methodologies that optimize water use for Bakken operations.
- Identify nontraditional water supply sources and innovative options for water reuse.
Bakken Water Opportunities Assessment

- Fracture flowback quantity and quality data collected from 89 wells, representing five producers.
- Because of low initial flowback water recovery rates and extremely high dissolved salt content, recycling of Bakken fracture flowback water is challenging.
- A pilot project using reverse osmosis (RO) to treat brackish groundwater was conducted.
- If access to freshwater sources is limited, RO treatment may be economically feasible.
Bakken Optimization Program Kickoff
Program Goals

• Maximize oil production from Bakken and Three Forks wells by employing an “all of the above” approach, including:
  – Advanced reservoir characterization.
  – Improved drilling/stimulation/completion/production techniques and sequences.
  – Optimizing wellsite surface operations:
    ♦ Reduce costs
    ♦ Reduce development and operation impacts to surrounding landowners
    ♦ Reduce demands on surrounding infrastructure and water sources
Today’s Desired Outcomes

- Define consortium membership
  - Identify point of contact within each consortium member organization
- Develop prioritized list of projects
  - Define specific project goals
  - Outline scope of work
  - Convey rough schedule
Program Description

- **Phase I – Drilling 11 New Wells**
- **Phase II – Completions**
- **Phase III – Reservoir Engineering**
- **Phase IV – Expansion Applications via 3-D Seismic**
- **Phase V – Optimization of Wellsite Operations**

**Pilot hole logs, core data, other data gathering from multiple wells to create a 3-D picture of what happens during and after the hydraulic fracture treatments in a multistage horizontal well. Continental will analyze this data set to:**

- Assess total resource available in the second and third benches of the Three Forks Formation (separate and unique?).
- Confirm whether these benches are distinct and independent of the existing Middle Bakken.
- Predict areas of future sweet spots.

**Site logistics, waste management, on-site hydrocarbon utilization, water management, process optimization, and systems failure analysis with an eye on decreased environmental impact.**
Hawkinson Project Summary

Stan Wilson
Continental Resources, Inc. (CLR)
Bakken Petroleum System Redefined

Charlotte 1-22H core photos (UV light)
308’ with 154’ of oil fluorescence

The International Center for Applied Energy Technology®
CLR: Deep Three Forks Development

- Ten-well coring program (2012)
- Lower Three Forks exploration net CAPEX 2013
  - Productivity Project
    - Exploratory and appraisal: $123MM net cost (20 gross wells)
  - Pilot Density Projects
    - Three 320-acre density tests: $161MM net cost (34 gross wells)
    - One 160-acre density test: $36MM net cost (13 gross wells)
Past: Dual-Reservoir Development

Middle Bakken and Three Forks Wells on 320-acre Spacing

Lodgepole

Upper Bakken Shale

Middle Bakken

Lower Bakken Shale

Three Forks

Multiple Fracture Stages

10,000’ below surface

2 miles

1320’

660’  660’

1320’
Dual-Zone Tests

Mathistad 1-35H and 2-35H wells
McKenzie Co., North Dakota
T150N R96W

Medicine Hole 14-27H and 2-27H wells
Dunn Co., North Dakota
Conclusion from Dual-Zone Tests

• Neither zone can be adequately drained by completion in another zone.

• Limited connectivity will require wells in both zones to adequately harvest the reserves.

• Reserves from Middle Bakken and Three Forks are similar in magnitude.
## Current Development: Bakken and Three Forks

### LODGEPOLE

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
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<tbody>
<tr>
<td>Upper Bakken Shale</td>
<td></td>
</tr>
<tr>
<td>Middle Bakken</td>
<td></td>
</tr>
<tr>
<td>Lower Bakken Shale</td>
<td></td>
</tr>
<tr>
<td>Upper Three Forks 1st Bench</td>
<td>Three Forks 1st Bench</td>
</tr>
<tr>
<td>Lower Three Forks 2nd Bench</td>
<td>Three Forks 2nd Bench</td>
</tr>
<tr>
<td>Lower Three Forks 3rd Bench</td>
<td>Three Forks 3rd Bench</td>
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<tr>
<td>Lower Three Forks 4th Bench</td>
<td>Three Forks 4th Bench</td>
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</table>

### THREE FORKS (TFS)

<table>
<thead>
<tr>
<th>Bench</th>
<th>Description</th>
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<tbody>
<tr>
<td>1st Bench</td>
<td>Three Forks 1st Bench</td>
</tr>
<tr>
<td>2nd Bench</td>
<td>Three Forks 2nd Bench</td>
</tr>
<tr>
<td>3rd Bench</td>
<td>Three Forks 3rd Bench</td>
</tr>
<tr>
<td>4th Bench</td>
<td>Three Forks 4th Bench</td>
</tr>
</tbody>
</table>

### NISKU

- OVERPRESSURED BAKKEN PETROLEUM SYSTEM
- TECHNICALLY RECOVERABLE
- ADDITIONAL INDICATED PAY

- Middle Bakken

- 10,000’ Below Surface

- Multiple Fracture Stages
Multiple Bench Testing

- Charlotte 1280-acre unit
- Producing zones today
  - Middle Bakken
  - 2nd bench TF
  - 3rd bench TF
- WOC- MB, TF1, and TF2
- First unit to have wellbores in four different zones

1280 acres
Sec 15 and 22, T152N-R99W

- Charlotte 4-22H
- Charlotte 2-22H
- Charlotte 3-22H-3
- Charlotte 5-22H
- Charlotte 6-22H

Producing
Waiting on Completion
Third-Party* Simulation Supports 160-Acre Spacing

Conclusions of third party simulation:

- Eight wells per zone
- First well recovers 1.0 MMBoe
- Eight wells recover 5.6 MMBoe
- Eight wells average 700 MBoe per well (70% of one-well scenario)

*Ryder Scott Co. LP, Reservoir Solutions, June-August 2012 /Vol. 15, No. 2.
Continental Resources
Hawkinson – 22-27-147N-96W
1280-acre-Unit Full Development Project

14 wells in 1280 unit
(4 MB, 3 TF1, 4 TF2, 3 TF3)

1320’ interwell spacing between same-zone wells
Phases I–IV (Hawkinson Project)

• Define reservoir drainage of the MBK, TF1, TF2, and TF3

• Confirm whether these formations are distinct and separate from each other

• Determine the optimal number of fracture stages

• Determine appropriate well spacing required for most efficient reservoir drainage

• Increase spacing unit ultimate recovery

• Predict areas of future reservoir sweet spots
Bakken Wellsite Optimization
Summary

John Harju
EERC
Phase V – Optimization of Wellsite Operations

• Consortium-based phase to help industry partners optimize oil and gas activities and improve the efficiency of operation.
• Project scope of work will be directed by the consortium (industry partners and Oil and Gas Research Council representative), with priority along, but not limited to, the following topic areas:
  – Site logistics
    ♦ Focused on evaluation of equipment siting and workflow at multioperation and/or multiwell locations
  – Waste management
    ♦ Focused on improved means of handling drilling and production wastes
  – Hydrocarbon utilization
    ♦ Focused on improving the production of oil, gas, or natural gas liquids (NGLs) from wellsites
  – Water management
    ♦ Focused on technologies to limit demand for freshwater, decrease wastewater production, and reduce water/wastewater trucking to and from the wellsite
  – Process optimization and systems analysis
    ♦ Focused on analysis of failures at the wellsite that affect production efficiency
This Work Addresses North Dakota Priorities

- **Reduce flaring**
  - Survey available technologies, assess their application, and demonstrate scaled technologies

- **Reduce environmental impacts**
  - Explore surface operations that minimize truck traffic (resulting in decreased diesel emissions, decreased road damage, decreased maintenance costs, decreased road dust, and decreased incidence of spills)
  - Investigate technologies to recycle wastewater and decrease freshwater demand
  - Minimize land use impacts (well pad footprints)
  - Address the NORM (naturally occurring radioactive material) waste issue with science and outreach/education

- **Define Bakken system resources**
  - Gather new data with advanced tools to characterize the Middle Bakken and multiple benches of the Three Forks

- **Maximize Bakken system recovery**
  - Use new data to define two new undeveloped zones and to feed models that will help predict optimum well spacing to maximize resource extraction
  - Reduce OPEX via focus on systems assessment toward holistic reservoir and operations management

- **Public education and outreach**
## Budget

<table>
<thead>
<tr>
<th>Sponsors</th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Total</th>
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<td>CLR Share – In-Kind</td>
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<td>$40,989,233</td>
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<td><strong>$44,389,233</strong></td>
<td><strong>$26,451,534</strong></td>
<td><strong>$115,230,000</strong></td>
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$6.26M CLR subcontract; $2.94M EERC

### Commercial Partners

- Continental Resources, Inc. (subcontract and in-kind agreement in final negotiations)
- Marathon Oil Company (Paid – Year 1)
- Whiting Petroleum Corporation (Paid – Year 1)
- Nuverra Environmental Solutions (Invoiced – Year 1)
# Participation Framework

<table>
<thead>
<tr>
<th>No. of Wells</th>
<th>Fee</th>
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<tr>
<td>≥150</td>
<td>$100,000/year</td>
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<tr>
<td>&lt;150</td>
<td>$50,000/year</td>
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<tr>
<td>Select Service Companies</td>
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## Expected Year 1

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<tr>
<th>Phase</th>
<th>NDIC</th>
<th>Industry</th>
<th>In-Kind CLR</th>
<th>Other (DOE)</th>
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<tr>
<td>Phases I–IV (CLR)</td>
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<td><strong>Phase V (EERC)</strong></td>
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<td>Task 5 – Process Optimization and Systems Failure Analysis</td>
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<td>Remaining Funds to Be Assigned</td>
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<td><strong>Total Phase V</strong></td>
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<td><strong>Total Year 1</strong></td>
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<td>$40,989,233</td>
<td>$985,799</td>
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** Potential project with DOE – Performance Evaluation and Sensitivity Analysis of Salt-Tolerant Gels to Various Water Salinities and Chemistries.
# Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Details</th>
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<tbody>
<tr>
<td>Task 1 - Hydrocarbon Utilization</td>
<td>C. Woccen</td>
<td>Fact Sheet - Associated Gas Flaring</td>
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<tr>
<td>Project 1.1 - Skewed Gas Flaring Minimization and Improved Flare Emission Measurement/Air Quality Impact Assessment</td>
<td>J. Almilie</td>
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<tr>
<td>Task 2 - Waste Management</td>
<td>J. Almilie</td>
<td>Fact Sheet - NORM</td>
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<tr>
<td>Project 2.1 - Water Management</td>
<td>B. Kuzz</td>
<td>Fact Sheet - Water Treatment and Reuse</td>
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<tr>
<td>Project 3.1 - Performance Evaluation and Sensitivity Analysis of Salt-Tolerant Gels to Various Water Salinities and Chemistry</td>
<td>B. Kuzz</td>
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<td>Task 4 - Site Logistics</td>
<td>J. Almilie</td>
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<tr>
<td>Task 5 - Process Optimization and Systems Failure Analysis</td>
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</table>

**M1 - Kickoff Meeting with Project Sponsors**

**M2 - Annual Review Meeting with Project Sponsors**

**D1 - Quarterly Report**

**D2 - Fact Sheet - Associated Gas Flaring**

**D3 - Fact Sheet - Water Treatment and Reuse**

**D4 - Fact Sheet - NORM**

**D5 - Final Report**

M = Milestone  D = Deliverable
Seeding the Conversation –
Development of Project Priorities
Producer Recommended Optimization Opportunities
Well Site Optimization – Phase V

• Facility Design – Efficiency could be gained by allowing vendors to source equipment and explore common layouts across producers based on solid engineering design.

• Failure Analysis – Perform failure analysis and develop remedy/mitigation for basinwide problems such as well failure, corrosion, etc.

• Water Chemistry – Third party validation of vendor-recommended water treatment approaches could help optimize treatment and minimize chemical use.
Producer Recommended Optimization Opportunities
Well Site Optimization – Phase V (continued)

- Waste Management – Investigate options for drill cuttings disposal including viability of disposal via injection well, land farming, and others.

- Emission Testing – Third party validation of equipment designed to reduce emissions including engineered flares, bifuel, exhaust gas treatment.

- Fracture Modeling – Desire for data showing the extent of fractures and impacts to formations of interest.

- Pressure Maintenance/Enhanced Oil Recovery (EOR) – Investigation into the effectiveness of different strategies to enhance oil recovery in the Bakken.
Additional Optimization Project Concepts
Well Site Optimization – Phase V (continued)

• Site Logistics
  – Evaluate design, layout, and workflow to improve efficiency at simultaneous operation sites

• Waste Management
  – Investigate alternative options for waste (trash, packaging, sewage)
  – Process drill cuttings (hydrocarbon recovery or destruction)
  – NORM waste inventory or regulation science

• Hydrocarbon Utilization
  – Evaluate technologies that use wellhead gas for drilling, completions, and production activities
  – Evaluate small-scale NGL recovery viability, define threshold efficiency

• Water Management
  – Water supply and disposal options; assess quantity, quality, and capacity
  – Develop wastewater treatment demonstration facility to enable technology demonstration/validation

• Process Optimization and Systems Failure Analysis
  – Investigate systems integration opportunities
A Potential DOE Project –
A Look at Flaring Emissions,
Flaring Minimization
on Already Connected Wells, and
Gathering Network Modeling
Flaring Minimization, Improved Emission Measurement, and Air Quality Impact Assessment

• Proposal submitted in response to DOE solicitation
• Total amount requested: $1,175,307
  – DOE funds: $940,397
  – Bakken Optimization Program (NDIC): $234,910
• Proposed start date: October 1, 2013
• Project duration: 30 months
• Project participants: ONEOK
Project Goals

• Define new methodologies for wellsite flare emission measurement.
  – Must be developed to provide accurate emission data in several pollutant categories if regional air quality models are to be improved.

• Assess technical requirements and economics of various operational methods to limit gas flaring at wells already connected to gas-gathering networks.

• Develop modeling tools to help industry predict dynamics of adding new wells to existing gas-gathering infrastructure.
Another Potential DOE Project – Salt-Tolerant Gels
Performance Evaluation and Sensitivity Analysis of Salt-Tolerant Gels

- Proposal submitted in response to DOE solicitation
- Total amount requested: $1,059,849
  - DOE funds: $847,726
  - Bakken Optimization Program (NDIC): $212,123
- Proposed start date: October 1, 2013
- Project duration: 30 months
- Potential collaborators: Baker Hughes and Schlumberger
Project Goals

• To provide an objective, systematic performance assessment of various salt-tolerant gels utilizing nonpotable water resources from the Williston Basin.

• To estimate the economic and environmental benefits of this approach.
  – Reduced truck traffic and associated impacts
  – Lower water acquisition and disposal costs
  – Increased flexibility for industry
Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

World Wide Web: www.undeerc.org
Telephone No.: (701) 777-5157
Fax No.: (701) 777-5181

John Harju, Associate Director for Research
E-Mail: jharju@undeerc.org
Action Items

• Define consortium membership

• Identify point of contact within each consortium member organization

• Develop prioritized list of projects
  – Project 1:
  – Project 2:
  – Project 3:
Applied Geology Lab Equipment

- Optical profilometer
- +20-ton universal compression frame
- Flexible-wall permeameter
- Hoek-style triaxial and core-flood cells
- Scanning electron microscopy (SEM)
- Supergamma spectrometer
- GC–MS
- Thermal dilatometer
- Ion chromatographer
- X-ray diffraction (XRD) and x-ray fluorescence (XRF)
- Helium porosimeter
- Petrographic microscope
Geomechanical Work

- Bakken peak strength consistently fell in the area of 45,000 psi, with minor fluctuations likely tied to microstructure and facies.
- Three Forks geomechanical strength tended to be less predictable.
- In general, for both Bakken and Three Forks:
  - Structureless and weakly laminated samples yielded higher peak strength.
  - Strongly laminated and chaotically bedded samples were weaker.
Proppant Embedment and Penetration Testing
Modeling and Simulation

Modeling Capabilities

• Log and well test normalization and interpretation
• Petrophysical analysis
• Property modeling, including facies modeling using multiple-point statistics
• Fluid modeling and equation-of-state calibration
• Numerical simulation, including history matching and prediction
Dickinson Lodgepole Mounds
Soil Gas Field Analyses

- Near active wells and between active wells (interspaced)

- Near plugged and abandoned (P&A) wells (three-spot)
Soil Remediation

- Joint industry–government-funded programs.
- Remediation of soils impacted by hydrocarbons and gas-processing constituents.

- Complete removal of amines after 200 days of operation.
- Other parameters were below regulatory limits after 300 days of operation.

EERC
The International Center for Applied Energy Technology®
Innovative Management of Produced Water and Fracture Fluids

Produced brine is suitable (ideal) for use in deep (>2200 ft) drilling applications.

Treated water is suitable for use in surface and near-surface (<2200 ft) drilling applications.

In some states, treated water can be used for stock-watering and/or irrigation.


Joint industry–government-funded project.
Rich-Gas Test Results

• Simulated rich-gas tests at the EERC
  – Diesel replacement rates of greater than 40% can be achieved, and the GTI Bi-Fuel system can control fuel use to ensure safe engine operation.
  – Matching engine load with diesel replacement rate is important to prevent poor fuel utilization and to minimize unburned hydrocarbon emissions.

• Field testing of gas-powered drilling operations
  – GTI Bi-Fuel system was operated August–September.
  – The EERC installed a data acquisition system to enable real-time continuous monitoring and logging of engine performance; provided on-site technical support throughout field test.
  – Data analysis and reporting are ongoing; final report will be submitted to NDIC in late 2012.
  – Demonstrated efficient, economical use of wellhead gas; vendor claimed savings of >$3000/day.